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TropWATER

MARINE MONITORING PROGRAM

Annual Report for **inshore seagrass** monitoring

2015 - 2016

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Front cover image: Close-up of seagrass (*Cymodocea rotundata* and *Thalassia hemprichii*) on the reef flat at Green Island. ©Dieter Tracey 2013

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Acronyms & Abbreviations Used In This Report

CV	coefficient of variation
DERM	Department of Environment and Resource Management
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
JCU	James Cook University
km	kilometre
m	metre
MMP	Marine Monitoring Program
NRM	Natural Resource Management
P2R	Paddock to Reef Integrated Monitoring, Modelling and Reporting Program
SE	Standard Error
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research
QPSMP	Queensland Ports Seagrass Monitoring Program

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River discharge data provided by the State of Queensland (Department of Natural Resources and Mines) 2016. The conceptual diagram symbols are courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Center for Environmental Science. Climate data courtesy of the Australian Bureau of Meteorology, and tide data courtesy Maritime Safety Queensland, Department of Transport and Main Roads.

Executive summary

The Marine Monitoring Program (MMP) undertaken in the Great Barrier Reef (GBR) lagoon, assesses the long-term effectiveness of the Australian and Queensland Government's Reef Water Quality Protection Plan (Reef Plan). The MMP, established in 2005, is a critical component in the paddock to reef monitoring modelling and reporting program (P2R) that tracks changes in regional water quality and its impact on the GBR as land management practices are improved across Reef catchments.

The inshore seagrass component of the MMP assessed seagrass abundance (per cent cover), community structure, relative meadow extent, reproductive health, and nutrient status from inshore seagrass meadows at 29 locations throughout the GBR. Sites were predominately lower littoral (only exposed to air at the lowest of low tides), hereafter referred to as intertidal, although four locations also included shallow subtidal meadows. Each of the Natural Resource Management regions (Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary) were represented, including each of the major seagrass habitat types where possible (estuarine, coastal, reef, subtidal).

Environmental pressures are also recorded including within-canopy water temperature, canopy light, sediment composition as well as macroalgae and epiphyte abundance, further data obtained from the Australian Bureau of Meteorology and from the MMP inshore water quality subprogram.

Discharge from most GBR rivers in 2015-16 was at or below the long-term median, except the Fitzroy and some of the smaller rivers in the central and southern GBR. Despite this, seagrass meadows were exposed to turbid sediment laden waters (primary and secondary waters) for much of the wet season (76-100 per cent of weeks in November to April, except at four reef sites which were 9-55 per cent of weeks). Daily light, or irradiance (I_d), was also lower (12.8 mol m^{-2} d^{-1}) than the long-term average (13.4 mol m^{-2} d^{-1}) particularly in the Wet Tropics, Burdekin and Burnett Mary regions. Within-canopy seawater temperatures in the central and northern GBR were higher than the long-term (10 year) average over the 2015-16 monitoring period for the second year in a row. High water temperatures (>35°C) were exceeded for a record number of days in the three southern and central regions with the highest in the Mackay Whitsunday region (77 d) followed by the Fitzroy region (63 d). Extreme temperatures (>40°C) occurred in most regions but were relatively infrequent, and instead, water temperature was likely to have a chronic and cumulative impact on seagrass meadow condition. To summarise the environmental pressures: 52 per cent of locations had lower than average daily light, particularly across the Cape York, Wet Tropics and Burnett Mary NRM regions; seagrass in all regions except for the Burnett Mary were exposed to high seawater temperatures for more than 10 per cent of the year; increasing epiphyte loads at 51 per cent of sites resulted in above GBR average epiphyte cover at 53 per cent of sites; and nutrient enrichment at 45 per cent of sites, and of these, 22 per cent with elevated nitrogen.

In the 2015-16 monitoring period, overall seagrass abundance (per cent cover) improved relative to the previous year, but remained in *moderate* condition; however, 50 per cent of sites remained classified as poor or very poor in abundance (below the guidelines). Seagrass abundance has generally increased since 2011 as meadows recover from widespread declines occurring from 2009 to 2011 that left meadows in a very poor condition. This decline was the result of multiple years of above average rainfall and climate-related impacts followed by extreme weather events in early 2011. The seagrass losses had significant flow-on effects for dugong and green turtle populations (Meager and Limpus 2012), which are highly dependent on certain seagrass species as their primary food supply.

Ecological resilience includes the capacity of an organism to resist disturbance ("resistance") and to recover to a stable state ("recovery"), which determines the capacity of a system to maintain its function when affected by disturbances (Folke *et al.* 2004; Bernhardt and Leslie 2013; Unsworth *et al.* 2015). The attributes of seagrasses that are indicative of a seagrass meadow exhibiting resistance include: abundance, species composition (in particular diversity of life history strategies including both colonising and persistent species), continuity (or spatial extent), genetic diversity, and storage reserves (Unsworth*, et al.* 2015), but the latter two are not measured in this MMP program. Recovery of seagrass meadows is facilitated by reproductive output, seed banks and seagrass species composition (noting that some attributes are vital to both).

In 2015-16, the indicators of seagrass resilience (resistance and recovery) showed varied response, with some indicators improving, and others declining depending on the region and habitat. The key indicators of improvement in resistance were increasing abundance (per cent cover) at 38 per cent of sites (predominately coastal habitats) while 36 per cent of sites remained stable. The regions with the greatest improvement in abundance (per cent cover) during 2015-16 were Cape York, Mackay-Whitsunday and the Burnett Mary NRMs, where 48 per cent of sites increased from the previous monitoring period, while the Wet Tropics also improved slightly (increasing the score from very poor to poor). The Burdekin was the only region to decline in abundance, but it remained in *moderate* condition. Meadow area expanded or remained unchanged/at their maximum relative extent at 82 per cent of sites. Furthermore, meadows continued to undergo a transient state change with increasing composition of foundation (opportunistic and persistent) species at 57 per cent of sites replacing colonising species, which had been dominant since 2011.

Of notable concern, however, is that the capacity of foundational seagrass to recover from the cumulative impacts of past disturbances continued to be limited. The proportion of seagrass displaying colonising life history traits remained above GBR average at 26 per cent of sites and these species can facilitate recovery from disturbance. However, recovery of foundational species from loss is dependent on presence of a seed bank and recruitment of new populations. The indicators of limited recovery capacity in 2015-16 were; the absence of seed banks at 36 per cent of sites and declining seed banks at another 32 per cent of sites; and below average reproductive effort at 90 per cent of sites.

Across the GBR NRM regions, the seagrass report card scores improved during 2015-16 in the Cape York, Mackay Whitsunday, Fitzroy and Burnett Mary, but declined slightly in the Wet Tropics and Burdekin regions. Seagrass across most of the regions is still recovering from multiple years of climate related impacts, which has likely left a legacy of reduced resilience. Overall, the condition of the inshore seagrass meadows of the GBR has changed little over the last 12 months (2015-16), remaining in a **poor state** (Table 1), despite generally favourable environmental conditions. Based on current rates of recovery, as well as examples taken from previous localised impacts (Birch and Birch 1984; Campbell and McKenzie 2004), a return to a moderate or good condition could occur within the next 1-2 years (i.e. >5 years from impact), provided conditions remain favourable.

Table 1. *Report card for seagrass condition for the GBR and each NRM region: June 2015 - May 2016. Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20).*

Region	Seagrass Abundance	Reproductive Effort	Nutrient status (C:N ratio)	**Seagrass Index**
Cape York	59	6	36	34
Wet Tropics	27	15	32	25
Burdekin	50	46	58	51
Mackay Whitsunday	49	21	32	34
Fitzroy	25	4	36	22
Burnett Mary	42	25	50	39
GBR	52	15	40	35

1 Preface

The management of water quality remains a strategic priority for the Great Barrier Reef Marine Park Authority (GBRMPA) to ensure the long-term protection of the coastal and inshore ecosystems of the Reef (Great Barrier Reef Marine Park Authority 2014). A key management tool is the Reef Water Quality Protection Plan (Reef Plan; Anon 2013), with the actions being delivered through the Reef 2050 Plan. The Reef 2050 Plan includes the Reef Trust, to which the Australian Government has committed continued funding to protect the Reef through improvements to the quality of water flowing into the Reef lagoon, and the Reef 2050 Long Term Sustainability Plan, which provides a framework for the integrated management of the GBRWHA.

Long-term water quality and ecosystem monitoring in the inshore Great Barrier Reef (GBR) lagoon is undertaken through the Marine Monitoring Program (MMP), which was formerly known as the Reef Plan MMP. The GBRMPA has responsibility for implementation of this program. Further information on the program objectives, and details on each sub-program are available on-line http://bit.ly/2mbB8bE. The seagrass sub-program in 2015-16 was also supported by the Great Barrier Reef Foundation (monitoring of Cape York locations in early 2016), with contributions also from the Seagrass-Watch program (Cape York, Wet Tropics, Burdekin, Mackay Whitsunday and Burnett Mary) and Queensland Park and Wildlife Service (QPWS). A key output of the Paddock to Reef Program is an annual report card, including an assessment of Reef water quality and ecosystem condition to which the MMP contributes assessments and information. The first Annual Reef Plan Report Card for 2009 (Reef Water Quality Protection Plan Secretariat 2011), serves as a baseline for future assessments, and report cards for 2010, 2011, 2012/13, 2014 and 2015 have since been released (available at www.reefplan.qld.gov.au).

James Cook University (JCU) was contracted to provide the inshore seagrass monitoring component. The program has adapted methods outlined in McKenzie *et al.* (2003) and those applied in Seagrass-Watch (a global seagrass assessment and monitoring program). The MMP inshore seagrass monitoring program design and reporting structure is an evolving process. Program providers developed the program in collaboration with GBRMPA in 2005, with assistance by expert working groups and AIMS (De'ath 2005). In 2008-09, subtidal sites in the Wet Tropics and Burdekin regions were included to improve the scope of the program. The program underwent an extensive external review in 2013-14, including a revision of program objectives, a statistical review (testing program design and indicator sensitivity), conceptual modelling of indicator selection, and a working group to prioritise changes (Kuhnert *et al.* 2014).

Each year a report summarising the condition and trend of inshore seagrass of the GBR over the past year is published on the GBRMPA website. The annual reports are peer-reviewed every year and program providers endeavour to incorporate reviewer comments.

This report includes data on flood plume exposure from the inshore water quality monitoring subprogram, and a Case Study on Responses of seagrass abundance to temperature and light among habitat types. The report also incorporates the data and/or reported findings from related seagrass monitoring programs Seagrass-Watch and the separately funded Queensland Ports Seagrass Monitoring Program.

2 Introduction

Seagrasses are an important component of the marine ecosystem of the Great Barrier Reef. The ecosystem services provided by seagrass ecosystems makes them a high conservation priority (Cullen-Unsworth and Unsworth 2013). Certain seagrasses are the primary food for marine green turtles and dugongs, which are seagrass specialists (Read and Limpus 2002; Arthur *et al.* 2008; Marsh *et al.* 2011;). Seagrass form highly productive habitats for a large number of invertebrates, fish and algal species (Carruthers *et al.* 2002a), which are of commercial (e.g. prawns) and subsistence fisheries importance (Coles *et al.* 1993; Cullen-Unsworth and Unsworth 2013). Seagrass also produce natural biocides and improve water quality by controlling pathogenic bacteria to the benefit of humans, fishes, and marine invertebrates such as coral (Lamb *et al.* 2017). Nutrient cycling in seagrass meadows makes them one of the most economically valuable ecosystems in the world (Costanza *et al.* 1997) and the retention of carbon within their sediments contributes significantly to Blue Carbon sequestration (Fourqurean *et al.* 2012; Unsworth *et al.* 2012a).

Much of the connectivity in reef ecosystems depends on intact and healthy non-reef habitats, such as seagrass meadows (Waycott *et al.* 2011). These non-reef habitats are particularly important to the maintenance and regeneration of populations of reef fish such as Emperor fish (*Lethrinus spp*) and Tuskfish (*Choerodon spp*) (Cullen-Unsworth *et al.* 2014). In addition, the incorporation of carbon within seagrass tissues can affect local pH and increase calcification of coral reefs, thereby mitigating the effects of ocean acidification (Fourqurean*, et al.* 2012; Unsworth*, et al.* 2012a). Therefore, monitoring changes in seagrasses meadows not only provides an indication of coastal ecosystem health, but also improves our capacity to predict changes to adjacent reefs, mangroves and associated resources upon which coastal communities depend (Heck *et al.* 2008).

Chronic declines in inshore water quality in the GBR since European settlement have led to major ecological shifts in many GBR marine ecosystems (De'ath and Fabricius 2010; Roff *et al.* 2013). Multiple pressures are the cause of this decline, including intensive use of the GBR catchments for agriculture and grazing, and coastal development for urban centres and commercial ports (Brodie *et al.* 2013). Flood waters deliver terrestrially sourced pollutants (e.g., sediments, nutrients, pesticides) into the GBR, dispersing them over the sensitive ecosystems including seagrass meadows (summarised in Schaffelke *et al.* 2013).

Tropical seagrass ecosystems of the GBR are a complex mosaic of different habitat types comprised of multiple seagrass species (Carruthers*, et al.* 2002a). There are 15 species of seagrass in the GBR (Waycott *et al.* 2007) and high diversity of seagrass habitat types is provided by extensive bays, estuaries, rivers and the 2600 km length of the Great Barrier Reef with its reef platforms and inshore lagoon. They can be found on sand or muddy beaches, on reef platforms and in reef lagoons, and on sandy and muddy bottoms down to 60 metres or more below Mean Sea Level (MSL).

Approximately 3,464 km^2 of inshore seagrass meadows has been mapped in Great Barrier Reef World Heritage Area (GBRWHA) in waters shallower than 15m (McKenzie *et al.* 2014d; Saunders *et al.* 2015; Carter *et al.* 2016; McKenzie *et al.* 2016; C. Howley, Unpublished data) (Figure 1). Although this represents only 10 per cent of the total seagrass area estimated within the GBRWHA (McKenzie *et al.* 2010c), the ecosystem services inshore seagrass meadows provide are of far greater importance than those provided by the offshore/deepwater seagrasses. Inshore seagrass meadows are structurally large, composed of foundational (opportunistic and persistent) species, store more carbon in their sediments, are of higher fisheries importance, and the main feeding pastures for dugong and green sea turtle (Watson *et al.* 1993; Sheppard *et al.* 2009 Lanyon *et al.* 1989; McKenzie*, et al.* 2010c; Lavery *et al.* 2013). It is these meadows that occur at the frontline of runoff and inshore water quality deterioration (McKenzie*, et al.* 2010c). The remaining extent (90 per cent or 32,335 km^2) of seagrass in the GBRWHA is located in the deeper waters (>15m) of the lagoon (Coles *et al.*

2009; Carter*, et al.* 2016), however, these meadows are relatively sparse, structurally smaller, highly dynamic, composed of colonising species, and not as productive as inshore seagrass meadows for fisheries resources (McKenzie*, et al.* 2010c; Derbyshire *et al.* 1995). Overall, the total estimated area of seagrass (34,841 km^2) within the GBRWHA represents more than 50 per cent of the total recorded area of seagrass in Australia (Green and Short 2003) and between 6 per cent and 12 per cent globally (Duarte *et al.* 2005), making the Great Barrier Reef's seagrass resources globally significant.

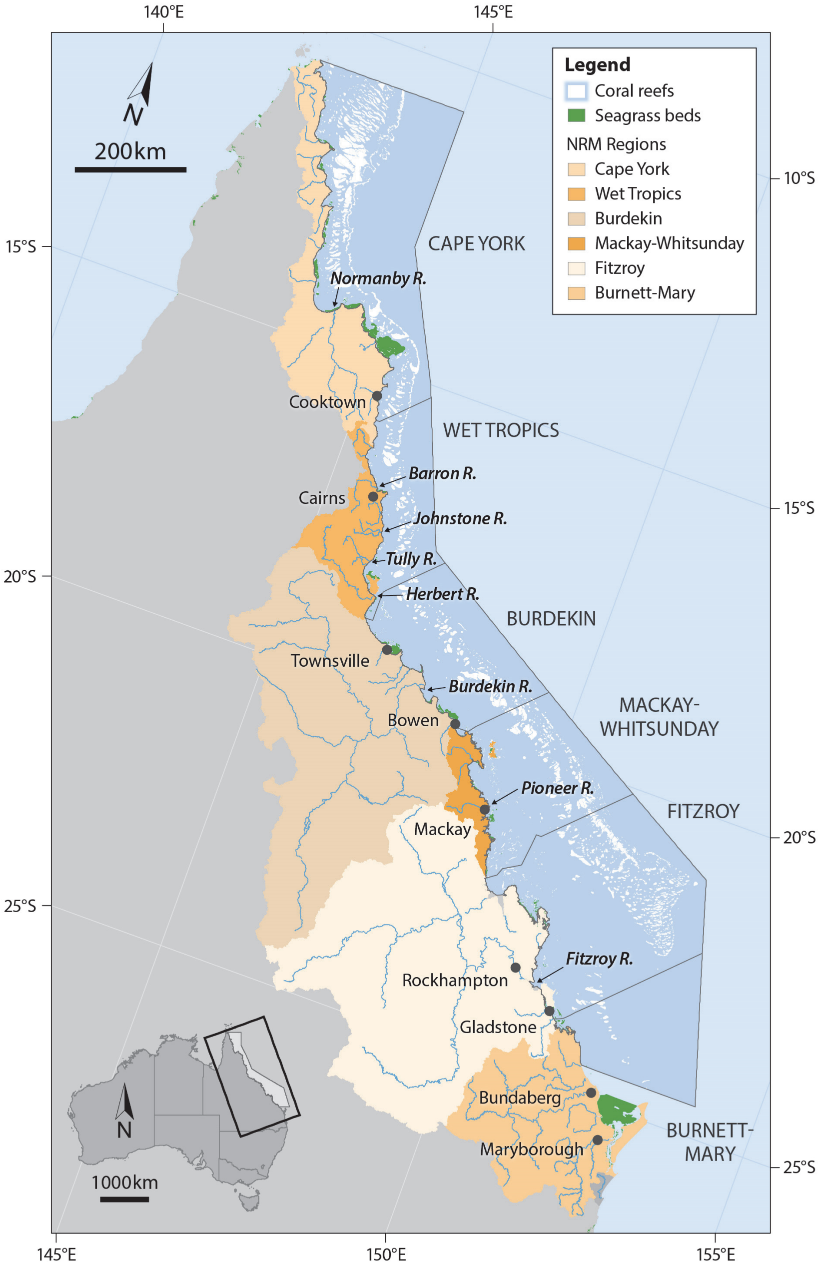

Figure 1. *The Great Barrier Reef Marine Park, major marine ecosystems (coral reefs and surveyed seagrass meadows), NRM regions and marine NRM regions (delineated by dark grey lines) and major rivers. From Waterhouse et al. 2017.*

Seagrasses in the GBR can be separated into four major habitat types: estuary/inlet, coastal, reef and deepwater (Carruthers*, et al.* 2002a) (Figure 2). All but the outer reef habitats are significantly influenced by seasonal and episodic pulses of sediment-laden, nutrient-rich river flows, resulting from high volume summer rainfall. Cyclones, severe storms, wind and waves as well as macro grazers (fish, dugongs and turtles) influence all habitats in this region to varying degrees. The result is a series of dynamic, spatially and temporally variable seagrass meadows.

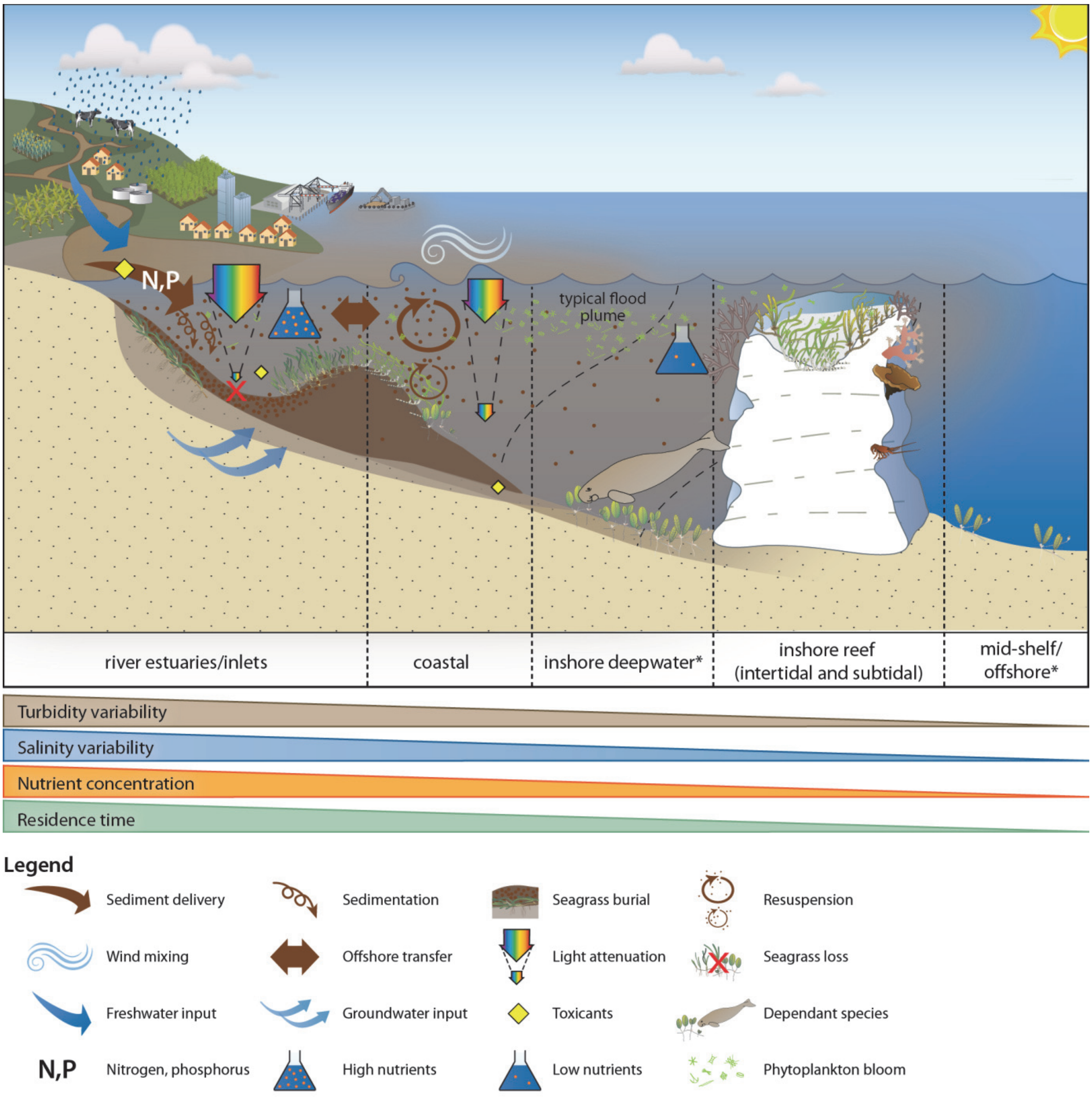

Figure 2. *General conceptual model of seagrass habitats in north east Australia and the water quality impacts affecting the habitat (adapted from Carruthers et al., 2002, and Collier et al. 2014)*

The seagrass ecosystems of the GBR, on a global scale, would be for the most part categorised as being dominated by disturbance-favouring colonising and opportunistic species (e.g. *Halophila*, *Halodule* and *Zostera*), which typically have low standing biomass and high turnover rates (Carruthers *et al.* 2002, Waycott *et al.* 2007). In more sheltered areas, including reef top or inshore areas in bays, more stable and persistent species are found, although these are still relatively responsive to disturbances (Carruthers*, et al.* 2002a; Waycott*, et al.* 2007; Collier and Waycott 2009).

Conceptual basis for indicator selection

As seagrasses are well recognised as indicators of integrated environmental pressures, monitoring their condition and trend can provide insight into the condition of the surrounding environment (e.g. Dennison *et al.* 1997). There are a number of measures of seagrass condition and resilience that can be used to assess how they respond to environmental pressures, and these measures are referred to here as indicators. We have developed a matrix of indicators that respond on different temporal scales (Figure 3). Indicators include plant changes, meadow-scale changes and state change (Figure 3). These indicators also respond at different temporal scales, with sub-lethal indicators able to respond from seconds to months, while the meadow-scale effects usually take many months to be detectable.

A robust monitoring program benefits from having a suite of indicators that can indicate sub-lethal stress that forewarns of imminent loss, as well as indicators of meadow-scale changes, which are necessary for interpreting broad ecological changes. Indicators included in the MMP span this range of scales, in particular for indicators that respond from weeks (tissue nutrients, isotopes), through to months (abundance and reproduction), and even years (abundance and meadow extent). Furthermore, indicators are conceptually linked to each other, and to environmental drivers of concern, in particular, water quality (p 34, Kuhnert, *et al.* 2014).

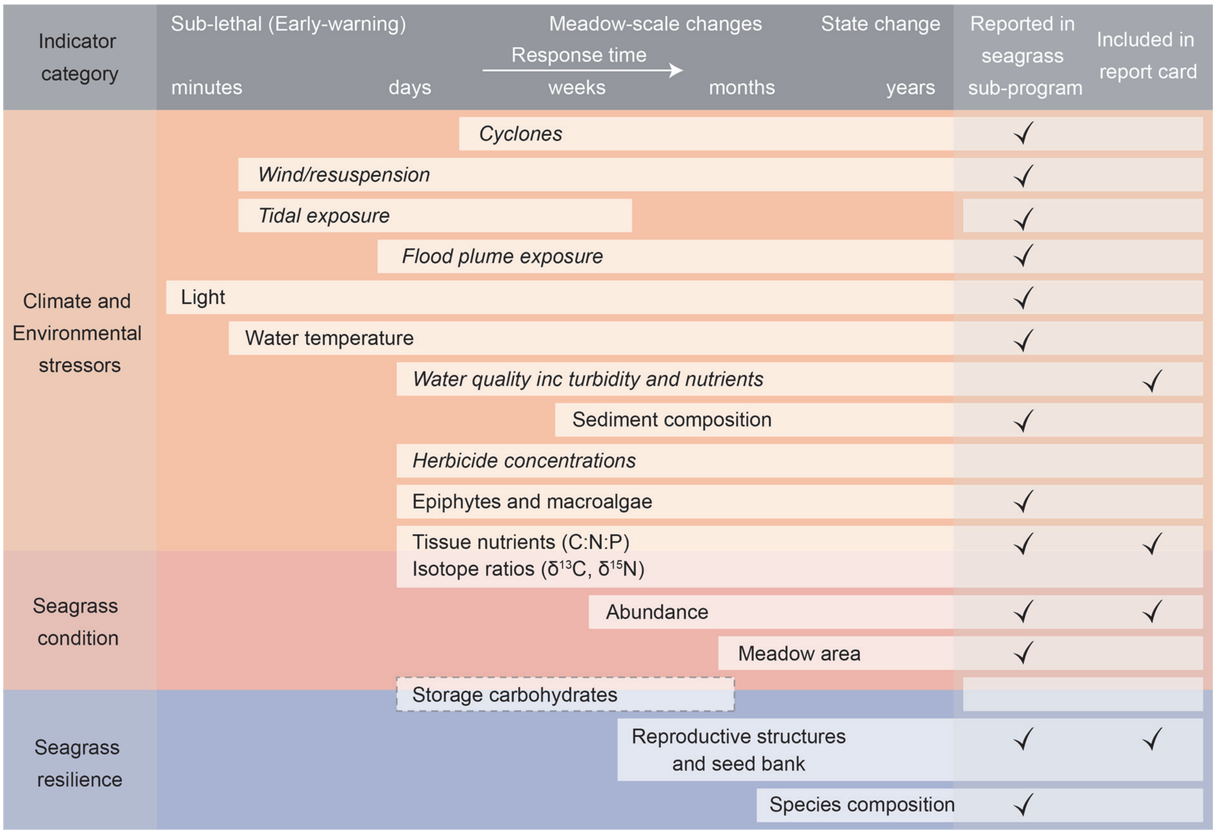

Figure 3. *Climate, environmental, seagrass condition and seagrass resilience indicators reported as part of the MMP Inshore Seagrass monitoring 2015-16. Regular text are indicators measured in the inshore seagrass program, white box with dashed line are indicators in development, and italicised text are indicators collected in other programs or by other institutions (see Table 2 for details on suppliers). All indicators are shown against their response time which span from minutes to years.*

Measures of Environmental stressors

Climate and environment stressors are aspects of the environment, either physico-chemical or biological that affect seagrass meadow condition (Figure 3). Some environmental stressors change rapidly (minutes/days/weeks/months) but can also undergo chronic shifts (years) (Figure 2). Stressors include:

- Climate (e.g. cyclones, seasonal temperature)
- Local and short-term weather (e.g. wind and tides)
- Water quality (e.g. river discharge, plume exposure, nutrient concentrations, suspended sediments, herbicides)
- Biological (e.g. epiphytes and macroalgae)
- Substrate (e.g. grain size composition)
- Seagrass environmental integrators (e.g. tissue nutrients).

Indicators which respond more quickly (e.g. light) provide important early-warning of potentially more advanced ecological changes (as described below). However, a measured change in a fast-responding environmental indicator is not enough in isolation to predict whether there will be further ecological impacts, because the change could be short-term. These indicators provide critical supporting information to support interpretation of slower responding seagrass condition and resilience indicators.

Measures of seagrass condition

Condition indicators such as meadow abundance and extent indicate the state of the plants/population and reflect the cumulative effects of past environmental conditions (Figure 3). Abundance can respond to changes in environment on time-scales ranging from weeks to months (depending on species) in the GBR, while meadow area generally tends to adjust over longer time-scales (months to years). Seagrass area and abundance are integrators of past conditions, and are vital indicators of meadow condition; however, these indicators can also be affected by external factors such as grazing by megaherbivores (including dugongs and turtles). Therefore, they are not suitable as stand-alone indicators of environmental change they require indicators that can be linked more directly to specific pressures. These condition indicators also do not demonstrate capacity to resist or recover from additional impacts (Unsworth*, et al.* 2015).

Measures of seagrass resilience

Ecological resilience is “the capacity of an ecosystem to absorb repeated disturbances or shocks and adapt to change without fundamentally switching to an alternative stable state” (Holling 1973), and therefore it relates to the ability of a system to both resist and recover from disturbances (Unsworth*, et al.* 2015) (Figure 3). Changes in resilience indicators show if the ecosystem is in transition (i.e. has already, or may undergo a state-change). Sexual reproduction (flowering, seed production and persistence of a seedbank) is an important feature of recovery (and therefore, of resilience) in seagrass meadows of the GBR. Coastal seagrasses are prone to small scale disturbances that cause local losses (Collier and Waycott 2009), and therefore disturbance-speclaist species i.e. colonisers tend to dominate throughout the GBR. Community structure (species composition) is also an important feature conferring resilience, both resistance (as some species are more resistant to stress than others), and recovery (as some species may rapidly recover and pave the way for meadow development) (Figure 4).

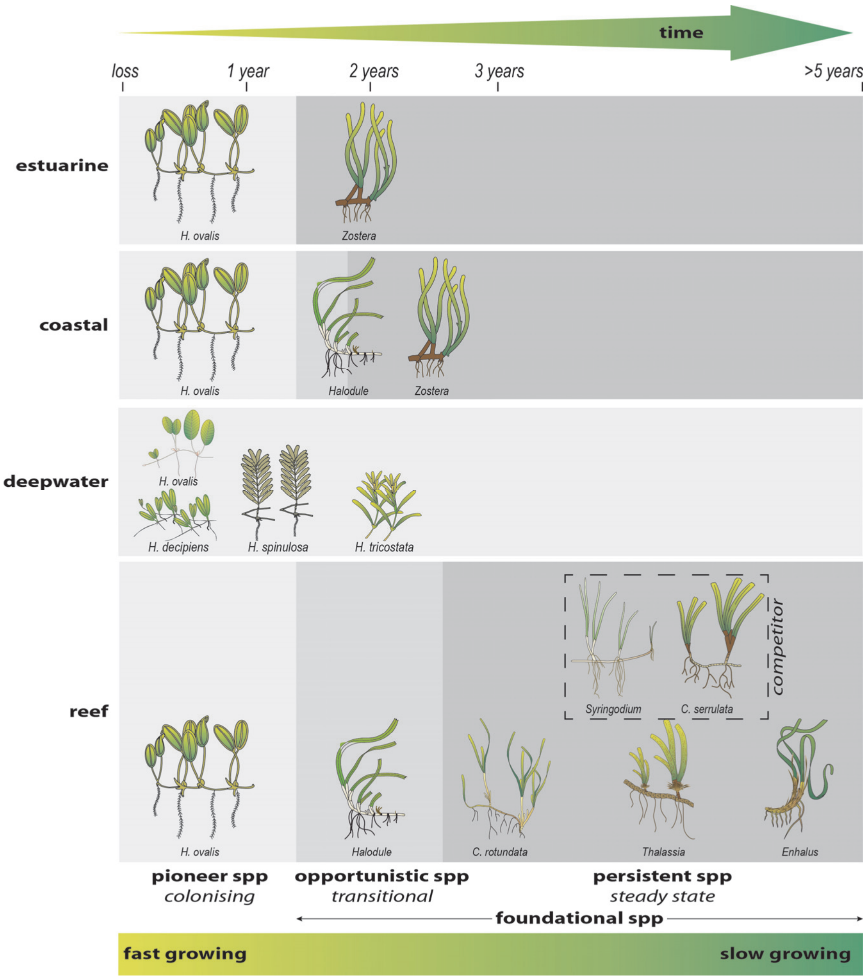

Figure 4. *Illustration of seagrass recovery after loss and the categories of successional species over time. Developed for this report from recovery dynamics observed in monitoring since the 1980's in the GBR (Birch and Birch 1984; Preen et al. 1995; McKenzie and Campbell 2002; Campbell and McKenzie 2004; McKenzie et al. 2014a; Rasheed et al. 2014).*

This report presents data from the eleventh period of monitoring inshore seagrass ecosystems of the Great Barrier Reef under the MMP (undertaken from June 2015 to May 2016; hereafter called "2015-16"). The key aims of the inshore seagrass monitoring sub-program of the MMP were to:

- Report on the abundance and species composition of seagrass (including landscape mapping) in the late dry season of 2015 and the late wet season of 2016 at inshore intertidal and subtidal locations,
- Report on the reproductive health of the seagrass species present at inshore intertidal and subtidal locations,
- Report on tissue nutrient concentrations (carbon, nitrogen and phosphorus) and epiphyte loads of foundation seagrass species (e.g. genus *Halodule, Zostera, Cymodocea*) at each inshore intertidal and subtidal location,
- Report on spatial and temporal patterns in light, turbidity and temperature at sites where autonomous loggers are deployed,
- Report on trends in seagrass condition
- Report on seagrass community in relation to environment condition and trends, and
- Integrate reporting on GBR seagrass condition including production of seagrass report card metrics for use in an annual Paddock to Reef report card.

3 Methods summary

In the following, an overview is given of the sample collection, preparation and analyses methods. Detailed documentation of the methods used in the MMP, including quality assurance and quality control procedures, is available in Appendix 2.

3.1 Climate and environmental pressures

Maximum daily air temperature, total daily rainfall, 3pm wind speed and average daily cloud cover (average of 9am and 3pm total cloud), and cyclone tracks were accessed from the Australian Bureau of Meteorology from meteorological stations which were proximal to monitoring locations (Table 2). As the height of locally produced, short-period wind-waves can be the dominant factor controlling suspended sediment on inner-shelf of the GBR (Larcombe *et al.* 1995; Whinney 2007), the number of days wind speed exceeded 25km hr^{-1} was used as a surrogate for elevated resuspension pressure on inshore seagrass meadows. Moderate sea state with winds >25km hr^{-1} can elevate turbidity by three orders of magnitude in the inshore coastal areas of the GBR (Orpin *et al.* 2004). To determine if the tidal exposure regime may be increasing stress on seagrass and hence drive decline, tidal height observations were accessed from Maritime Safety Queensland and duration of annual exposure (hours) was determined for each meadow (i.e. monitoring site), based on the meadows height relative to the Lowest Astronomical Tide (Appendix 2, Table 58).

The presence of inshore seagrass meadows along the GBR places them at high risk of exposure to waters from adjacent watersheds and exposure to flood plumes is likely to be a significant factor in structuring inshore seagrass communities (Collier*, et al.* 2014; Petus *et al.* 2016). Hence we used river discharge volumes as well as frequency of exposure to inshore flood plumes as indicators of flood plume impacts to seagrasses. Plume exposure is generated by wet season monitoring under the MMP in the water quality sub-program (Waterhouse*, et al.* 2017). The MMP inshore water quality sub-program includes a remote sensing component, which describes water quality characteristics for 22 weeks of the wet season (November – April). Water quality is described as colour classes of turbid, brown primary water (class 1 – 4), green secondary water (class 5), and waters influenced by flood plumes (salinity <30PSU, coloured dissolved organic matter (CDOM) threshold of 0.24 m^{-1} class 6). Colour classes are derived from MODIS True colour satellite images. Exposure to flood plumes is described in this report as frequency of exposure to primary (turbid, sediment laden) or secondary (green, nutrient rich) water during the wet season. Methods are detailed in Devlin *et al.* (2015).

Autonomous iBTag™ submersible temperature loggers were deployed at all sites identified in Appendix 2, Table 35. The loggers recorded temperature (accuracy 0.0625°C) within the seagrass canopy every 30 – 90 minutes. iBCod™22L submersible temperature loggers were attached to the permanent marker at each site above the sediment-water interface.

Submersible Odyssey™ photosynthetic irradiance autonomous loggers were attached to permanent station markers at 20 intertidal and 4 subtidal seagrass locations from the Cape York region to the Burnett Mary region (Appendix 4, Table 42). Detailed methodology for the light monitoring can be found in Appendix 2. Measurements were recorded by the logger every 15 minutes and are reported as total daily light (mol m^{-2} d^{-1}). Automatic wiper brushes cleaned the optical surface of the sensor every 15 minutes to prevent marine organisms fouling.

Sediment type was recorded at the 33 quadrats at each site in conjunction with seagrass abundance measures using a visual/tactile estimation of sediment grain size composition (0-2 cm below the sediment/water interface) as per standard protocols described in McKenzie *et al.* (2003). Qualitative field descriptions of sediment composition were differentiated according to the Udden-Wentworth grade scale as this approach has previously been shown to provide an equivalent measure to sieve-derived datasets (Hamilton, 1999; McKenzie 2007).

Table 2. *Summary of climate and environment data included in this report, showing historical data range, measurement technique, measurement frequency, and data source. Methodology for data collected in this program is further detailed below, and in Appendix 2. *=variable duration of data availability depending on site*

	Data range	Method	Measurement frequency	Reporting units	Data source
Climate					
Cyclones	1968 - 2016	remote sensing and observations at nearest weather station	yearly	No. yr^{-1}	Bureau of Meteorology
Rainfall	1889 - 2016*	rain gauges at nearest weather station	daily	mm mo^{-1} mm yr^{-1}	Bureau of Meteorology
Riverine discharge	1970 – 2016	water gauging stations at river mouth		L d^{-1} L yr^{-1}	DSITI[#], compiled by Devlin et al In prep
Plume exposure	2006 – 2016 wet season (Dec – Apr)	remote sensing and field validation	weekly	frequency of water type (1 – 6) at the site	MMP inshore water quality program (Devlin et al)
Wind	1997 – 2016*	anemometer at 10 m above the surface, averaged over 10 minutes, at nearest weather station	3pm wind speed	days >25 km hr^{-1}	Bureau of Meteorology
Tidal exposure	1999 – 2016	wave height buoys at station nearest to monitoring site	3 – 10 min	hours exposed during daylight	Maritime Safety Queensland, calculated exposure by MMP Inshore Seagrass monitoring
Cloud cover	1999 – 2016*	measured visually by estimating the fraction (in eighths or oktas) of the dome of the sky covered by cloud at nearest weather station	9am & 3pm	ockta (daily average)	Bureau of Meteorology
Environment within seagrass canopy					
Water temperature	2002 – 2016	iBTag	30 – 90 min	^{o}C, Temperature anomalies, exceedance of thresholds	MMP Inshore Seagrass monitoring
Light	2008 – 2016	Odyssey 2Pi PAR light loggers with wiper unit	15 min	Daily light (I_d) mol m^{-2} d^{-1} Frequency of threshold exceedance (per cent days)	MMP Inshore Seagrass monitoring
Sediment grain size	1999 – 2016	Visual / tactile description of sediment grain size composition	3 mo – 1yr	proportion mud	MMP Inshore Seagrass monitoring

[#] Department of Science, Information Technology and Innovation

3.2 Sampling design & site selection

The sampling design was selected to detect changes in inshore seagrass meadows in response to changes in water quality associated with specific catchments or groups of catchments (Region) and to disturbance events. The locations/meadows were selected by the GBRMPA, using advice from expert working groups in 2004. The selection of locations/meadows was based upon a number of competing factors:

1. meadows were representative of inshore seagrass habitats and seagrass communities across each region (based on Lee Long *et al.* 1993, Lee Long *et al.* 1997, Lee Long *et al.* 1998; McKenzie *et al.* 2000b; Rasheed *et al.* 2003; Campbell *et al.* 2002; Goldsworthy 1994)
2. where possible include legacy sites (e.g. Seagrass-Watch, MTSRF) or former seagrass research sites (e.g. Dennison *et al.* 1995; Inglis 1999; Thorogood and Boggon 1999; Udy *et al.* 1999; Haynes *et al.* 2000; Campbell and McKenzie 2001; Mellors 2003; Campbell and McKenzie 2004; Limpus *et al.* 2005; McMahon *et al.* 2005; Mellors *et al.* 2005; Lobb 2006).
3. a Minimum Detectable Difference (MDD) below 20 per cent (at the 5 per cent level of significance with 80 per cent power) (Bros and Cowell 1987).

Sites were selected using mapping surveys across the regions prior to site establishment. Ideally mapping was conducted immediately prior to site positioning, however in most (60 per cent of) cases it was based on historic (>5yr) information. Representative meadows were those which covered the greater extent within the inshore region, were generally the dominant seagrass community type and were within GBR baseline abundances (based on Coles *et al.* 2001a; Coles *et al.* 2001c, 2001b, 2001d). To account for spatial heterogeneity of meadows within habitats, two sites were selected at each location. If meadow overall extent was larger than ~15hecatres (0.15 km^2), replicate sites were often located within the same meadow.

From the onset, inshore seagrass monitoring for the MMP was focused primarily on intertidal/lower littoral seagrass meadows due to:

- accessibility and cost effectiveness (limiting use of vessels and divers)
- Occupational Health and Safety due to dangerous marine animals (e.g., crocodiles, box jellyfish and irukandji)
- occurrence of meadows in estuarine, coastal and reef habitats across the entire GBR, and
- where possible, provides an opportunity for community involvement, ensuring broad acceptance and ownership of Reef Plan by the Queensland and Australian community.

Some of the restrictions for working in hazardous waters are overcome by using drop cameras, however, drop cameras only provide abundance measures and do not contribute to the other metrics (e.g. tissue nutrients, reproductive effort). Although considered intertidal within the MMP, the meadows chosen for monitoring were in fact lower littoral (rarely exposed to air). The long-term median annual daylight exposure (the time intertidal meadows are exposed to air during daylight hours) was 1.7 per cent (all meadows pooled) (Table 58). This limited the time monitoring could be conducted to the very low spring tides within small tidal windows (mostly 1-4hrs per day for 3-6 days per month for 6-9 months of the year). Traditionally, approaches developed for monitoring seagrass to assess changes in water quality were developed for subtidal meadows typified by small tidal ranges (e.g., Florida = 0.7m, Chesapeake Bay = 0.6m) and clear waters where the seaward edges of meadows were only determined by light (EHMP 2008). Unfortunately, depth range monitoring in subtropical/tropical seagrass meadows has had limited success due to logistic/technical issues (e.g. accuracy defining deep edge of a fragmented meadow, and positional accuracy of the autoset level's graduated staff with increasing horizontal distance) (B. Longstaff, pers. comm. 05 May 2004) and seagrass meadows within the Great Barrier Reef lagoon do not conform to traditional ecosystem models because of the systems complexity (Carruthers*, et al.* 2002a), including:

- a variety of habitat types (estuarine, coastal, reef and deepwater);
- a large variety of seagrass species with differing life history traits and strategies;
- tidal amplitudes spanning 3.42m (Cairns) to 10.4m (Broad Sound) (www.msq.qld.gov.au; Maxwell 1968);
- a variety of sediment substrates, from terrigenous with high organic content, to oligotrophic calcium carbonate;
- turbid nearshore to clearer offshore waters;
- grazing dugongs and sea turtles influencing meadow community structure and landscapes;
- near-absence of shallow subtidal meadows south of the Whitsundays due to the large tides which scour the seabed.

Deepwater (>15m) meadows across the GBR are predominately dominated by *Halophila* species and are highly variable in abundance and distribution (Lee Long *et al.* 1999). Due to this high variability they do not meet the current criteria for monitoring, as the MDD is very poor at the 5 per cent level of significance with 80 per cent power (McKenzie *et al.* 1998), and will require a different approach if to be included in future. Predominately stable lower littoral and shallow (>1.5m below Lowest Astronomical Tide) subtidal meadows of foundation species (e.g., *Zostera, Halodule*) are best for determining significant change/impact (McKenzie *et al.* 1998). Where possible, shallow subtidal and lower littoral monitoring sites were paired when dominated by similar species.

Due to the high diversity of seagrass species across the GBR, it was decided in consultation with GBRMPA to direct monitoring toward the foundation seagrass species across the seagrass habitats (Figure 5). A foundation species is the dominant primary producer in an ecosystem both in terms of abundance and influence, playing central roles in sustaining ecosystem services (Angelini *et al.* 2011). The activities of foundation species physically modify the environment and produce and maintain habitats that benefit other organisms that use those habitats.

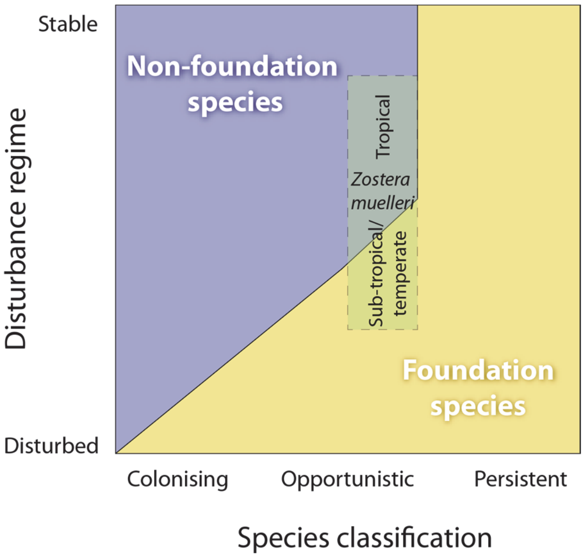

Figure 5. *Illustration showing how foundational species can include species display colonising, opportunist or persistent life history traits depending on disturbance regime. Foundation species are the species types that are at the pinnacle of meadow succession. A highly disturbed meadow (due to wave/wind exposure, or low light regime) might always only ever have colonising species as the foundational species, while a less disturbed meadow can have persistent species form the foundation. Also, whether Zostera muelleri is a foundation species is influenced by whether it grows in the tropics or in the sub-tropics, as it is more likely to form a foundation species in the sub-tropics even if it is disturbed.*

For the seagrass habitats assessed in the MMP, the foundation seagrass species were those species which typified the habitats both in abundance and structure when the meadow was considered in its steady state (opportunistic or persistent) (Kilminster *et al.* 2015). The foundation species were all di-meristematic leaf-replacing forms from the following families: *Cymodocea, Enhalus, Halodule, Thalassia* and *Zostera* (Table 3).

The timing of the monitoring within the MMP was decided by the GBRMPA, using advice from expert working groups. As the major period of runoff from catchments and agricultural lands was the tropical wet season/monsoon (December to April), monitoring was focussed on the late dry (growing) season and late wet season to capture the condition of seagrass pre and post wet.

Forty five sites at 21 locations were monitored during the 2014-15 monitoring period (Table 3). This included eight coastal, four estuarine and nine reef locations (i.e. two-three sites at each location). At the reef locations in the Burdekin and Wet Tropics, intertidal sites were paired with a subtidal site (Table 3). Data from an additional eight sites were included from the Seagrass-Watch program to improve the spatial resolution where possible (Table 4). A description of all data collected during the sampling period under the monitoring contract has been collated by Natural Resource Management (NRM) region, site, parameter, and the number of samples collected per sampling period is listed in Table 42. The seagrass species (including foundation) present at each monitoring site is listed Table 3.

In 2005 and 2014, the monitoring program received thorough independent statistical analysis and review (De'ath 2005; Kuhnert*, et al.* 2014). The development and any modifications of the program were evaluated by the Paddock to Reef Independent Science Panel. Program reports and results are reviewed annually by independent seagrass experts external to GBRMPA and MMP.

Table 3. *MMP inshore seagrass long-term monitoring site details including presence of foundation (■) and other (□) seagrass species sampled for plant tissue and reproductive health. NRM region from www.nrm.gov.au. * = intertidal, ^=subtidal. CR = Cymodocea rotundata, CS = Cymodocea serrulata, EA = Enhalus acoroides, HD = Halophila decipiens, HO = Halophila ovalis, HS = Halophila spinulosa, HU = Halodule uninervis, SI = Syringodium isoetifolium, TH – Thalassia hemprichii, ZM = Zostera muelleri*

GBR region	NRM region (*Board*)	Basin	Monitoring location	Site		Latitude		Longitude		CR	CS	EA	HD	HO	HS	HU	SI	TH	ZM
Far Northern	Cape York (*Cape York Natural Resource Management*)	Jacky Jacky / Olive-Pascoe	Shelburne Bay *coastal*	SR1*	Shelburne Bay	11°	53.233	142°	54.851					□		■		■	
				SR2*	Shelburne Bay	11°	53.251	142°	54.938										
			Piper Reef *reef*	FR1*	Farmer Is.	12°	15.352	143°	14.020	■				□				■	
				FR2*	Farmer Is.	12°	15.448	143°	14.185										
		Normanby / Jeannie	Stanley Island *reef*	ST1*	Stanley Island	14°	8.576	144°	14.680	■		■		□		■	□	■	
				ST2*	Stanley Island	14°	8.547	144°	14.588										
			Bathurst Bay *coastal*	BY1*	Bathurst Bay	14°	16.082	144°	13.961	■				□		■	□	■	
				BY2*	Bathurst Bay	14°	16.062	144°	13.896										
		Endeavour	Cooktown *reef*	AP1*	Archer Point	15°	36.500	145°	19.143	■	■	□		□		■		■	□*
				AP2*	Archer Point	15°	36.525	145°	19.108										
Northern	Wet Tropics (*Terrain NRM*)	Daintree	Low Isles *reef*	LI1*	Low Isles	16°	23.11	145°	33.88					□		■		■	
				LI2^	Low Isles	16°	22.97	145°	33.85					□		■			
		Mossman / Barron / Mulgrave-Russell / Johnstone	Yule Point *coastal*	YP1*	Yule Point	16°	34.159	145°	30.744					□		■			□*
				YP2*	Yule Point	16°	33.832	145°	30.555										
			Green Island *reef*	GI1*	Green Island	16°	45.789	145°	58.31	■	□			□		■		■	
				GI2*	Green Island	16°	45.776	145°	58.501										
				GI3^	Green Island	16°	45.29	145°	58.38	■	■			□		■	□	■	
		Tully / Murray / Herbert	Mission Beach *coastal*	LB1*	Lugger Bay	17°	57.645	146°	5.61					□		■			
				LB2*	Lugger Bay	17°	57.674	146°	5.612										
			Dunk Island *reef*	DI1*	Dunk Island	17°	56.6496	146°	8.4654	■	■			□		■		■	
				DI2*	Dunk Island	17°	56.7396	146°	8.4624										
				DI3^	Dunk Island	17°	55.91	146°	08.42		■		□	□		■			
Central	Burdekin (*NQ Dry Tropics*)	Ross / Burdekin	Magnetic island *reef*	MI1*	Picnic Bay	19°	10.734	146°	50.468					□		■			□*
				MI2*	Cockle Bay	19°	10.612	146°	49.737	■	■			□		■	□	■	
				MI3^	Picnic Bay	19°	10.734	146°	50.468		■		□	□	□	■			
			Townsville *coastal*	SB1*	Shelley Beach	19°	11.046	146°	45.697		□			□		■			■
				BB1*	Bushland Beach	19°	11.028	146°	40.951										
			Bowling Green Bay *coastal*	JR1*	Jerona (Barratta CK)	19°	25.380	147°	14.480					□		■			■
				JR2*	Jerona (Barratta CK)	19°	25.281	147°	14.425										
	Mackay Whitsunday (*Reef Catchments*)	Proserpine / O'Connell	Repulse Bay coastal	MP2*	Midge Point	20°	38.099	148°	42.108					□		■			■
				MP3*	Midge Point	20°	38.080	148°	42.280										
			Whitsundays *reef*	HM1*	Hamilton Island	20°	20.7396	148°	57.5658					□		■	□		■
				HM2*	Hamilton Island	20°	20.802	148°	58.246										
		Plane	Mackay *estuarine*	SI1*	Sarina Inlet	21°	23.76	149°	18.2					□		□			■
				SI2*	Sarina Inlet	21°	23.712	149°	18.276										
Southern	Fitzroy (*Fitzroy Basin Association*)	Shoalwater / Fitzroy	Shoalwater Bay *coastal*	RC1*	Ross Creek	22°	22.953	150°	12.685					□		■			■
				WH1*	Wheelans Hut	22°	23.926	150°	16.366										
			Keppel Islands *reef*	GK1*	Great Keppel Is.	23°	11.7834	150°	56.3682					□	□	■			■
				GK2*	Great Keppel Is.	23°	11.637	150°	56.3778										
		Calliope / Boyne	Gladstone Harbour *estuarine*	GH1*	Gladstone Hbr	23°	46.005	151°	18.052					□		□*			■
				GH2*	Gladstone Hbr	23°	45.874	151°	18.224										
	Burnett Mary (*Burnett Mary Regional Group*)	Baffle	Rodds Bay *estuarine*	RD1*	Rodds Bay	24°	3.4812	151°	39.3288					□		□			■
				RD2*	Rodds Bay	24°	4.866	151°	39.7584										
		Mary	Hervey Bay *estuarine*	UG1*	Urangan	25°	18.053	152°	54.409					□		□			■
				UG2*	Urangan	25°	18.197	152°	54.364										

** indicates presence adjacent, but not within, 50m x 50m site. Zostera muelleri = Zostera muelleri* subsp. *capricorni, as revision of Zostera capricorni (Jacobs et al. 2006) resulted in classification to subspecies.*

Table 4. *Details of additional inshore seagrass long-term monitoring sites from the Seagrass-Watch and QPWS drop-camera programs, including presence of foundation (■) and other (□) seagrass species. NRM region from www.nrm.gov.au. * = intertidal, ^=subtidal.*

GBR region	NRM region (*Board*)	Basin	Monitoring location	Site		Latitude		Longitude		CR	CS	EA	HD	HO	HS	HU	SI	TH	ZM
Far Northern	Cape York *(Cape York Nat Res Manage)*	Lockhart	Lloyd Bay *coastal*	LR1^	Lloyd Bay	12°	47.788	143°	29.117					□	□	■			
				LR2^	Lloyd Bay	12°	49.488	143°	28.500										
Northern	Wet Tropics	Tully / Murray / Herbert	Rockingham Bay *reef*	GO1	Goold Island	18°	10.437	146°	9.196	■	■			□		■			
			Missionary Bay *coastal*	MS1^	Missionary Bay	18°	12.950	146°	12.753					□		■			
				MS2^	Missionary Bay	18°	12.316	146°	13.010										
Central	Burdekin (*NQ Dry Tropics*)	Ross / Burdekin	Townsville *coastal*	SB2*	Shelley Beach	19°	10.953	146°	45.764		□			□		■			■
	Mackay Whitsunday (*Reef Catchments*)	Don	Shoal Bay *reef*	HB1*	Hydeaway Bay	20°	4.487	148°	28.930	■				□		■		■	
				HB2*	Hydeaway Bay	20°	4.297	148°	28.846										
		Proserpine	Pioneer Bay *coastal*	PI2*	Pioneer Bay	20°	16.176	148°	41.586					□	□	■			■
				PI3*	Pioneer Bay	20°	16.248	148°	41.844										
		Proserpine / O'Connell	Whitsunday Islands *reef*	TO1^	Tongue Bay	20°	14.399	149°	0.931					□		■		■	
				TO2^	Tongue Bay	20°	14.197	149°	0.697										
		O'Connell	Newry Islands *coastal*	NB1^	Newry Bay	20°	52.057	148°	55.531		■			□	□	■	■		
				NB2^	Newry Bay	20°	52.328	148°	55.436										
Southern	Burnett Mary (*Burnett Mary Regional Group*)	Burrum	Hervey Bay *coastal*	BH1*	Burrum Heads	25°	11.290	152°	37.532					□		■			■
				BH3*	Burrum Heads	25°	12.620	152°	38.359										

3.3 Seagrass condition monitoring

3.3.1 Seagrass abundance, composition and extent

Field survey methodology followed standardised protocols (detailed in McKenzie *et al.* (2003) and Appendix 2). At each location, with the exception of subtidal sites, sampling included two sites nested (within 500m of each other) in a location. Subtidal sites were not replicated within locations. Intertidal sites were defined as a 5.5 hectare area within a relatively homogenous section of a representative seagrass community/meadow (McKenzie *et al.,* 2000). Monitoring at sites in the late dry (September/October 2015) and late wet (March/April 2016) of each year was conducted by a qualified and trained scientist. In the centre of each site, during each survey, observers recorded the percent seagrass cover within 33 quadrats (50 cm × 50 cm, placed every 5 m along three 50m transects, placed 25m apart). The sampling strategy for subtidal sites was modified to sample along 50m transects 2 – 3 m apart (aligned along the depth contour) due to logistics of SCUBA diving in waters of poor visibility. Mapping of the meadow landscape (including patches and scars) within each site was also conducted as part of the monitoring in both the late dry and late wet periods. Mapping followed standard methodologies (McKenzie *et al.* 2001) using a handheld GPS on foot. Where the seagrass landscape tended to grade from dense continuous cover to no cover over a continuum that included small patches and shoots of decreasing density, the meadow edge was delineated where there was a gap with the distance of more than 3 metres (i.e. accuracy of the GPS). Therefore the entire 5.5 hectare site was mapped (seagrass and no seagrass).

Seagrass species were identified as per Waycott *et al.* (2004). Species were further categorised according to their life history traits and strategies and classified into colonising, opportunistic or persistent as broadly defined by Kilminister *et al.* (2015) (for detailed methods, see Appendix 2).

3.3.2 Seagrass reproductive health

Seagrass reproductive health was assessed from samples collected in the late dry 2015 and late wet 2016 at locations identified in Table 3. Samples were processed according to standard methodologies (see Appendix 2).

In the field, 15 haphazardly placed cores (100mm diameter x 100mm depth) of seagrass were collected from an area adjacent (of similar cover and species composition) to each monitoring site. In the laboratory, reproductive structures (spathes, fruits, female and male flowers) of plants from each core were identified and counted for each samples and species. Reproductive effort was calculated as number of reproductive structures (fruits, flowers, spathes; species pooled) per core for analysis.

Seeds banks and abundance of germinated seeds were sampled according to standard methods (McKenzie *et al.* 2010a) by sieving (2mm mesh) 30 cores (50mm diameter, 100mm depth) of sediment collected across each site and counting the seeds retained in each. For *Zostera muelleri*, where the seed are <1mm diameter, intact cores (18) were collected and returned to the laboratory where they were washed through a 710µm sieve and seeds identified using a hand lens/microscope.

3.3.3 Seagrass tissue nutrients

In the late dry season (October) 2014, leaf tissue samples from the foundational seagrass species were collected from each monitoring site for nutrient content analysis (Table 3). For nutrient status comparisons, collections were recommended during the growth season (e.g. late dry when nutrient contents are at a minimum) (Mellors*, et al.* 2005) and at the same time of the year and at the same depth at the different localities (Borum *et al.* 2004). Shoots from three haphazardly placed 0.25m^2 quadrats were collected from an area adjacent (of similar cover and species composition) to each monitoring site. Species within the sample are separated, and all species (except *Halophila* spp.) were analysed for tissue nutrient content. All leaves within the sample were separated from the below ground material in the laboratory and epiphytic algae removed by gently scraping. Dried and milled leaf samples were analysed according to McKenzie*, et al.* 2010a. Elemental ratios (C:N:P) were calculated on a mole:mole basis using atomic weights (i.e., C=12, N=14, P=31).

The ratios for each species are presented in the appendix of this report (Table 1). As an overview of results, and for the calculation of report card score, ratio values are pooled among the foundational species at each site. Changing C:N ratios have been found in a number of experiments and field surveys to be related to light levels, as leaves with an atomic C:N ratio of less than 20, may suggest reduced light availability when N is not in surplus (Abal *et al.* 1994; Grice *et al.* 1996; Cabaço and Santos 2007; Collier *et al.* 2009b). The ratio of N:P is also a useful indicator as it is a reflection of the *"Redfield"* ratios (Redfield *et al.* 1963), and seagrass with an atomic N:P ratio of 25 to 30 can be determined to be 'replete' (well supplied and balanced macronutrients for growth) (Atkinson and Smith 1983; Fourqurean *et al.* 1997b; Fourqurean and Cai 2001). When N:P values are in excess of 30, this may indicate P-limitation and a ratio of less than 25 is considered to show N limitation (Atkinson and Smith 1983;Duarte 1990; Fourqurean *et al.* 1992b; Fourqurean and Cai 2001). The median seagrass tissue ratios of C:P is approximately 500 (Atkinson and Smith 1983), therefore deviation from this value is also likely to be indicative of some level of nutrient enriched or nutrient limited conditions. A combination of these ratios can indicate seagrass environments which are impacted by nutrient enrichment. Plant tissue which has both a high N:P and low C:P indicates an environment of elevated (saturated) nitrogen.

Further detail on methodology for nutrient sampling can be found in appendix 2.

3.4 Data analyses

In this report, results are presented to reveal temporal changes in seagrass community attributes and key environmental variables. Generalised additive models (GAMs) and generalised additive mixed effects models (GAMMs) were also fitted to seagrass attributes for each habitat, to identify the presence and consistency of trends, using the mgcv (Wood 2006;Wood 2014) package in R 3.2.1 (R Core Team 2014). GAMs and GAMMs (Wood 2006) were used to decompose the irregularly spaced time series into its trend cycles (long-term) and periodic (seasonal) components.

GAMMs are an extension of additive models (which allow flexible modelling of non-linear relationships by incorporating penalized regression spline types of smoothing functions into the estimation process), in which the degree of smoothing of each smooth term (and by extension, the estimated degrees of freedom of each smoother) is treated as a random effect and thus estimable via its variance as with other effects in a mixed modelling structure (Wood 2006).The results of these analyses are graphically presented in a consistent format: Predicted values from the model were plotted as bold black lines, the 95 per cent confidence intervals of these trends delimited by grey shading. If an r^2 for a trend line was less than 0.5 no line of best fit was shown.

Several GAMs and GAMMs were used on seagrass cover, light, epiphyte cover and macroalgae cover to tease out trends at the habitat, regional and location scale over time. When dealing with data where there are two replicate sites at a given location (e.g. YP1 and YP2 for Yule Point), site was incorporated as a random factor in the models to account for spatial correlation. However, as part of our regular model validation process, if the boxplot with Pearson's residuals plotted against Site showed very similar values for each site within each location then a GAM was used instead of a GAMM.

Per cent cover data models were fitted using a quasi-binomial distribution due to the proportional (bound between 0 and 1) nature of the data. Raw data at the quadrat level was used to provide the maximum resolution for modelling. However, this led to a very large proportion of 0 in some data sets causing high heterogeneity of variance for some models. For this reason, GAMMs for epiphyte and macroalgae cover are not presented and the inclusion in future reports of Zero inflated GAMMs is being investigated. Light data models were fitted using a gamma distribution due to the strictly positive continuous nature of the data. GAM were used in this instance as PAR loggers are deployed at one site per location and therefore site do not act as a random factor. In addition of the GAMMs, non-linear regressions and polynomials were used (at the request of past reviewers) to show trends in seagrass abundance (per cent cover) over time; 95 per cent confidence intervals are displayed.

The majority of meadows have been in a "recovery mode" since losses in 2008-2011. As such, there have been periods of limited sample availability (e.g. for tissue nutrients", and the absence of data has restricted whether multivariate analysis can be undertaken routinely. Analysis is currently underway to more fully interrogate the temporal and covariate components of the data as the time series of observations lengthen.

3.5 Reporting Approach

The data is presented in a number of ways depending on the indicator and section of the report:

- Report card scores for seagrass condition are presented at the start of each section. These are a numerical summary of the condition within the region relative to a regional baseline (described further below),
- Climate and environmental pressures are presented as averages (daily, monthly or annual) and threshold exceedance,
- Seagrass community data such as seagrass abundance, leaf tissue nutrients are presented as averages (sampling event, season or monitoring period with Standard Error) and threshold exceedance data,
- Seagrass ecosystem data such as sediment composition, epiphyte and macroalgae are presented as averages (sampling event, season or monitoring period) and relative to the long-term,
- Trend analysis (GAMM plots) are also used to explore the long-term temporal trends in biological and environmental indicators.

Within each region, estuarine and coastal habitat boundaries were delineated based on the Queensland coastal waterways geomorphic habitat mapping, Version 2 (1:100 000 scale digital data) (Heap *et al.* 2015). Reef habitat boundaries were determined using the AUSLIG (now the National Mapping Division of Geosciences Australia) geodata topographic basemap (1:100 000 scale digital data). Conceptual diagrams have been used to illustrate the general seagrass habitats type in each region and can be found in Appendix 1 with the background description of each NRM region. Symbols/icons have been used in the conceptual diagrams to illustrate major controls, processes and threats/impacts.

3.6 Calculating scores for the Report card

Three indicators (presented as unitless scores) were selected by the GBRMPA, using advice from expert working groups and the Paddock to Reef Integration Team, for the seagrass report card:

1. seagrass abundance (per cent cover)
2. reproductive effort
3. nutrient status (leaf tissue C:N ratio)

The methods for score calculation was chosen by the Paddock to Reef Integration Team (i.e. not the authors of this report) and all report card scores are transformed to a five point scale from 0 to 100 to allow integration with other components of the Paddock to Reef report card (Department of the Premier and Cabinet 2014). The methods and scoring system for the report card are detailed in Appendix 3. *Please note that the scale from 0 to 100 is unitless and should not be interpreted as a proportion or ratio.*

3.6.1 Seagrass abundance

Seagrass abundance state in the MMP is measured using the median seagrass per cent cover relative to the site or reference (habitat type within each NRM region) guideline. Abundance guidelines (threshold levels) were determined using the long-term (>4 years) baseline where the percentile variance plateaued (generally 15-20 sampling events), thereby providing an estimate of the true percentile value (McKenzie 2009). Guidelines for individual sites were only applied if the conditions of the site aligned with reference conditions and the site had been subject to minimal/limited disturbance for 3-5 years (see Appendix 3).

Abundance state at each site for each monitoring event was allocated a grade: *very good*, median per cent cover at or above 75th percentile; *good*, median per cent cover at or above 50th percentile; *moderate*, median per cent cover below 50th percentile and at or above low guideline; *poor*, median per cent cover below low guideline; and *very poor*, median per cent cover below low guideline and declined by >20 per cent since previous sampling event). The choice of whether the 20th or 10th percentile is used for the low guideline depends on the within-site variability; generally the 20th percentile is used, unless within-site variability was low (e.g., CV<0.6), whereby the 10th percentile was more appropriate as the variance would primarily be the result of natural seasonal fluctuations (i.e. nearly every seasonal low would fall below the 20th percentile). Details on the percent cover guidelines can be found in Appendix 3.

A grade score from 0 to 100 (Table 5) was then assigned to enable integration with other seagrass indicators and other components of the P2R report card (Department of the Premier and Cabinet 2014). Annual seagrass abundance scores were calculate using the average grade score for each site (including all sampling events per year), each habitat and each NRM. Please note that the scores are unitless and should not be interpreted as a proportion or ratio.

Table 5. *Scoring threshold table to determine seagrass abundance status. low = 10th or 20th percentile guideline (see Appendix 3, Table 45). NB: scores are unitless.*

grade	percentile category	score	status
very good	75-100	100	81 - 100
good	50-75	75	61 - 80
moderate	low-50	50	41 - 60
poor	<low	25	21 - 40
very poor	<low by >20 per cent	0	0 - 20

3.6.2 Seagrass reproductive effort

Most seagrass species of the GBR produce flowers in the late dry season, so reproductive effort is sampled once during the late dry season. However, the timing of peak flowering density and the mode of reproduction is variable among species (Waycott*, et al.* 2007). In order to incorporate all available information on reproduction, including recent past reproduction (as evidenced by seeds and fruits) and current reproduction (flowers and inflorescences) all reproductive structures are measured.

The average density of reproductive structures over a 5 year period (2005-2010) was used to determine a guideline value for a combination of all reproductive structures for all species, in each habitat type, across the GBR during the late dry (coastal intertidal = 8.22±0.71, estuarine intertidal = 5.07±0.41, reef intertidal = 1.32±0.14),). The total number of reproductive structures per core measured during the current monitoring event (Sept/October 2015) was normalised using this GBR average, with the ration then being ranked from very good to very poor (Table 6).

Table 6. *Scores for late dry monitoring period reproductive effort average against long-term (2005-2010) GBR habitat average. NB: scores are unitless.*

description	***Reproductive Effort monitoring period / long-term***	***ratio***	***score***	***0-100 score***	***status***
very good	≥4	4.0	4	100	81 - 100
good	2 to <4	2.0	3	75	61 - 80
moderate	1 to <2	1.0	2	50	41 - 60
poor	0.5 to <1	0.5	1	25	21 - 40
very poor	<0.5	0.0	0	0	0 - 20

3.6.3 Seagrass nutrient status.

Tissue nutrient content of seagrass leaves including carbon (C), nitrogen (N) and phosphorus (P) were measured in seagrass leaves. Tissue nutrients are indicators of integrated recent ('recent' being defined by leaf life-span and ranging from days to months prior to sampling) environmental conditions. The absolute tissue nutrient concentrations (%C, %N & %P) are used to calculate the atomic ratio of nutrients in seagrass leaves. The C:N ratio was chosen for the purpose of the report card score as it is the ratio that indicates a change in either light or nitrogen availability at the meadow scale. C:N ratios were compared to a global average value of 20:1 (Atkinson and Smith 1983; Fourqurean*, et al.* 1992b), with values less than 20:1 indicating either reduced light or excess N is available to the seagrass. Values higher than 20:1 suggest light saturation and low nitrogen availability (Abal*, et al.* 1994; AM Grice*, et al.*, 1996; Udy & Dennison 1997). C:N ratios from the late dry sampling (Sept/Oct 2015) were categorised on their departure from the guideline and transformed to a 0 to 100 score as shown in Table 7.

Table 7. *Scores for leaf tissue C:N against guideline to determine light and nutrient availability. NB: scores are unitless.*

description	**C:N ratio range**	**Score ($\bar{R}$) range and status**
very good	C:N ratio >30*	81 - 100
good	C:N ratio 25-30	61 - 80
moderate	C:N ratio 20-25	41 - 60
poor	C:N ratio 15-20	21 - 40
very poor	C:N ratio <15*	0 - 20

3.6.4 Seagrass index

The seagrass index is an average score (0-100) of the three seagrass status indicators chosen for the MMP. Each indicator is equally weighted as we have no preconception that it should be otherwise. To calculate the overall score for seagrass of the Great Barrier Reef (GBR), the regional scores were weighted on the percentage of GBRWHA seagrass (shallower than 15m) within that region (Table 8). *Please note: Cape York omitted from the GBR score in P2R reporting prior to 2012 due to poor representation of inshore monitoring sites throughout region.*

Table 8. *Area of seagrass shallower than 15m in each NRM region (from McKenzie, et al. 2010c) within the boundaries of the Great Barrier Reef World Heritage Area.*

NRM	**Area of seagrass** (km^2)	**per cent of GBRWHA**
Cape York	2,078	0.60
Wet Tropics	207	0.06
Burdekin	587	0.17
Mackay Whitsunday	215	0.06
Fitzroy	257	0.07
Burnett Mary	120	0.03
GBRWHA	**3,464**	**1.00**

4 Results & Discussion

The following results and discussion section provides detail on the overall climate, environmental pressures and seagrass responses for the 2015-16 monitoring period, in context of longer-term trends. It is structured as:

1. GBR-wide summary: overall GBR-wide trends and trends for each habitat type represented separately
2. a chapter on each NRM region starting with the most northern, Cape York
3. Case study: Assessing the effects of light and temperature on seagrass abundance

Each section (aside from the case studies) contains data on environmental pressures as well as the indicators that are used for calculating the report card score, or data that may be included in the report card in the future:

1. A summary of the key findings from the overall section including a summary of the report card score
2. Climate, river discharge and flood plume exposure
3. Within-canopy light threshold exceedance
4. Within-canopy temperature threshold exceedance
5. Seagrass abundance and extent
6. Seagrass species composition based on life history traits
7. Seagrass reproductive effort and seed banks
8. Seagrass leaf tissue content (C:N, N:P and C:P ratios)
9. Epiphyte and macroalgae abundance
10. Seagrass meadows sediment characteristics
11. Findings from other seagrass monitoring programs (e.g., QPSMP)
12. Report card score

The following supporting data, identified as important in understanding the Results and discussion sections (including any long-term trends), is detailed within Appendix 4:

1. Climate (daily maximum air temperature, monthly rainfall, monthly cloud cover, and monthly 3pm wind speed) relevant to each monitoring location
2. Annual daytime tidal exposure at each monitoring site
3. Daily within canopy seawater temperature at each monitoring site
4. Daily light each monitoring location
5. Sediment grain size composition at each monitoring site
6. Epiphyte and macroalgae abundance at each monitoring site
7. Meadow extent within each monitoring site (5.5 ha)
8. Location and seagrass species composition at each monitoring site
9. Seagrass leaf tissue nutrient C:N, C:P, and N:P at each monitoring location
10. Seagrass leaf tissue nutrient isotopic signature ($\delta^{13}C$, $\delta^{15}N$) concentrations, for each species at each monitoring habitat within each NRM region
11. Tables detailing statistical analysis

4.1 GBR-wide Summary

2015-16 was the lowest period on record for cyclone activity in Australia and discharge from most GBR rivers was at or below the long-term median. Despite this, exposure to turbid primary and secondary green water types (assessed using remote sensing by the MMP inshore water quality sub-program) was high, ranging from 76-100 per cent of wet season weeks (November to April) at all sites except at four reef sites which had lower levels of exposure (9-55 per cent). Daily light, or irradiance (I_d), was also lower (12.8 mol m^{-2} d^{-1}) than the long-term average (13.4 mol m^{-2} d^{-1}). Reductions in I_d occurred in the Wet Tropics, Burdekin and Burnett Mary regions, and in estuarine and reef intertidal habitats. Acute light thresholds were exceeded the most frequently at subtidal sites and coastal sites in the Burdekin region.

Within canopy temperatures were higher in all regions during 2015-16 than the long-term average. It was also the second year in a row of above average temperature in northern and central GBR sites. High water temperatures (>35°C) were exceeded for a record number of days in the three southern and central regions with the highest in the Mackay Whitsunday region (77d) followed by the Fitzroy region (63 d). These elevated temperatures may have affected seagrass photosynthesis and respiration, and hampered recovery from previous flood-related losses in combination with lower than average light levels in 2015-16.

Seagrass abundance (per cent cover) across the shallow inshore GBR has continued to recover from the losses caused by multiple years of above average rainfall followed by an extreme cyclone and associated flooding events in early 2011. In 2015-16, abundance (all meadows and sampling events) increased slightly (not significant) from the previous period to 15.7 ±1.5 per cent, but remained below the GBR long-term average (19.2 ±2.1 per cent, Jun00-May10) and GBR historical baseline (22.6 ±1.2 per cent Nov84-Nov88) (McKenzie *et al.* 2015). In the 2015-16 monitoring period, the GBR-wide seagrass abundance score continued to increase and remained at a *moderate* rating. The increase was due mostly to continued recovery of abundance in the Mackay Whitsunday and the Burnett Mary regions, and large increase at coastal Wet Tropics (per cent cover doubled at Yule Point since 2014-15).

Fifty per cent of the MMP sites examined in 2015-16 remained classified as poor or very poor in abundance, with an annual average abundance (all sites and sampling events) of 16.1 ±2.1 per cent for estuarine, 16.2 ±1.4 per cent for coastal, 15.3 ±1.3 per cent for subtidal coast, 14.6 ±1.3 per cent for reef and 16.2 ±1.6 per cent for subtidal reef. Seagrass species richness also differed between locations and habitats in the GBR Region, with inshore reef habitats more specious than meadows at coastal or estuarine habitats. However, since 2011, meadows monitored in the GBR have undergone a state change being firstly dominated by a greater than average proportion of seagrass species displaying colonising traits, until the 2014-15 monitoring period when the foundation (opportunistic and persistent) seagrass species became more dominant. In 2015-16, the proportion of colonising species increased at reef sites, reduced at estuarine sites and were unchanged at coastal sites. Despite ongoing recovery in seagrass abundance, the overall seagrass score was reduced and remained *poor* due to trends in the other two indicators.

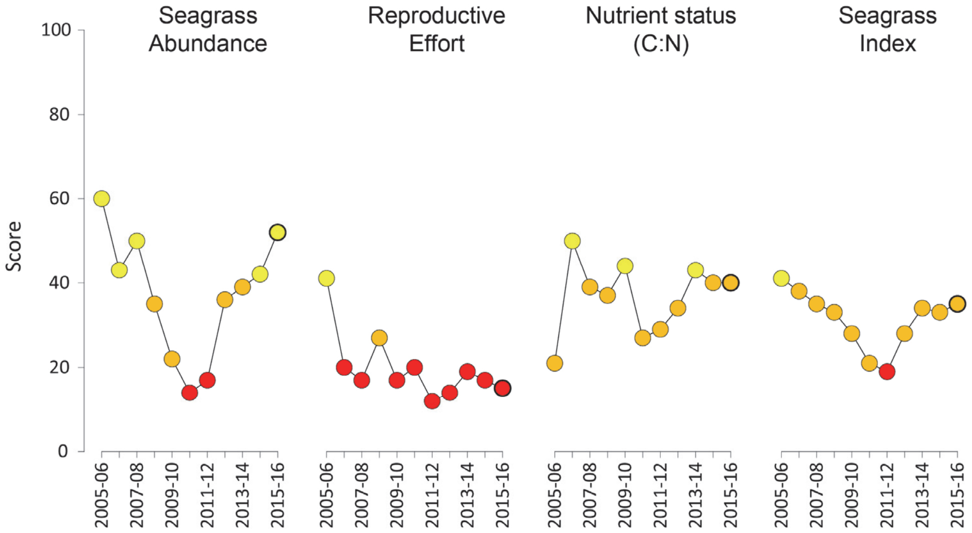

Figure 6. *Report card scores (NRM regional averages pooled) for each indicator and total seagrass index over the life of the MMP. Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

Reproductive effort declined slightly and remained **very poor**. Reproductive effort increased at estuary and coastal habitats, but declined in reef intertidal and reef subtidal habitats in 2015-16 relative to the previous year. Reproductive effort increased to poor (from very poor) in the Burnett Mary region, and increased, but remained moderate in the Burdekin, while in all other regions reproductive effort was unchanged and remained poor (Mackay Whitsunday) or very poor (Cape York, Wet Tropics, Fitzroy). Seed banks, which had shown some signs of improvement following 2011 extreme events, continued to increase in coastal habitat in 2015-16, but were seasonally variable in other habitats and declined slightly compared to previous years. Low reproductive effort will hinder replenishment of the depauperate seed banks in reef habitat, and seed banks are therefore likely to remain low in coming years. Most meadows can be considered vulnerable to further disturbances because they have limited capacity to recover from seed (low resilience).

Seagrass leaf tissue nutrients of foundation species remained **poor** in late 2015 (Figure 5), indicating that nitrogen (N) was in surplus relative to light availability (C:N reduced). In the Burdekin region, C:N decreased to moderate from good while in the Burnett Mary region C:N increased to moderate from poor and in all other regions there were no substantial changes and the C:N score remained poor. The ratio of nitrogen to phosphorus (N:P) in seagrass tissue increased in some habitats, predominantly reef habitats, in the Wet Tropics, Burdekin and Mackay-Whitsunday regions. This was associated with increased per cent N in reef habitat, but stable and low per cent.

Across the GBR NRM regions, the seagrass report card scores in 2015-16 did not substantially change, and were **poor** in all regions except the Burdekin which remained **moderate** (Figure 7). Cape York increased in abundance at reef sites despite the heat wave that passed through in early 2016, but the meadows remain in poor condition due to low reproductive effort and seed bank density. The seagrass in the Wet Tropics remains in poor condition overall, but there is large variability among sites and habitats, reflecting the multiple stressors in this region. The coastal sites in the northern Wet Tropics (Yule Point) have continued to improve over the last 12 months. In contrast, northern reef sites have declined further since 2014-15, and in the southern Wet Tropics, recovery since 2011 has been extremely slow, or absent with signs that negative feedbacks have prevented recovery (i.e. recalcitrant degradation sensu. O'Brien *et al.* 2017). The Burdekin region remains in moderate condition after rapid recovery from disturbances in 2011; however, declines in abundance and tissue nutrients at reef sites as well as reduced light and frequent exposure to secondary water signals that meadows are at risk from poor water quality. The Mackay Whitsundays also increased in abundance, but poor reproductive effort, low seed bank density, and low tissue nutrient scores, particularly at the reef sites, makes this region vulnerable to further disturbances. The Fitzroy was the only region that increased its overall score (from very poor to poor), but the improvement was marginal, and meadows remain highly vulnerable. The Burnett Mary region increased in abundance and tissue nutrients, but low reproductive effort and seed bank density means that the meadows remain highly vulnerable.

The fluctuating seagrass condition scores across the GBR indicate a system that is recovering, with past climate and anthropogenic impacts leaving a legacy of reduced resilience. The overall increase in abundance indicates a system that is on a recovery trajectory. Therefore, reproductive effort and seed bank density may start to increase and build resilience in following years if there are no major disturbances.

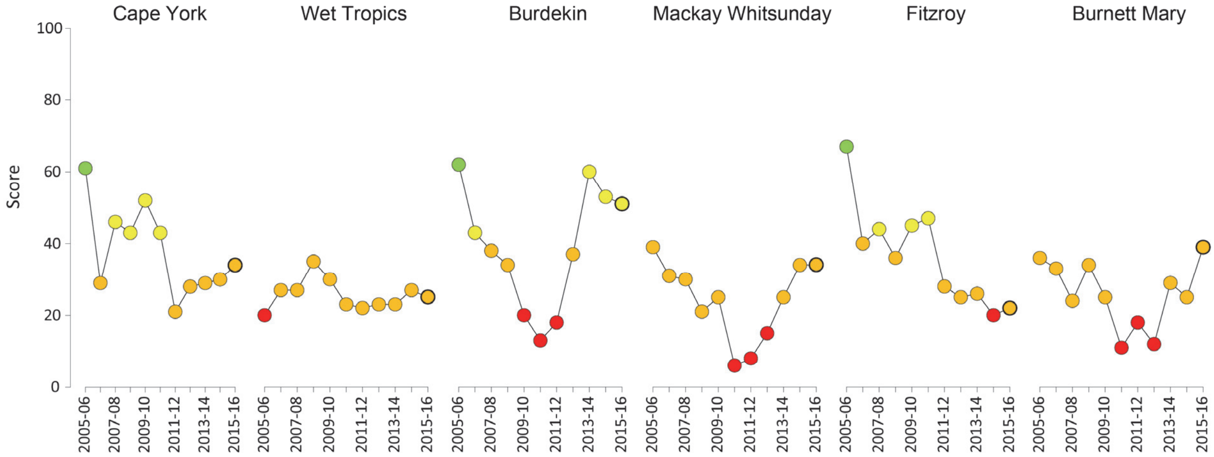

Figure 7. *Report card of seagrass condition for each NRM region (averaged across indicators). Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

4.1.1 Climate and environmental pressures

Environmental stressors from cyclones, river discharge, wind and water quality in 2015-16 were relatively moderate in the inshore GBR (Table 9). However, within canopy water temperature was above average throughout the GBR, with meadows in the southern and central GBR experiencing record high temperatures. Furthermore, despite low river discharge and better than average water quality (Waterhouse, *et al.* 2017), most meadows had a high frequency of exposure to primary or secondary water (86 per cent) and within canopy light levels were below average. The reason for the below-average light conditions cannot be determined from this data alone; however, the water quality sub-program reports that turbidity (NTU), and total suspended solids (TSS), have been below average, but the concentrations of dissolved and particulate carbon, and particulate nitrogen and phosphorus have increased in some parts of the Burdekin and Wet Tropics (see Waterhouse et al 2017 for further details).

The 2015-16 year had the lowest cyclone activity on record. There was one tropical cyclone to affect the region named TC Tatiana, which briefly reached a category 2 on the 12th February 2016. It did not make landfall nor enter the GBR, but it did produce some powerful swells along the southeast Queensland coast (Bureau of Meteorology 2016b). Although rainfall was above average, river discharge was well below average for the second year in a row (Table 10). However, some rivers in the central and southern GBR (e.g. Fitzroy River, Waterpark Creek, Kolan, Burnett and Burrum Rivers) had above-average discharge in 2015-16, with the Fitzroy River discharging the greatest total flows relative to all other catchments in 2015-16, followed by the Normanby River in Cape York.

Table 9. *Summary of environmental conditions at monitoring sites across the GBR in 2015-16 compared to the long-term average (range indicated for each data set). Regional and habitat-specific levels are provided in later sections. *intertidal only.*

Environmental condition		**Long-term average**	**2015-16**
Climate			
Cyclones (1968-2016)		4	1
Rainfall (1998-2016)		1204.2 mm	1478.8 mm
Riverine discharge (1970-2016)		49,403,162 L yr^{-1}	35,225,038 L yr^{-1}
Turbid water exposure (2006-2016)		*not available*	86 per cent
Winds >25km hr^{-1} (1998-2016)		107.5 d yr^{-1}	110 d yr^{-1}
Within seagrass canopy			
Within canopy temperature (2003-2016)*		25.5 ±0.1°C (46.6°C)	25.9 ±0.1°C (41.6°C)
Within canopy light (2008-2016)		13.4 mol m^{-2} d^{-1}	12.8 mol m^{-2} d^{-1}
Proportion mud	*estuary intertidal* (1999-2016)	35.1 ±2.2 per cent	46.2 ±3.3 per cent
	coast intertidal (1999-2016)	20.1 ±2.9 per cent	19.5 ±2.9 per cent
	reef intertidal (2001-2016)	3.0 ±1.4 per cent	3.5 ±0.3 per cent
	reef subtidal (2008-2016)	0.6 ±0.2 per cent	4.8 ±0.4 per cent

Water quality at the seagrass sites is assessed from water type exposure (turbid primary water and green secondary water) derived from remote sensing (Waterhouse*, et al.* 2017). During 2015-16, most seagrass sites experienced high frequency of exposure to either primary or secondary water ($f_{(P+S)}$) because they are located in the near-shore margin which maintains poor water quality even during low flow conditions (Figure 8). All sites within the Burdekin and Burnett Mary regions were exposed to water that is brown, or partially brown and green for 100 per cent of wet season weeks (November to April), including the reef sites at Magnetic Island. Exposure was second highest in the Fitzroy and Mackay Whitsunday regions ranging from 76-100 per cent of wet season weeks (except Hamilton Island, 55 per cent). The Wet Tropics and Cape York regions had sites with the lowest levels of exposure due mostly to the number of offshore reef sites (Green Island 9 per cent, Piper Reef 23 per cent, Low Isles 26 per cent), but all other sites in the two northern regions also had a high exposure to primary and secondary water (86-100 per cent).

Daily incident light

Daily incident light (I_d, mol m^{-2} d^{-1}) reaching the top of the seagrass canopy in the GBR in 2015-16 (12.8 mol m^{-2} d^{-1}) was slightly lower than the long-term average (13.4 mol m^{-2} d^{-1}) (Figure 9). Cape York sites had the highest I_d (17.5 mol m^{-2} d^{-1}), followed by Fitzroy (15.7 mol m^{-2} d^{-1}), Mackay Whitsunday (14.5 mol m^{-2} d^{-1}), Wet Tropics (12.2 mol m^{-2} d^{-1}), Burnett Mary (10.6 mol m^{-2} d^{-1}) and, Burdekin sites had the lowest (9.9 mol m^{-2} d^{-1}). Both the Wet Tropics and Burdekin have subtidal sites, with lower I_d than intertidal sites, and these lowered their regional average. With these excluded, I_d in 2015-16 is third highest in the Wet Tropics (15.1 mol m^{-2} d^{-1}), while the Burdekin increases to second lowest (11.1 mol m^{-2} d^{-1}). The Id at Wet Tropics subtidal sites was 7.7 mol m^{-2} d^{-1} on average compared to 7.4 mol m^{-2} d^{-1} long-term average and 4.2 mol m^{-2} d^{-1} at the Burdekin subtidal site, compared to 5.6 mol m^{-2} d^{-1} long-term. Compared to the long-term average, in all regions I_d was lower than the long-term average, except in Mackay Whitsunday and Fitzroy regions; however loggers were only deployed for some of the 2015-16 year at Fitzroy and Cape York sites as monitoring was reduced to once per year and loggers recorded only from October-March. Daily light for each site is presented in Appendix 4.

Daily light in 2015-16 was the highest at reef intertidal habitat (15.7 mol m^{-2} d^{-1}), followed by the coastal intertidal sites (12.8 mol m^{-2} d^{-1}), estuarine sites (11.4 mol m^{-2} d^{-1}), and lowest at the reef subtidal sites (7.3 mol m^{-2} d^{-1}). Daily light was lower than the long-term average at estuarine sites (long-term average = 12.1 mol m^{-2} d^{-1}), and at reef intertidal sites (long-term average = 17.0 mol m^{-2} d^{-1}), while at coastal and reef sites subtidal sites, I_d was similar to the long-term averages (12.7 and

7.3 mol m^{-2} d^{-1}). However there were notable exceptions at Magnetic Island (reef subtidal), which was well below the long-term average with an an I_d (4.2 mol m^{-2} d^{-1}) lower than the acute light thresholds (5 mol m^{-2} d^{-1}).

Table 10. *Long term annual discharge (in megalitres) for the major GBR catchment rivers in proximity to the inshore seagrass monitoring sites (where data available) for the 2015-16 wet season(c.a., from Nov 1st to Apr 30th), compared against the previous wet seasons and long-term (LT) median. Colours indicate levels above LT median: yellow for 1.5 to 2 times; orange for 2 to 3 times, and red for greater than 3 times. Long term statistics were calculated based on the wet seasons from Nov 1st, 1949 to Apr 30th, 2000. Compiled by Waterhouse, et al. 2017.*

NRM	Basin	LT median	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2014 - 2015	2015 - 2016
Cape York	Jacky Jacky Ck	2,021,488	4,735,197	1,820,422	1,986,825	3,790,832	1,498,138	630,787
	Olive Pascoe R	2,526,860	5,918,996	2,275,527	2,483,531	4,738,541	1,872,672	788,484
	Lockhart R	1,600,345	3,748,697	1,441,167	1,572,903	3,001,076	1,186,026	499,373
	Stewart R	674,618	2,180,850	616,070	523,353	1,311,775	298,816	311,901
	Normanby R	4,159,062	11,333,284	2,181,990	3,462,238	5,059,657	2,914,859	3,407,359
	Jeannie R	1,263,328	2,824,817	1,048,269	695,195	1,869,982	1,434,447	1,581,015
	Endeavour R	821,163	1,836,131	681,375	451,877	1,215,488	932,391	1,027,660
Wet Tropics	Daintree R	1,722,934	3,936,470	2,396,905	1,668,302	5,137,023	1,905,224	1,623,478
	Mossman R	1,207,012	2,014,902	1,526,184	1,147,367	1,918,522	874,068	1,245,275
	Barron R	526,686	2,119,801	852,055	328,260	663,966	380,395	182,999
	Mulgrave-Russell R	4,457,940	7,892,713	5,696,594	3,529,862	5,420,678	3,145,787	3,253,825
	Johnstone R	4,743,915	9,276,874	5,338,591	3,720,020	5,403,534	3,044,680	3,416,331
	Tully R	3,536,054	7,442,768	3,425,096	3,341,887	4,322,496	2,659,775	2,942,770
	Murray R	1,227,888	4,267,125	2,062,103	1,006,286	1,531,172	366,212	974,244
	Herbert R	3,556,376	12,593,674	4,545,193	3,189,804	4,281,607	1,095,372	1,895,526
Burdekin	Black R	228,629	1,424,283	747,328	188,468	419,290	17,654	129,783
	Ross R	445,106	2,092,684	1,324,707	276,584	1,177,255	-	-
	Haughton R	553,292	2,415,758	1,755,712	517,069	573,976	120,674	267,986
	Burdekin R	4,406,780	34,834,316	15,568,159	3,424,572	1,458,772	880,951	1,807,104
	Don R	342,257	3,136,184	802,738	578,391	324,120	171,305	101,562
Mackay Whitsunday	Proserpine R	887,771	4,582,697	2,171,287	851,504	720,427	157,123	316,648
	O'Connell R	796,718	4,112,676	1,948,591	764,170	646,537	141,008	284,171
	Pioneer R	776,984	3,630,422	1,567,684	1,162,871	635,315	2,028,936	597,117
	Plane Ck	1,052,831	4,809,239	2,854,703	1,948,929	737,580	241,254	832,508
Fitzroy	Styx R	187,756	906,144	275,219	968,106	544,155	376,009	343,877
	Shoalwater R	213,653	1,031,129	313,180	1,101,638	619,211	427,872	391,308
	Water Park R	563,267	2,718,432	825,657	2,904,319	1,632,466	1,128,027	1,031,630
	Fitzroy R	2,852,307	37,942,149	7,993,273	8,530,491	1,578,610	2,681,949	3,589,342
	Calliope R	152,965	1,000,032	345,703	1,558,380	283,790	479,868	148,547
	Boyne R	38,691	252,949	87,443	394,178	71,782	121,378	37,574
Burnett Mary	Baffle R	367,525	3,650,093	1,775,749	2,030,545	275,517	710,352	257,093
	Kolan R	47,866	779,168	307,837	810,411	45,304	213,857	111,172
	Burnett R	234,463	9,421,517	643,137	7,581,543	218,087	853,349	381,054
	Burrum R	63,918	114,492	117,762	90,921	62,188	150,113	334,681
	Mary R	1,144,714	8,719,106	4,340,275	7,654,320	594,612	1,651,901	480,854

NB: *Values were obtained from DNRM (http://watermonitoring.dnrm.qld.gov.au/host.htm) and up-scaled using the methodology presented in section 4-8.*

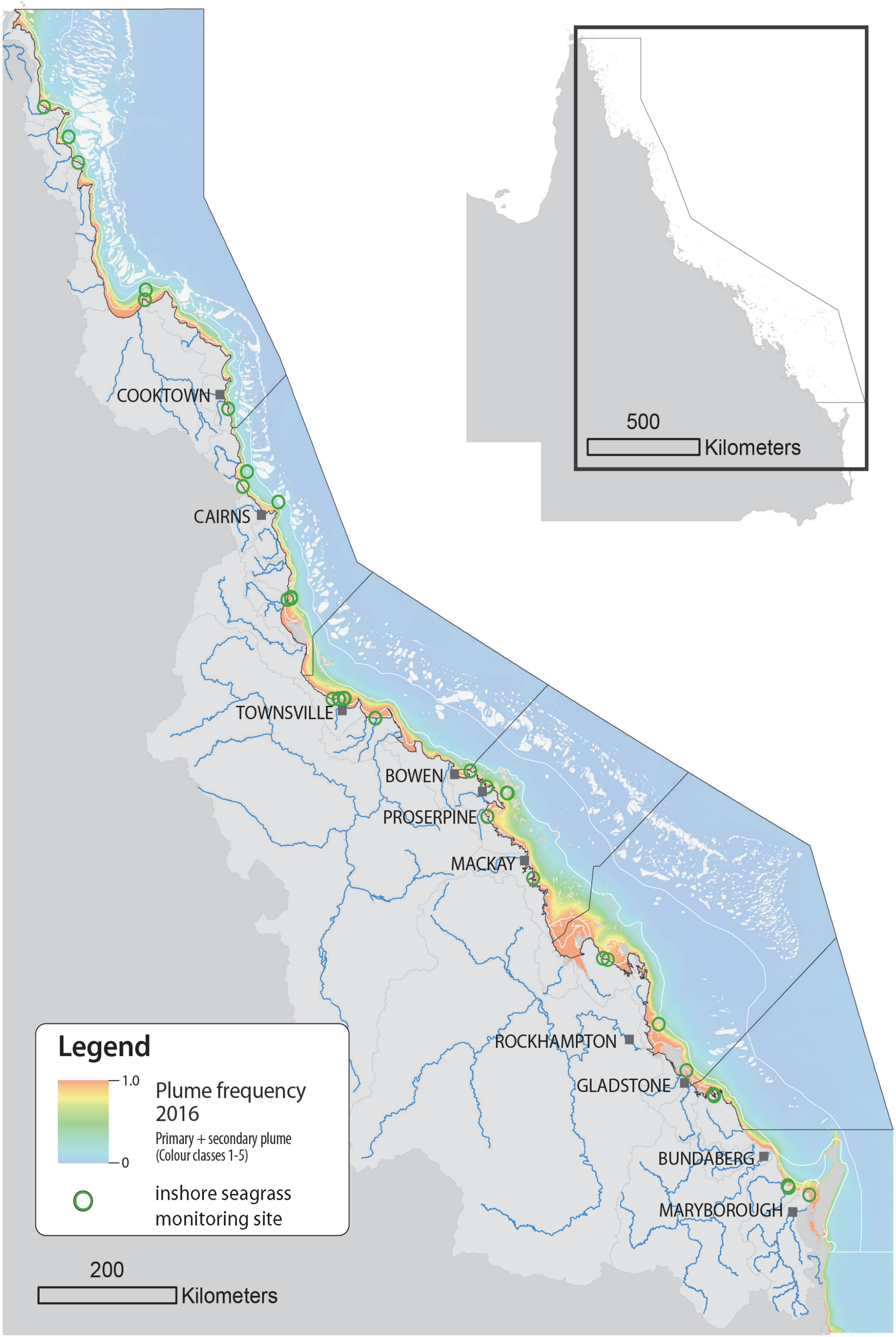

Figure 8. *Turbid water exposure (colour classes 1 – 5, primary and secondary water) frequency in the GBR from December 2015 to April 2016 ranging from frequency of 1 (red, always exposed) to 0 (dark blue, never exposed). Green circles show seagrass monitoring sites. From Waterhouse et al. 2017.*

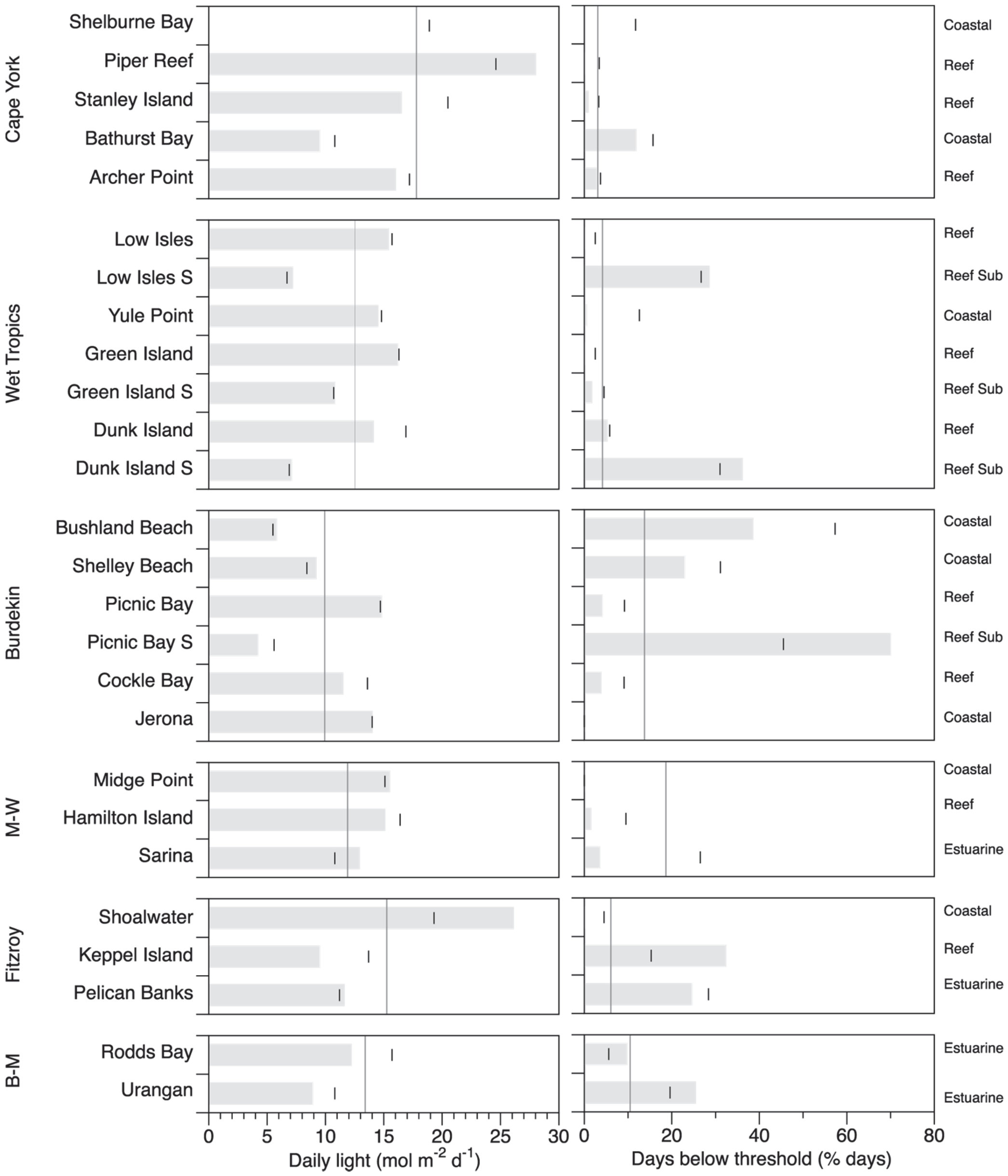

Figure 9. *Average daily light (left-hand panel) and thresholds exceeded (per cent days, right-hand panel) for coastal, estuarine, reef intertidal, and reef subtidal sites including the long-term average and the value for the 2015-16 reporting period. Grey bar = 2015-16, small lines represent long-term average of the site, and long-lines represent long-term average for the NRM region. NRM regions: WT= Wet Tropics, BDT = Burdekin; M-W = Mackay Whitsunday; F = Fitzroy; B-M = Burnett Mary.*

Threshold exceedance (number of days less than 5 mol m^{-2} d^{-1}, for northern *Halodule uninervis* dominated meadows (Collier *et al.* 2012b) and <6 mol m^{-2} d^{-1} for southern *Zostera muelleri* dominated meadows (Chartrand *et al.* 2016b) for 2015-16 (12.9 per cent of days) was similar to the long-term average (14.8 per cent of days). The thresholds were exceeded the most frequently in the Burdekin (23.2 per cent of days) followed by Fitzroy (19.0 per cent), Burnett Mary (17.6 per cent), Wet Tropics (10.3 per cent), Cape York (3.9 per cent) and the least often in Mackay Whitsunday (1.7 per cent) for the first time since monitoring began. The greatest level of exceedance was at the Magnetic Island subtidal site (70 per cent).

Daily light in shallow habitats can be affected by water quality, cloudiness and the depth of the site, which affects the frequency and duration of exposure to full sunlight at low tide (Anthony *et al.* 2004;

Fabricius *et al.* 2012); however, the differences in I_d among seagrass meadows is largely a reflection of site-specific differences in water quality as outlined in earlier reports (McKenzie*, et al.* 2015). Turbidity and chlorophyll monitoring is no longer in place at seagrass sites. However, flood plume mapping (Devlin*, et al.* 2015), is used to derive water type exposure at seagrass sites and frequency of exposure to these water types can be a predictor of changes in seagrass abundance (see case study 2, in McKenzie et al 2016).

Long-term trends demonstrate that the peak in canopy light occurs in September to December as incident solar irradiation reaches its maximum and prior to wet season conditions (Figure 10a). In 2015-16 the highest light levels were reached in late November 2015. The lowest light levels typically occur in the wet season in particular, in January to April, but in 2015-16 the lowest levels occurred in June 2015. The GAM model shows the long-term trends in within-canopy I_d and its level of prediction is improved with habitat included (Figure 10b) and so further detail on I_d within each habitat and NRM region is given in the following sections.

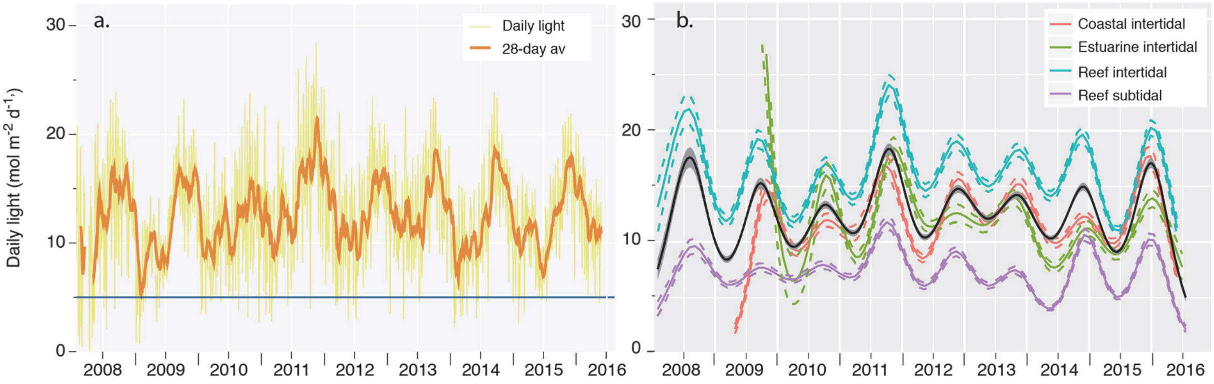

Figure 10. *Daily light for all sites combined (a.) and GBR-wide trend (GAM plot) in daily light for each habitat (b.) from 2008 to 2016.*

Within canopy seawater temperature

Within seagrass canopy seawater temperature data were collected from September 2003 to May 2016. The 2015-16 monitoring period included a heat wave (Bureau of Meteorology 2016a) causing wide-spread coral bleaching and mortality that affected Cape York, the Wet Tropics and, to a lesser extent, the Burdekin region. Within seagrass canopy water temperature was also above average throughout the GBR (Table 9). Within canopy water temperature in Cape York exceeded 35°C for a record number of days in 1 month (18d in February). However, within canopy temperature is often very high in Cape York, and the total annual exceedance (9.8 per cent of days) was lowest since measures began at all sites (2012), and was the second lowest level of exceedance among all regions in the GBR (Figure 11). Similarly, the Wet Tropics and Burdekin regions had above-average water temperature, but exceeded 35°C for 12 per cent of days, which is the median level for these regions. In contrast, the three southern NRM regions experienced above average temperatures, and the largest number of very warm days >35°C since records began in 2003-04. In the Mackay Whitsunday, temperatures were greater than 35°C for 77d (21 per cent), and in the Burnett Mary, water temperature exceeded 40°C for the first time since records began. With the exception of the Wet Tropics and Fitzroy regions, all other regions experienced extreme (>40°C) seawater temperatures in 2015-16. Cape York experienced extreme (>40°C) seawater temperatures in March 2016, Burdekin in February 2016, and both the Mackay Whitsunday and Burnett Mary in January-February 2016. The hottest seawater temperature recorded along the GBR during 2015-16 was 41.6°C, which was at Bathurst Bay (BY1) on 6 March 2016 at 2:00pm. However, these extreme temperature days (>40°C) that can cause photoinhibition were relatively low in frequency and were unlikely to cause burning or mortality, but elevated water temperature possibly had a chronic and cumulative impact on seagrass condition.

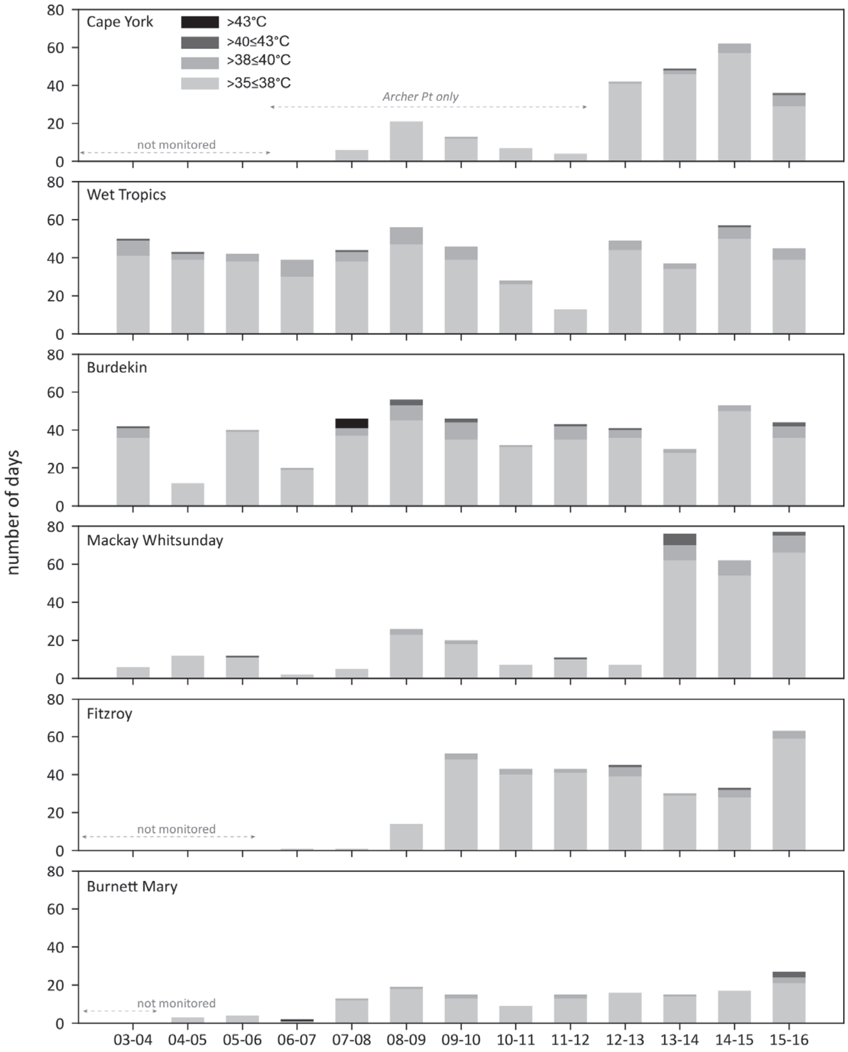

Figure 11. *Number of days when inshore intertidal sea temperature exceeded 35°C, 38°C, 40°C and 43°C in each monitoring period in each NRM region. Thresholds adapted from Campbell et al. 2006a; Collier, et al. 2012b.*

Within canopy seawater temperatures across the GBR were just above the long-term (10 year) average over the 2015-16 monitoring period (Table 9); the warmest in 5 years (Figure 12). The warmest period since MMP monitoring commenced was 2005-06 and the coolest was 2011-12 (Figure 12).

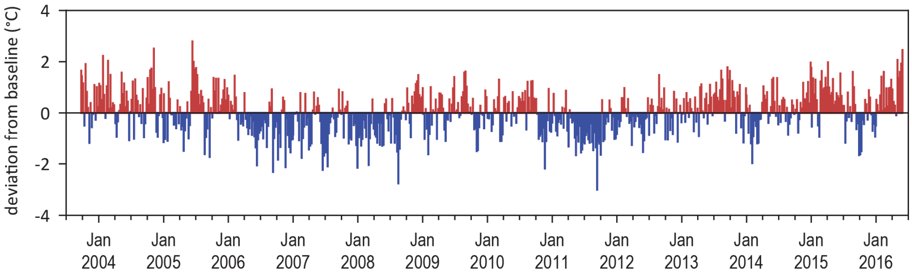

Figure 12. *Inshore intertidal sea temperature deviations from baseline for GBR seagrass habitats 2003 to 2016. Data presented are deviations from 13-year mean weekly temperature records (based on records from September 2003 to June 2016). Weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations.*

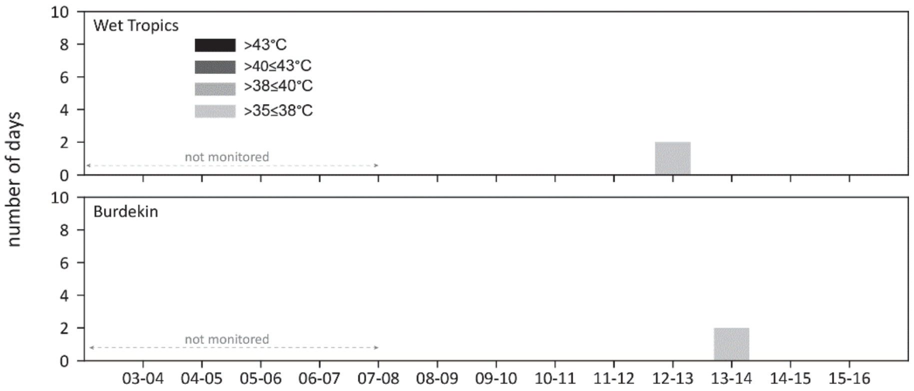

Figure 13. *Number of days when inshore subtidal sea temperature exceeded 35°C, 38°C, 40°C and 43°C in each monitoring period in each NRM region. Thresholds adapted from Campbell, et al. 2006a; Collier, et al. 2012b.*

4.1.2 Indicators of seagrass condition

In the 2015-16 monitoring period, although the overall seagrass abundance score improved (Figure 6), 50 per cent of the MMP sites examined remained classified as poor or very poor in abundance (below the guidelines see Appendix Table 45) in 2015-16, with an annual average abundance (per cent cover, all sites and sampling events) of 16.1 ±2.1 per cent for estuarine, 16.2 ±1.4 per cent for coastal, 15.3 ±1.3 per cent for subtidal coast, 14.6 ±1.3 per cent for reef and 16.2 ±1.6 per cent for subtidal reef.

Seagrass abundance (per cent cover) at meadows monitored in the MMP declined from 2005-06 until 2012-13, after which abundances increased. Based on the average score against the seagrass guidelines (determined at the site level), the abundance of inshore seagrass in the GBR over the 2015-16 period increased but remained in a **moderate** state (all sites and seasons pooled, unweighted).

Increases in the abundance score in 2015-16 compared to the previous monitoring period were found in the Cape York, Wet Tropics, Mackay Whitsunday and Burnett Mary NRMs, with the latter two improving from poor to moderate, while in the Wet Tropics, the score increased from very poor to poor (Figure 14). There were small declines in the Burdekin and Fitzroy NRMs, but the score classifications remained unchanged in moderate and poor condition, respectively (Figure 14).

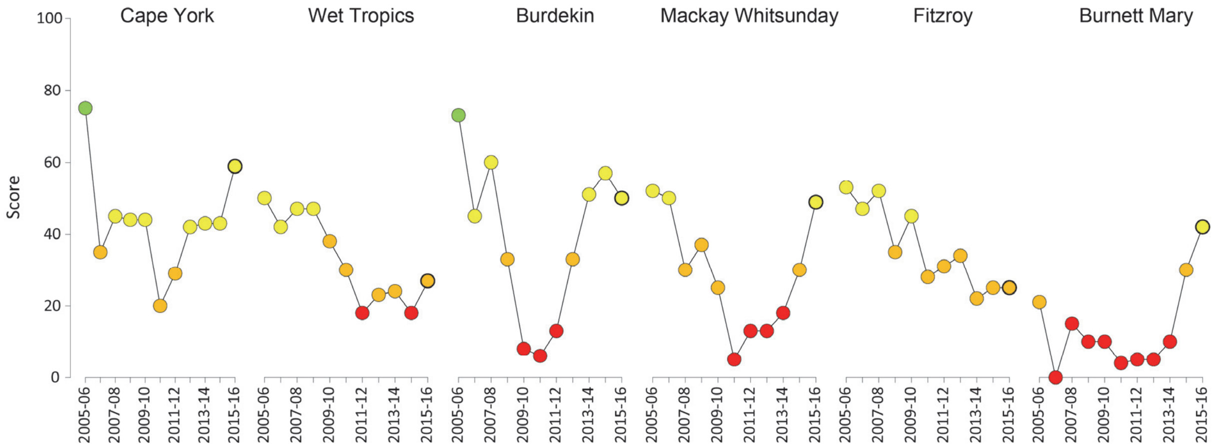

Figure 14. *Regional report card scores for seagrass abundance over the life of the MMP. For Paddock to Reef reporting scores are categorised in to a five point scale;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

Seagrass abundance scores have fluctuated within regions at habitats since monitoring was established. The most variable GBR seagrass habitat in abundance score (since 2005) was subtidal reef (CV=87 per cent), followed closely by intertidal reef (CV=73.6 per cent), estuary (CV=66.5 per cent) and lastly intertidal coast (CV=57.9 per cent).

The average seagrass per cent cover for the 2015-16 monitoring period was 15.7 ±1.5 per cent (all meadows and sampling events). Although slightly higher than the previous period (14.7 ±1.7 per cent in 2014-15), it remains below the GBR long-term average (19.2 ±2.1 per cent, Jun00-May10) and the GBR historical baseline (22.6 ±1.2 per cent Nov84-Nov88) (McKenzie*, et al.* 2015). Since 1999, the median percentage cover values for the GBR were mostly below 25 per cent cover, and depending on habitat, the 75th percentile occasionally extended beyond 50 per cent cover (Figure 15). These long-term percentage cover values were similar to the GBR historical baselines, where surveys from Cape York to Hervey Bay (between November 1984 and November 1988) reported most (three-quarters) of the percent cover values fell below 50 per cent cover (Lee Long*, et al.* 1993). The findings negate the assumption that seagrass meadows of the GBR should have abundances closer to 100 per cent before they are categorised as good.

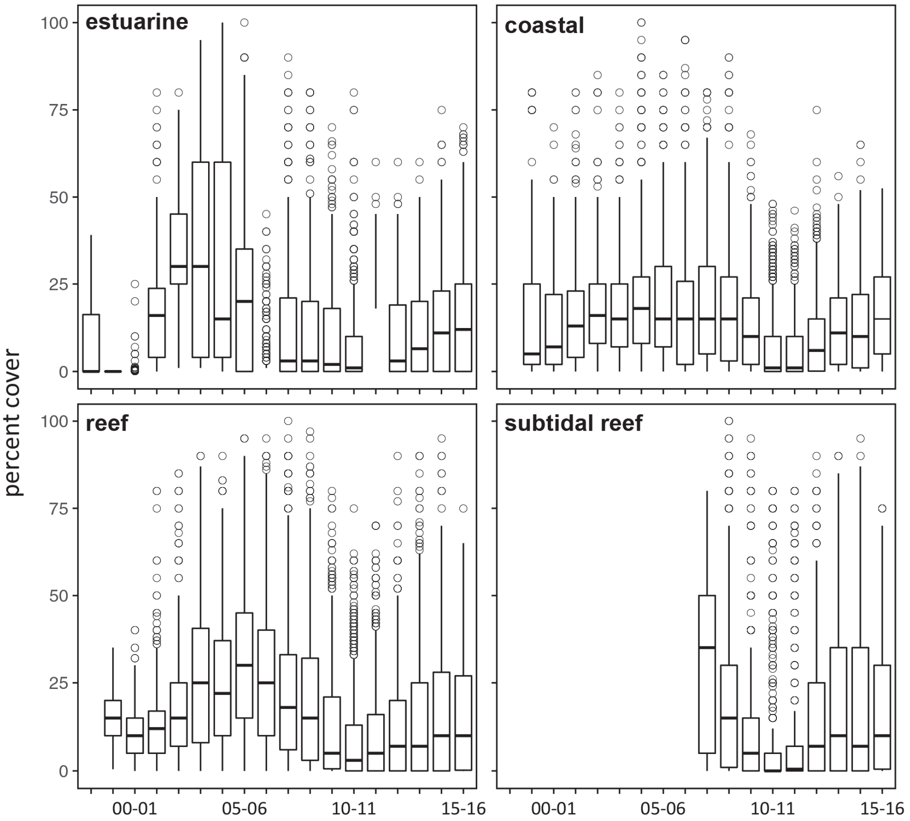

Figure 15. Seagrass percent cover measures per quadrat from meadows monitored from June 1999 to May 2016 (sites and habitats pooled). *The box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the dots represent outlying points.*

Long-term total seagrass abundance (percent cover) across the inshore GBR was generally higher in reef than coastal and estuarine habitats over the past decade, but in 2015-16 coastal sites had the highest average abundance (Figure 15). Over the past decade, the patterns of seagrass abundance in each GBR habitat have differed (Figure 16, Figure 17), however both reef (including intertidal and subtidal) and coastal habitats show declining trajectories from 2009 to 2011. Note that Figure 16 illustrates seagrass abundance scored relative to the 95th percentile for each site, to enable a focus on GBR-wide trends. Since 2011, meadow abundance has been increasing in most habitats. However, seagrass trends have fluctuated in estuary habitats, most often at smaller localised scales where there have been some acute event related changes (McKenzie *et al.* 2012b).

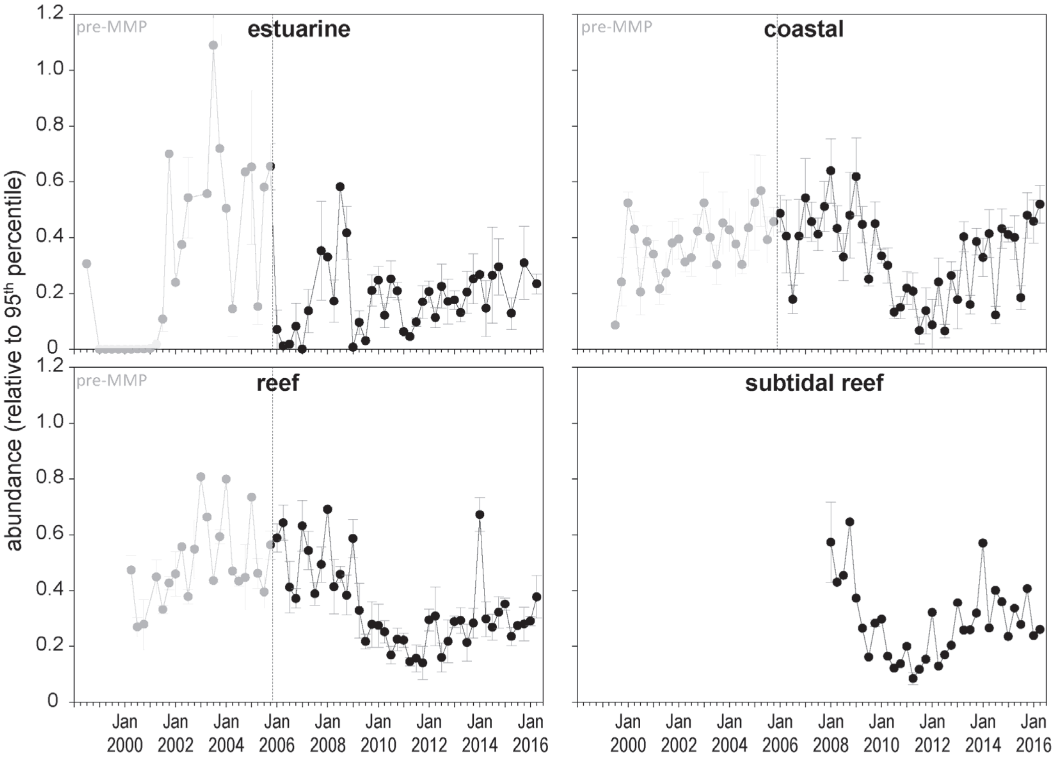

Figure 16. *Generalised trends in seagrass abundance for each habitat type (sites pooled) relative to the 95th percentile (equally scaled). The 95th percentile is calculated for each site across all data. Data prior and post implementation of the MMP displayed.*

An examination of the long term trends in seagrass abundance (per cent cover) across the Great Barrier Reef (habitats pooled) shows seagrass abundance gradually increased from 2001 to 2008 (with a mild depression in 2006-07 as a consequence of TC Larry)(Figure 17). From 2009, GBR seagrasses were in a declining trajectory as a result of multiple years of above average rainfall and climate-related impacts, rendering them in a vulnerable condition. The extreme weather events of early 2011 resulted in further substantial decline in inshore seagrass meadows throughout much of the GBR. Post 2011, seagrasses have progressively recovered, although by 2015-16 still remained below the 2008 levels (Figure 17).

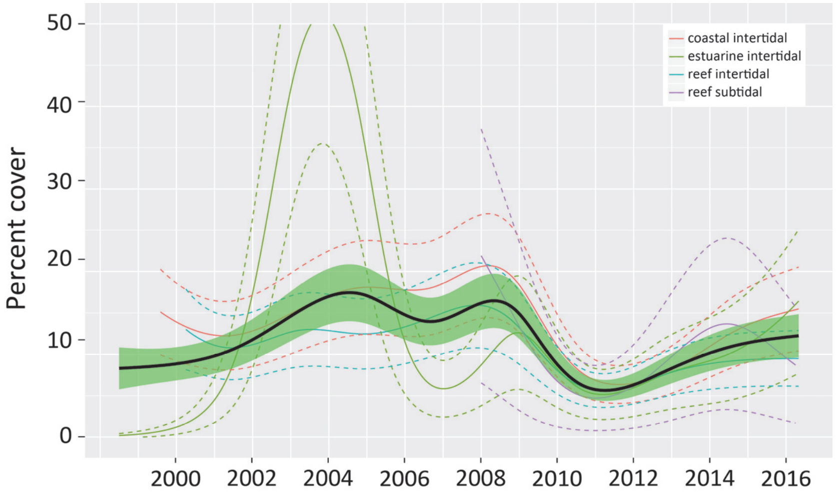

Figure 17. *Trends in seagrass abundance (per cent cover) for each habitat type across the GBR represented by a GAM plot. Trends are dark lines with shaded areas defining 95 per cent confidence intervals of those trends.*

After the extreme weather events in 2009 to 2011 that caused widespread declines in seagrass area and abundance, there was increasing proliferation of species displaying colonising traits such as *Halophila ovalis* at coast and reef sites (Figure 18, Appendix 4). However, over the 2015-16 monitoring period, the proportion of species displaying colonising traits remained low in coastal and estuarine habitats in favour of species displaying opportunistic or persistent traits (sensu Kilminster, *et al.* 2015). The displacement of colonising species is a natural part of the meadow progression expected during the recovery of seagrass meadows. This pattern has been observed during past disturbance events (Birch and Birch 1984), and in locally-intensive studies (Rasheed et al 2014) but these results (together with the succession of seagrasses at Magnetic Island presented in detail in the 2014-2015 report discussion) provide the most comprehensive evidence for meadow succession following substantial widespread disturbance events in tropical seagrass meadows that is known to the authors. Furthermore, this demonstrates the importance of species diversity, in particular diversity of species types, to overall resilience (Unsworth*, et al.* 2015). As such, species diversity is being considered for inclusion in the report card metric. In reef intertidal and reef subtidal habitats, there were small increases and the proportion of colonising species slightly exceeded the GBR long-term average (Figure 18).

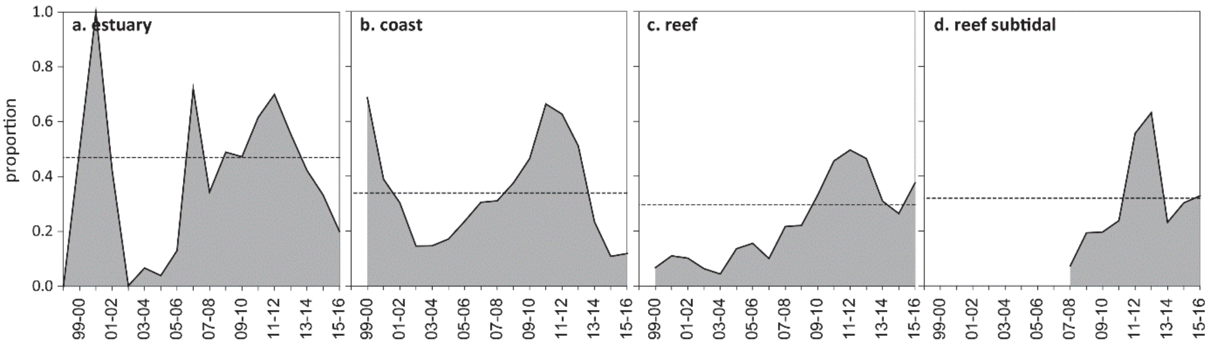

Figure 18. *Proportion of total seagrass abundance composed of species displaying colonising traits (e.g.* Halophila ovalis*) in a) estuary intertidal, b) coastal intertidal, c) reef intertidal and d) reef subtidal habitats (sites pooled) for the GBR (regions pooled) each monitoring period. Dashed line illustrates GBR average proportion of colonising species in each habitat type (*Table 44*).*

Reproductive effort across the GBR, are measured as per area estimates of the number of reproductive structures (spathes, fruits, female and male flowers) produced by any seagrass species during the sampling period, was higher in the late dry than in the late wet season in historical records (pre-2011), but during recovery the time for highest effort has become more variable. Reproductive effort was higher in estuary and coastal habitats over the long-term, with the highest historically recorded reproductive effort occurring in estuary habitats in 2006 (Figure 19). Reef habitats, both intertidal and subtidal reef sites, have the lowest reproductive effort. Reproductive effort has generally increased in coastal and estuary habitats since 2011: there was large increases in reproductive effort at coastal sites in the Burdekin, and at estuary sites in the Burnett-Mary. In particular, there was a decline in effort in reef habitats in the Wet Tropics, Burdekin, Mackay-Whitsundays, and there was no reproduction at the Fitzroy reef sites. This signals the risk of seed bank density declining which increases vulnerability to future disturbances (Figure 19).

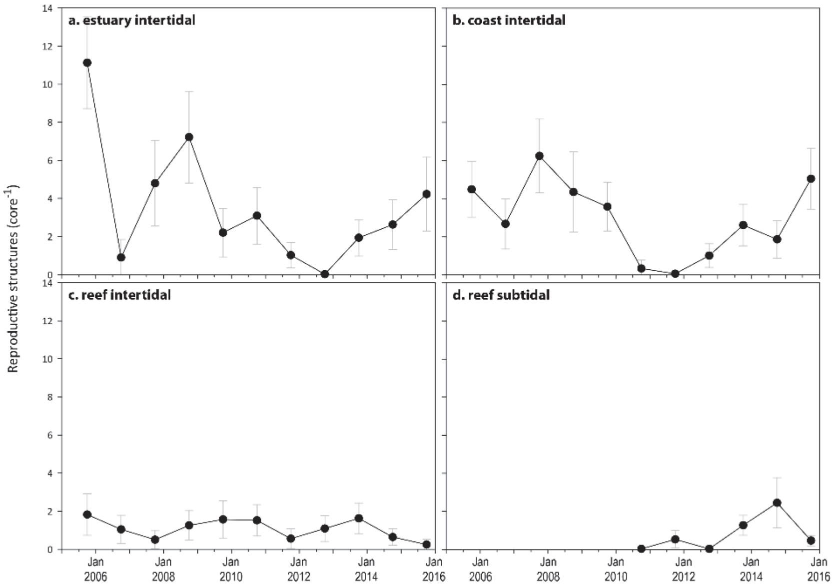

Figure 19. *Seagrass reproductive effort (number of reproductive structures produced by all seagrass species) during the late dry of each monitoring period, for a) estuary intertidal; b) coast intertidal; c) reef intertidal; d) reef subtidal.*

Reproductive effort across the GBR NRM regions during 2015-16 improved in the Burdekin, Fitzroy and Burnett Mary NRMs (Figure 20), but declined in Cape York, Wet Tropics, and Mackay Whitsunday NRMs. Reproductive effort in 2015-16 remained very low in the Cape York, Wet Tropics, and Fitzroy NRMs, low in Mackay Whitsunday and Burnett Mary and moderate in the Burdekin NRMs (Figure 20).

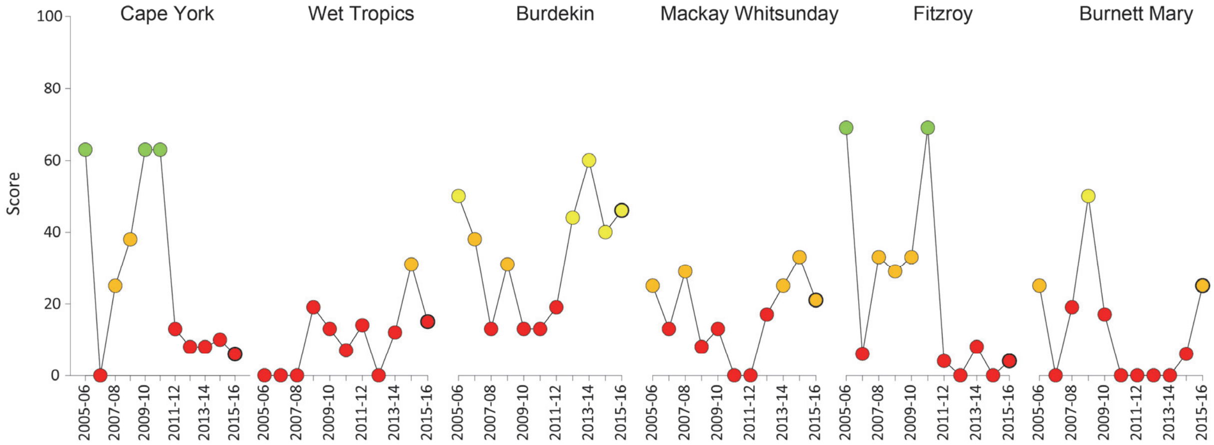

Figure 20. *Regional report card scores for seagrass reproductive effort over the life of the MMP. For Paddock to Reef reporting scores are categorised in to a five point scale; 🟩 = very good (81-100), 🟩 = good (61 - 80), 🟨 = moderate (41 - 60), 🟧 = poor (21 - 40), 🟥 = very poor (0 - 20). NB: Scores are unitless.*

Seagrass reproductive effort scores have fluctuated across regions and habitats over the greater monitoring period. The most variable GBR seagrass habitat in reproductive effort score since monitoring was established was intertidal coast (CV=133.2 per cent) and the least variable was subtidal (86.8 per cent).

Seed banks across the inshore GBR meadows were higher in late dry and greater in coastal than reef or estuarine habitats over the long-term (>10 years) (Figure 21). Coastal seed banks declined between 2008 and 2011, and have subsequently increased, but remain below the 2007-2008 levels (Figure 21b). However, in 2015-16 seed banks in other habitats have been highly variable (Figure 21a), which could have been caused by poor reproductive success (failure to form seeds) or loss of seed bank (germination or grazing). Seed bank density remains very low at estuary and reef intertidal habitats suggesting a reduced capacity to recover from disturbances. Seed banks are not currently included as a metric in the report card; however, given their importance as a feature of resilience in seagrasses of the GBR, they are being considered for future inclusion as an indicator in the reproduction metric.

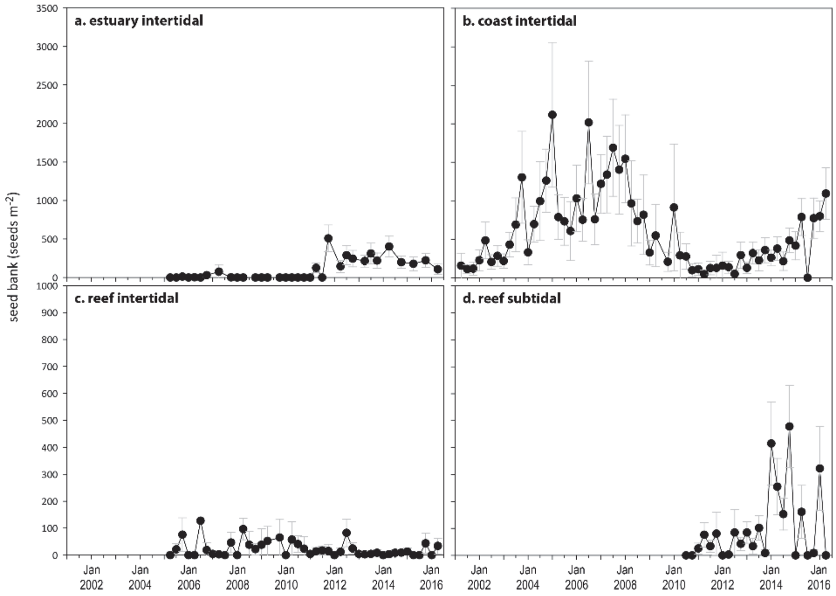

Figure 21. *Average seeds banks (seeds per square metre of sediment surface, all sites and species pooled) in GBR seagrass habitats: a) estuary intertidal; b) coast intertidal; c) reef intertidal; d) reef subtidal.*

4.1.3 Indicators of environmental condition

Seagrass tissue nutrients

Tissue nutrient concentrations are measured in the late dry (usually October) of the reporting period and differed both across and within habitats between years. It was necessary at some sites (see Table 3) to pool across foundation species as the presence of individual species has not remained constant over time at all locations since monitoring was established. As tissue nutrient ratios between co-occurring foundation species are not significantly different in this region (McKenzie*, et al.* 2012b), by pooling across species and habitat types, some trends are apparent.

Since 2005, median tissue nitrogen concentrations (per cent N) for all habitats have exceeded the global value of 1.8 per cent (Duarte 1990; Schaffelke *et al.* 2005) (Figure 22). During 2015-16, seagrass leaf per cent N, increased relative to the previous monitoring period at reef intertidal and reef subtidal habitats (Figure 22). Increasing per cent N may have resulted from slightly higher N availability; however, as annual discharge and plume exposure were generally low in 2015-16, this was unlikely to be a source of increased N. Percent N can also be affected by growth rates, and if the seagrasses were growing more slowly, then the tissue nitrogen content can be increased (discussed further below in relation to C:N). Per cent N remained stable or declined slightly at estuarine and coastal sites (Figure 22). Similarly, median leaf tissue phosphorus concentrations (per cent P) increased in estuarine and reef intertidal habitat but decreased at coastal and reef subtidal sites. All habitats had per cent P values that were very close to the global value of 0.2 per cent (Duarte 1990; Schaffelke*, et al.* 2005) in 2015 (Figure 22). In 2014, leaf tissue per cent P fell below the global median at estuarine habitats for the first time since 2009 (Figure 22).These findings and the low values in 2015 indicate that nutrients were unlikely to be limiting seagrass growth, however, some concerns have been raised as to accuracy of the global tissue nutrient values (Schaffelke*, et al.* 2005).

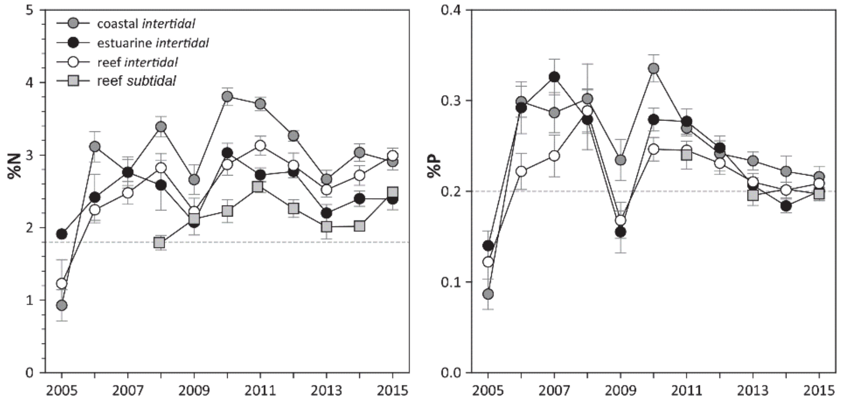

Figure 22. *Median tissue nutrient concentrations (±Standard Error) in seagrass leaves for each habitat type (species pooled) over the entire monitoring program. Dashed lines indicate global median values of 1.8 per cent and 0.2 per cent for tissue nitrogen and phosphorus, respectively (Duarte 1990).*

Since 2007, all three intertidal habitat types (coast, reef and estuary) had C:N ratios less than the global mean of 20 (16.4 – 19.7) (Figure 23). The low C:N values were associated with a tissue N content (per cent N, see Appendix 4, Table 61) that is also above the global mean. The largest change in 2015-16, compared to 2014-15, was at reef subtidal sites, where there was a large decrease in the C:N values (from 23.2 to 19.7), and a large increase in per cent N (2.0 to 2.5), indicating a large change in the demand for N relative to photosynthetic carbon uptake in 2015-16. The lowest C:N values were at Yule Point (11.8), and Hamilton Island (11.7), while the only sites with a C:N>20 in 2015 were at Green Island and Magnetic Island subtidal sites. Average daily light, which was slightly below average in subtidal meadows and is the lowest among habitat types (Figure 9), may also have contributed to lower C incorporation relative to N uptake.

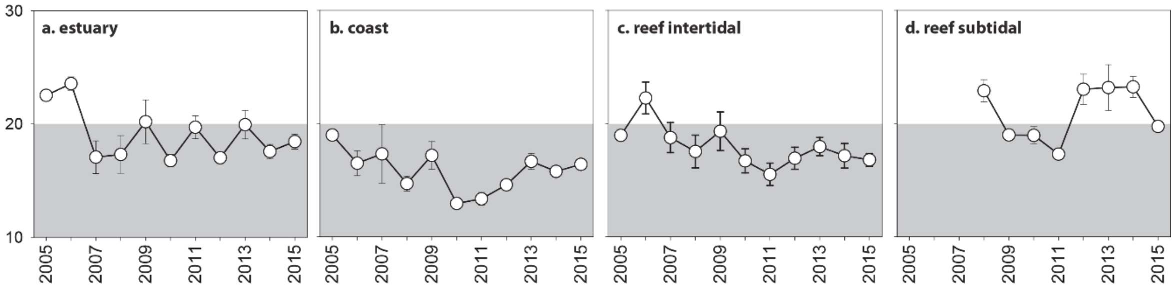

Figure 23. *Elemental ratios (atomic) of seagrass leaf tissue C:N for each habitat each year (foundation species pooled). Horizontal dashed line on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

Average leaf tissue δ^{15}N values decreased in all habitat types in 2015-16, except at reef intertidal sites in which *H. uninervis* and *C. rotundata* increased their δ^{15}N. Negative δ^{15}N values were found in some species at the Cape York reef (*T. hemprichii*) and coastal sites (*T. hemprichii* and *Z. muelleri*), Wet Tropics reef subtidal sites (*C. serrulata*) and the Fitzroy reef site (*H. uninervis* and *Z. muelleri*). Very low or negative values of δ^{15}N can indicate nitrogen sourced from nitrogen fixation (Peterson and Fry 1987; Owens 1988), which can supply one third to one half of seagrass demand (O'Donohue *et al.* 1991) or from fertiliser (Udy*, et al.* 1999). Moderate values indicate internal sources from remineralisation (Peterson and Fry 1987; Owens 1988) and higher values (>3‰) can indicate anthropogenic sources (e.g. sewage (Costanzo *et al.* 2001). Most seagrasses of the GBR are at the lower to middle range of the global δ^{15}N for seagrasses (-2 – 11‰) (Fourqurean *et al.* 1997a; Schubert *et al.* 2013) between 0.6‰ and 3‰ (Figure 24), suggesting the primary source of N was influence by fertiliser, N fixation and/or sewage (Udy and Dennison 1997b, see also Appendix A2.3). The less negative leaf tissue δ^{13}C values at coastal sites suggest lower C uptake (and therefore greater fractionation) (Grice*, et al.* 1996, see also Appendix A2.3), while at reef sites the more negative values suggest increased C uptake in 2015-16 (Figure 24). The degree of fractionation can be used as an estimate of photosynthetic rate (Grice et al 1996), hence this data suggests the seagrass on the coast and reef intertidal habitats are receiving more light and photosynthesising at a faster rate.

Intertidal seagrass habitats across the GBR were consistently improved in phosphorus (P) relative to carbon (C:P) i.e. C:P is increasing, a trend that has been consistent since 2010 (Figure 25). The increasing C:P indicates a reduction in supply of P, relative to demand and is consistent with reducing per cent P in seagrass tissue and also increased per cent C in some sites and species (Figure 22)(See also Appendix 4 for greater detail). At a GBR-wide scale, the ratio of N relative to P (N:P) was highly variable within habitat, owing to large variability in trends among regions. There were large increases in 2015-16 in N:P at reef sites in the Wet Tropics (increasing at Green Island), Burdekin (increasing at Magnetic Island) and Mackay-Whitsundays (Hamilton Island), but not in other regions. In coastal habitat, N:P increased in the Wet Tropics (at Yule Point), but decreased in Mackay Whitsundays and remained relatively stable in other regions. N:P declined in estuarine habitat in Mackay Whitsundays, and was relatively stable in the Fitzroy and Burnett-Mary regions. Leaf tissue N:P ratios were around 30 at coast and reef intertidal sites, which provides additional evidence of elevated N in the environment, the source of which is not apparent. Locations with the highest N:P were at Shelburne Bay (33.4), Archer Point (36.5), Yule Point (39.0), Dunk Island (33), Low Isles (32.7) and Hamilton Island (34.9). The C:P and N:P ratios are important for describing changes in nutrient availability relative to growth requirements. Therefore, these ratios will be considered for future inclusion as part of the tissue nutrients metrics in the GBR report card.

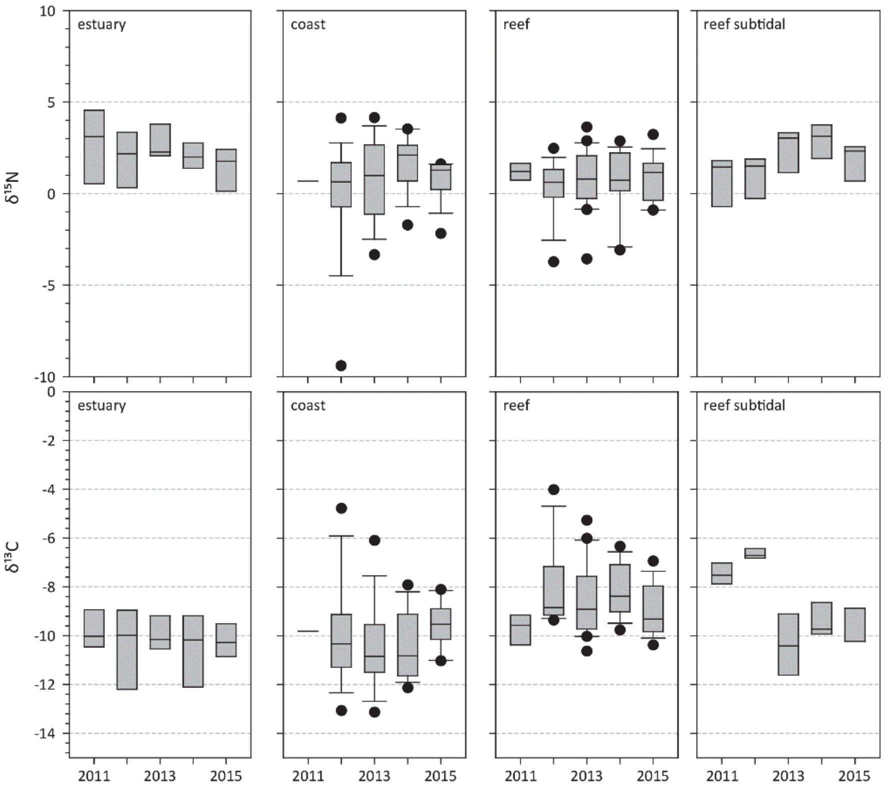

Figure 24. *Seagrass leaf tissue* $\delta^{13}C$ *and* $\delta^{15}N$ *concentrations from each GBR seagrass habitat (locations pooled) in the late dry from 2011 to 2015. The box represents the interquartile range of values, where the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and the black dots represent outlying points.*

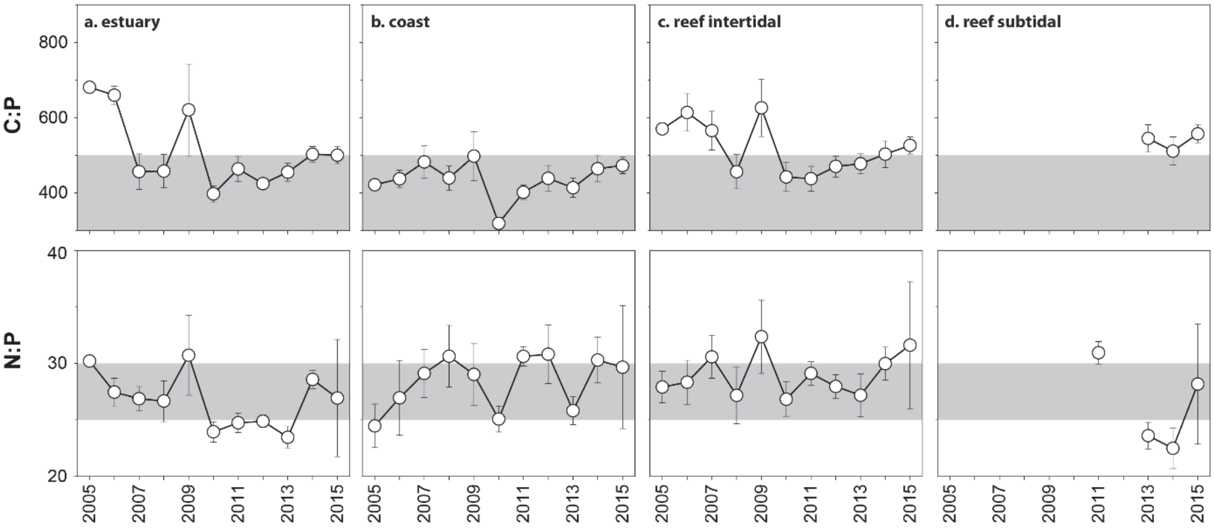

Figure 25. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for each habitat each year (foundation species pooled) (± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Horizontal dashed line on the C:P panel at 500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Seagrass nutrient status scores (using only C:N) were reduced in the Burdekin (from good to moderate), increased in the Burnett-Mary (from poor to moderate), and remained relatively stable and poor in all other regions in 2015-16 (Figure 26).

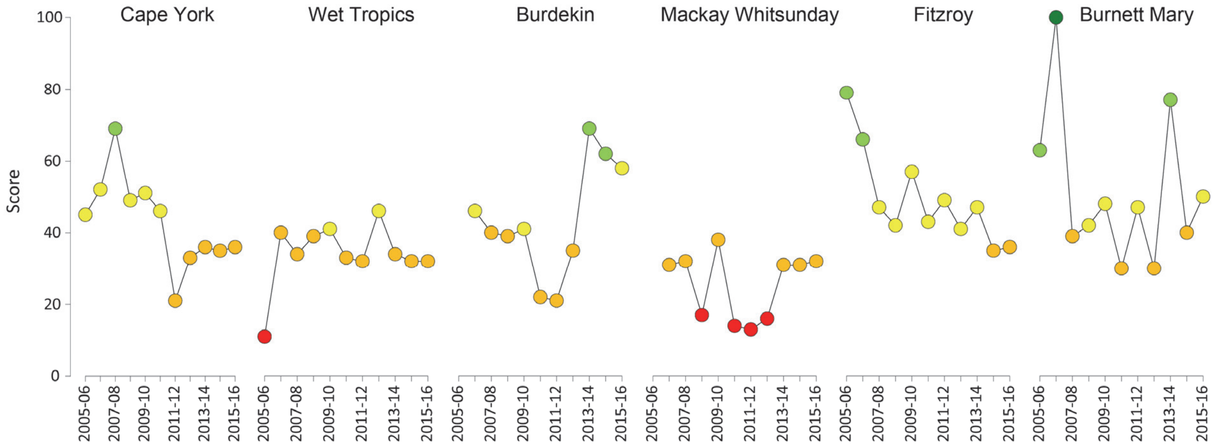

Figure 26. *Regional report card scores for seagrass leaf tissue nutrient status (C:N) over the life of the MMP. For Paddock to Reef reporting scores are categorised in to a five point scale;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20).*

Seagrass meadow sediments

Estuarine seagrass habitats across the GBR had a greater proportion of fine sediments (i.e. mud) than other habitats (Table 11). Sediments as coastal habitats were predominately medium and fine sands, while reef habitats (intertidal and subtidal) were dominated by medium sands (Table 11).

Table 11. *Long-term average (±SE) sediment composition for each seagrass habitat (pooled across regions and time) monitoring within the GBR (1999-2016)*

Habitat	Mud	Fine sand	Sand	Coarse sand	Gravel
estuarine intertidal	50.3 ±2.9	20.6 ±4.2	25.8 ±4.1	0.2 ±0.3	3.2 ±0.9
coastal intertidal	28.6 ±4.2	29.9 ±3.2	37.2 ±4.6	0.2 ±0.3	4.1 ±1.8
reef intertidal	5.7 ±2.0	10.5 ±1.3	50.7 ±4.2	16.5 ±3.0	16.7 ±2.8
reef subtidal	2.7 ±2.0	16.8 ±6.4	68.6 ±7.2	3.5 ±2.4	8.3 ±2.7

Since monitoring was established, the composition of sediments has fluctuated at all habitats, with the proportion of mud declining below the long-term average at estuary and coastal habitats immediately following periods of physical disturbance from storms (e.g. tropical cyclones) in 2006 and/or 2011. Conversely, the proportion of mud increased above the long-term average at reef (intertidal and subtidal) habitats during periods of extreme climatic events (e.g. tropical cyclones and/or flood events). During the 2015-16 monitoring period, the proportion mud decreased at estuarine habitats, but increased across all other habitats relative to the previous year (Figure 27).

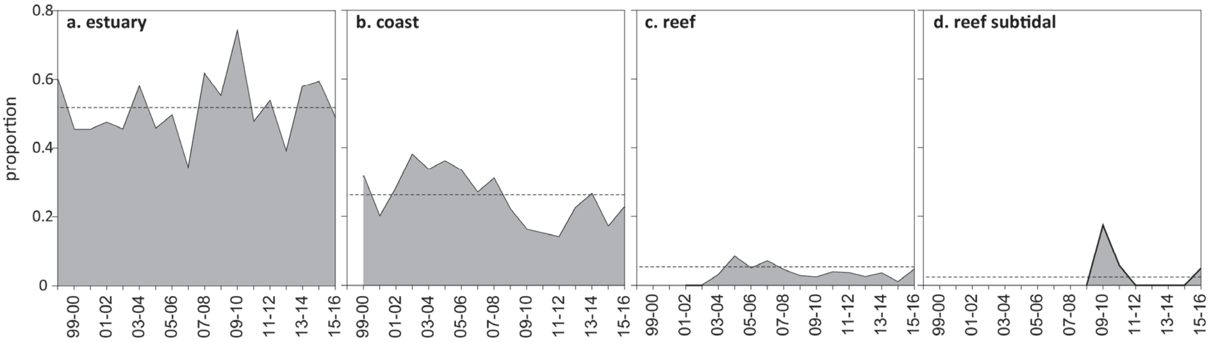

Figure 27. *Proportion of sediment composed of mud (grain size <63µm) at GBR seagrass monitoring habitats from 1999-2016.*

Epiphytes and macroalgae

Epiphyte cover on seagrass leaves across the GBR was higher in the wet than the dry season across all seagrass habitats in 2015-16, except at reef subtidal sites. Epiphyte cover was above the GBR long-term mean at estuary and subtidal reef sites, and similar to the long-term mean at coastal and reef intertidal sites (Figure 28). Epiphyte cover increased in 2015-16 in estuary habitat in the wet season, and reef subtidal habitat in the dry season, compared to 2014-15 (Figure 28).

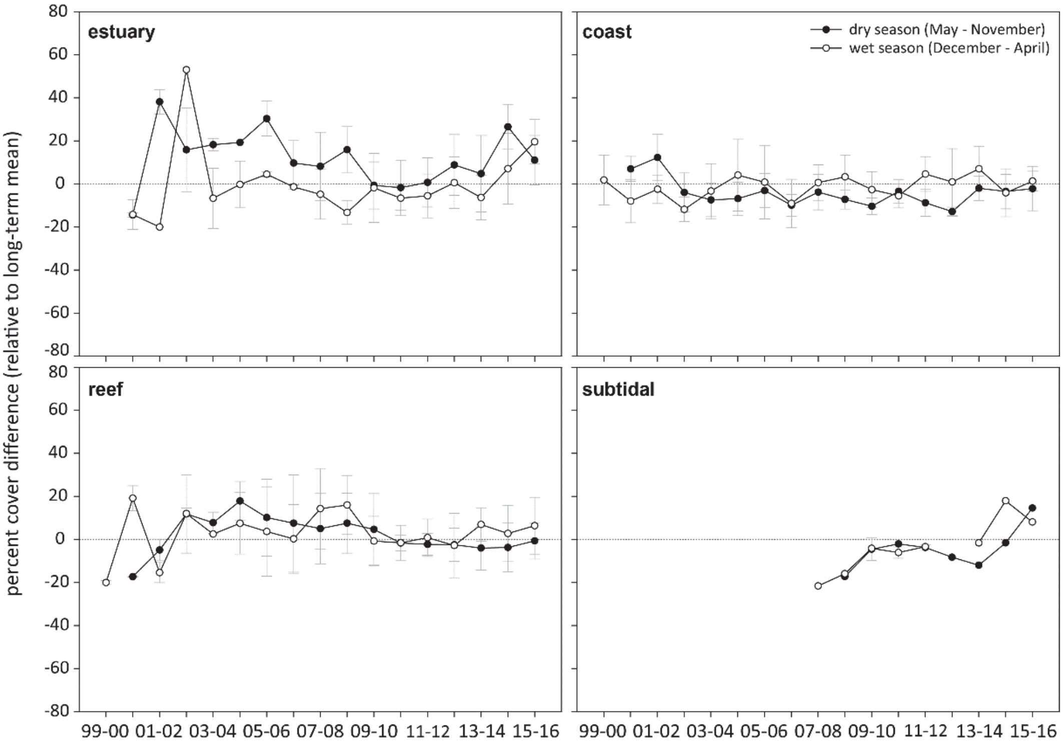

Figure 28. *Epiphyte abundance (per cent cover) relative to the long-term average for each GBR seagrass habitat (sites pooled, ±SE). GBR long-term average; estuarine = 16.2 ±8.4 per cent coastal=15.1 ±3.1 per cent, reef = 20.2 ±3.3 per cent, subtidal= 7.7 ±1.6 per cent.*

Macroalgae abundance is generally low and stable in the GBR seagrass habitats and there was again little change in 2015-16 (Figure 29). A gradual increase at reef habitats (subtidal and intertidal) during the late dry season over the last 3 years may suggest elevated nutrients at most sites.

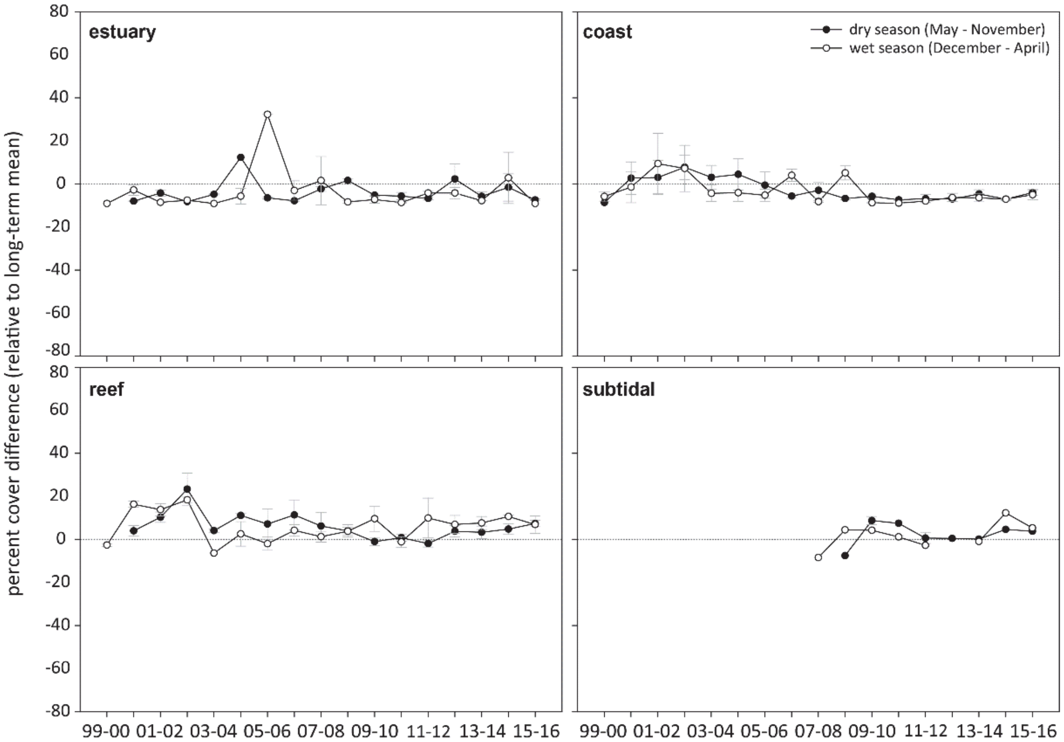

Figure 29. *Macroalgae abundance (per cent cover) relative to the long-term average for each inshore GBR seagrass habitat (sites pooled, ±SE). GBR long-term average; estuarine = 2.5 ±1.0 per cent, coastal=3.2 ±1.4 per cent, reef = 6.2 ±1.8 per cent, subtidal = 4.7 ±2.0 per cent.*

4.2 Cape York

4.2.1 2015-16 Summary

Waters entering the GBR lagoon from Cape York catchments are perceived to be of a high quality, with low levels of suspended sediments, nutrients and pesticides. Seagrass growth on reef and coastal habitats in the region appears primarily controlled by physical disturbance from waves/swell and associated sediment movement, with pulsed terrigenous runoff from seasonal rains affecting some coastal regions. Rainfall and river discharge in 2015-16 were below the long-term average. There was a high frequency of exposure to 'green' secondary water at seagrass sites in 2015-16, which indicates the possibility of some nutrient enrichment and light limitation. Within-canopy daily light was slightly below the long-term average but was the highest in the GBR; however light data was only recorded from October – March, as monitoring has been reduced to once per year. A heat wave swept through Cape York causing widespread coral bleaching and coral mortality. This occurred in a year when annual daytime tidal exposure was also above-average. Within canopy water temperature exceeded 35°C for a record total of 18 days in February 2016, and the highest recorded temperature (41.6°C in March 2016) is above the threshold known to cause photoinhibition.

One location in Cape York (Archer Point) has been monitored since 2005, while locations further north have only been monitored from 2011. This makes it difficult to assess long-term trends across Cape York. Seagrass abundance, as well as changes in abundance, varied among habitats within the region in 2015-16. On average, seagrass abundance increased relative to the previous period at reef sites; however, reef sites have low reproductive output and seed banks were depauperate. In contrast at coastal sites, abundance remained unchanged, but they maintain higher seed banks and reproductive effort compared to reef sites and may therefore have greater resilience on account of their good abundance and dense seed banks. Seagrass leaf tissue nutrients (C:N and N:P) indicate moderate nitrogen enrichment. On account of their moderate abundance, it appears seagrass across the Cape York NRM region were able to resist the less than favourable environmental conditions of 2015-16, in particular thermal stress, and the regional seagrass index improved slightly over the last 12 months, but remains **poor** (Figure 30).

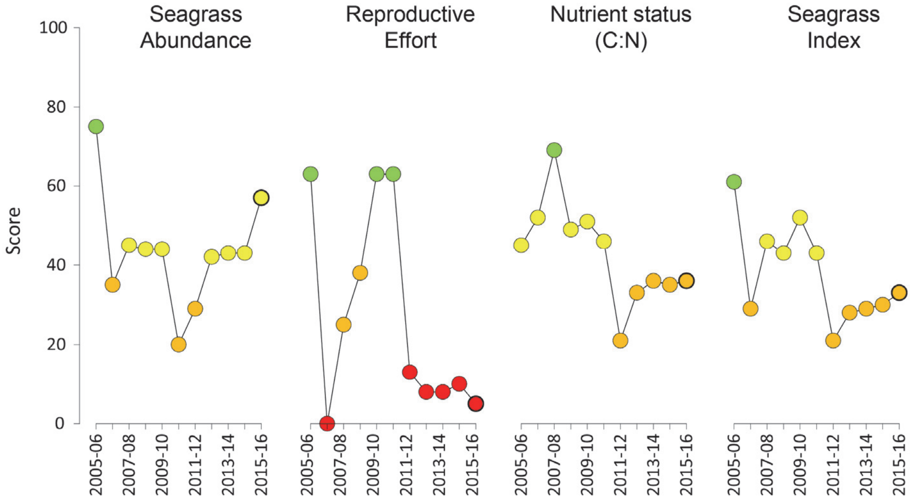

Figure 30. *Report card of seagrass condition (indicators and index) for the Cape York NRM region (averaged across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

4.2.2 Climate and environmental pressures

Rainfall and river discharge in 2015-16 were below the long-term average (Table 12). However, wind was above the long-term average for the second year in a row and may have continued to resuspend fine sediments with nutrients absorbed to their surface. The inshore waters of Cape York had predominantly secondary water type (green, phytoplankton rich water), and some primary type (turbid) exposure through the wet season (November-April, Figure 31). Bathurst Bay had the highest exposure to turbid primary water (43 per cent weeks). The frequency of exposure to both ($f_{(P+S)}$) ranged from 23 per cent to 100 per cent of weeks (excluding Bathurst Bay which had only 2 weeks of data) at seagrass monitoring sites (Table 13).

Table 12. *Summary of environmental conditions at monitoring sites in Cape York region in 2015-16 compared to the long-term average (long-term range indicated for each data set).*

	Long-term average	2015-16
Rainfall (1965-2016)	1568 mm	1365mm
River discharge (1970-2016)	13,066,864 L yr^{-1}	8,246,579 L yr^{-1}
Turbid water exposure (2006-2016)	*unavailable*	82 per cent
Daytime tidal exposure (2011-2016)	69.33 hrs yr^{-1}	85.83 hrs yr^{-1}
Wind (2002-2016)	98.3 days yr^{-1}	128 days yr^{-1}
Within canopy temperature (2011-2016)	26.6°C *(41.6°C)*	27.3°C *(41.6°C)*
Within canopy light (2012-2016)	18.4 mol m^{-2} d^{-1}	17.5 mol m^{-2} d^{-1}

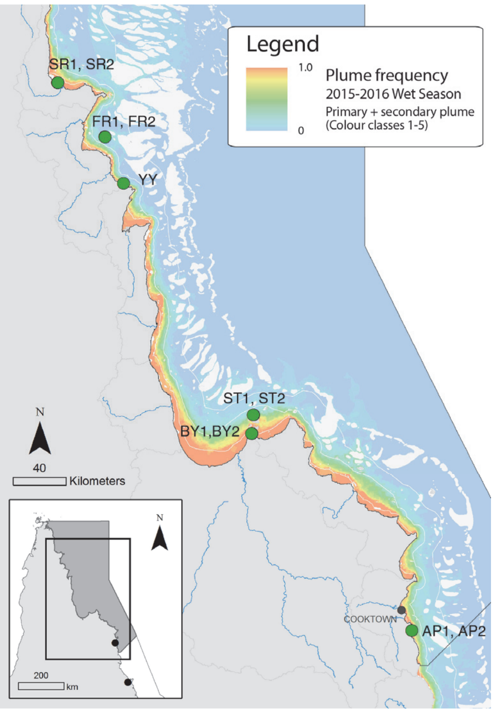

Figure 31. *Frequency of exposure to turbid water (colour classes 1-5) in the Cape York NRM, wet season (December 2015 – April 2016) composite. Frequency calculated as number of weeks in wet season exposed to primary or secondary water (colour classes 1 – 5). Each colour class category is described by mean water quality values for TSS, CDOM, chlorophyll a and K_d (PAR) (Devlin, et al. 2015;Waterhouse, et al. 2017). For site details, see Tables 3 & 4.*

Table 13. *Water type at each site derived from MODIS true colour images as colour classes of turbid primary water (class 1 – 4, red/brown), nutrient/chlorophyll-enriched secondary water (class 5, green), and tertiary (some freshwater/CDOM influence) or no plume influence (class 6 and 7 respectively, blue), for 22 weeks from December 2015 – April 2016. Also shown, median wet season colour class (Med), frequency of primary water as $f_{(P)}$, the frequency of secondary water as $f_{(S)}$, and the frequency of primary or secondary as $f_{(P+S)}$. *denotes data obtained from adjacent pixel.*

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	**Med**	$f_{(P)}$	$f_{(S)}$	$f_{(P+S)}$
AP1*	5	5	5		4	5	5	5	5	4	5	5	5	6	4	5	5	5	5	5	4	5	**5**	**0.19**	**0.76**	**0.95**
BY1*	5	4	5	5	4	4	5	5	4	4	5	4	5	5	5	5	4	4	4	5	5		**5**	**0.43**	**0.57**	**1.00**
FR1	6	6	6	7	7	6	6	6	7	6	6	6	6	6	5	5	5	6	5	5	6	6	**6**	**0.00**	**0.23**	**0.23**
SR1																2							**2**	**1.00**	**0.00**	**1.00**
ST1	6	5	5	5	2	5	5	5	6	5	5	5	5	5	5	6	5	5	5	5	5	5	**5**	**0.05**	**0.82**	**0.86**

Daily light at Cape York locations has been monitored since October 2012 when sites were established. However, in the 2014-15 reporting year, sampling was reduced to once per year, and loggers record for just 5 – 6 months after deployment, and after sampling (i.e. Oct-Mar/Apr). Furthermore, in these remote locations, missed sampling events caused by weather and logistics cause gaps in data (e.g. at SR in 2015-16). Daily light is generally very high at all Cape York sites (long-term average, 18.4 mol m^{-2} d^{-1}, GBR-wide , 13.4 mol m^{-2} d^{-1}); however, the trends are highly variable among sites with no distinct pattern that characterises benthic light over the past four years (Figure 32).

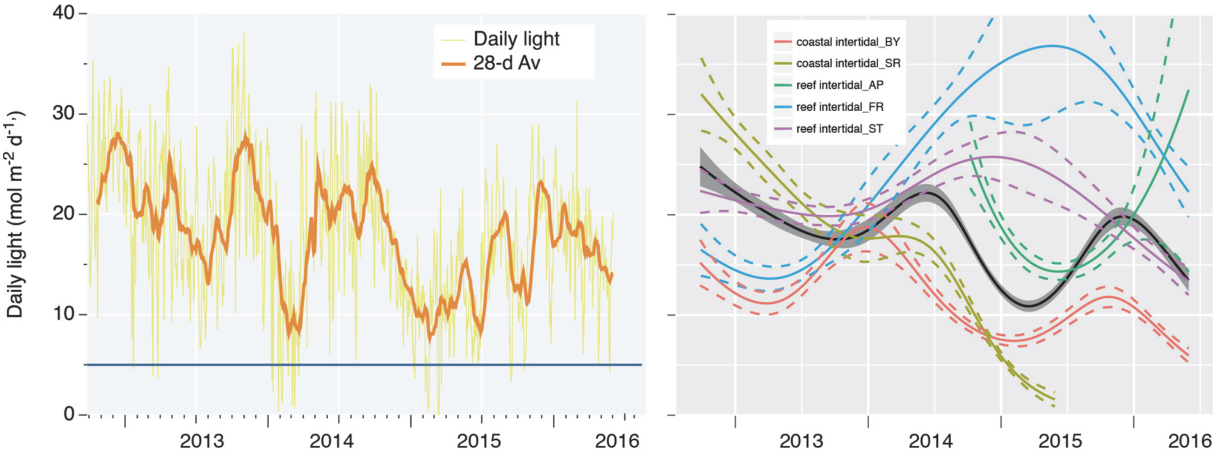

Figure 32. *Daily light (mean) at Cape York sites with 28-d rolling average from 2012 to 2016 (left) and GAM plots (right) with the black line showing mean trend for all sites (±95 per cent confidence interval in grey shade) and coloured lines (with CI's) for each location. Results of statistical analysis (GAM) and site-specific graphs (site-level daily light data plus 28-d rolling average) are shown in Appendix 5.*

Coastal and reef seagrass meadows of Cape York are frequently exposed to high temperatures; however, a heat wave swept across Cape York in the 2015-16 summer causing widespread coral bleaching and mortality (Reichelt 2016). In the summer of 2015-16 within-canopy temperature exceeded 35°C for 18 days in February (the largest monthly exceedance so far recorded), and 5 of these days were 38-40°C (Figure 33a). In March, 35°C was exceeded on 11 days, and on one of these days within-canopy temperature reached 41.6 °C at Bathurst Bay, which can cause photoinhibition (Figure 33). Temperature exceeded the median in every week in 2016 (January - June) (Figure 33b) and average annual within canopy temperatures in 2015-16 were slightly above the long-term average (Table 12). However, the total number of days >35°C (36 d, 9.8 per cent), was the lowest since monitoring at all Cape York sites was initiated (2012) and was the second lowest rate of exceedance among the regions in the GBR in 2015-16.

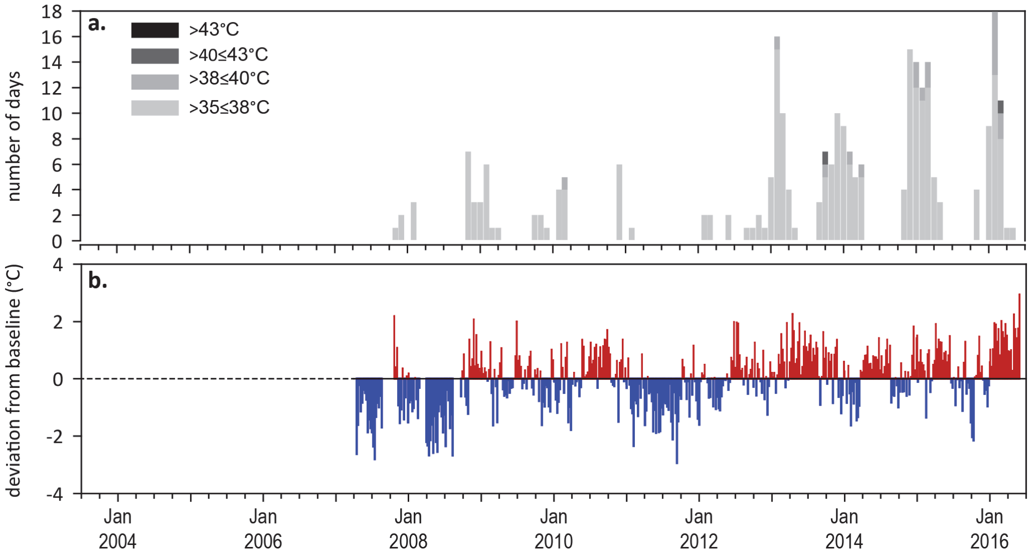

Figure 33. *Inshore within canopy sea temperature for intertidal seagrass habitats in the Cape York NRM region from April 2007 to June 2016: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006a); b) deviations at Archer Point from 7-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations). Dashed line represents period when monitoring not established.*

4.2.3 Indicators of seagrass condition

Three seagrass habitat types were assessed across the Cape York region in 2015-16, with data from 12 sites (Table 14).

Table 14. *List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Cape York NRM region. For site details see Table 3 and Table 4. Open square indicates not measured in 2015-16. † drop camera sampling (QPWS), *Seagrass-Watch.*

Habitat	Site		abundance	composition	distribution	Reproductive effort	seed banks	Leaf tissue nutrients	Meadow sediments	Epiphytes	Macroalgae
coastal intertidal	BY1	Bathurst Bay	■	■	■	■	■	■	■	■	■
	BY2	Bathurst Bay	■	■	■	■	■	■	■	■	■
	SR1	Shelburne Bay	■	■	■	■	■	■	■	■	■
	SR2	Shelburne Bay	■	■	■	■	■	■	■	■	■
coastal subtidal	LR1†	Lloyd Bay	■	■							■
	LR2†	Lloyd Bay	■	■							■
reef intertidal	AP1	Archer Point (Walsh Bay)	■	■	■	■	■	■	■	■	■
	AP2	Archer Point (Walsh Bay)	■	■	■	■	■	■	■	■	■
	FR1	Farmer Is. (Piper Reef)	■	■	■	■	■	■	■	■	■
	FR2	Farmer Is. (Piper Reef)	■	■	■	■	■	■	■	■	■
	ST1	Stanley Island	■	■	■	■	■	■	■	■	■
	ST2	Stanley Island	■	■	■	■	■	■	■	■	■
	YY1*	Yum Yum Beach (Weymouth Bay)	□	□			□		□	□	□

Seagrass abundance, composition and extent

The seagrass abundance score across the region increased, but remained moderate in 2015-16 (Figure 30). The increase in seagrass abundance in 2015-16 was attributed to increases at reef intertidal habitats, but these remained in a poor state. Coastal sites were in moderate condition, and the score did not change in 2015-16.

The most southern location (Archer Point reef habitat) has been monitored for the greatest period of time in the region, while the other four locations were established in 2012 (Figure 34d). Since monitoring was established at Archer Point (AP1) in 2003, seagrass cover has generally followed a seasonal trend with higher abundance in late dry period (McKenzie et al. 2012a). Previous analysis (reported in 2014-15) at all locations in Cape York has shown that variation in seagrass cover at reef habitats does not follow a seasonal pattern at most locations: 16.2 per cent in the late dry and 15.9 per cent in late wet season. Seasonality can no longer be interpreted as sites are visited just once per year in the late dry. Seagrass abundance in the late dry of 2015-16 increased compared to late dry 2014-15 at the majority of reef sites, but the increases at Piper Reef were marginal (1 per cent), as it recovers from disturbance from TC Lam in 2014 (Figure 34a).

In response to the heat wave in Cape York, the Stanley Island site was also additionally monitored in the late wet, and seagrass cover had increased from 9.6 per cent in the late dry 2015 to 13.7 per cent in the late wet (June 2016).

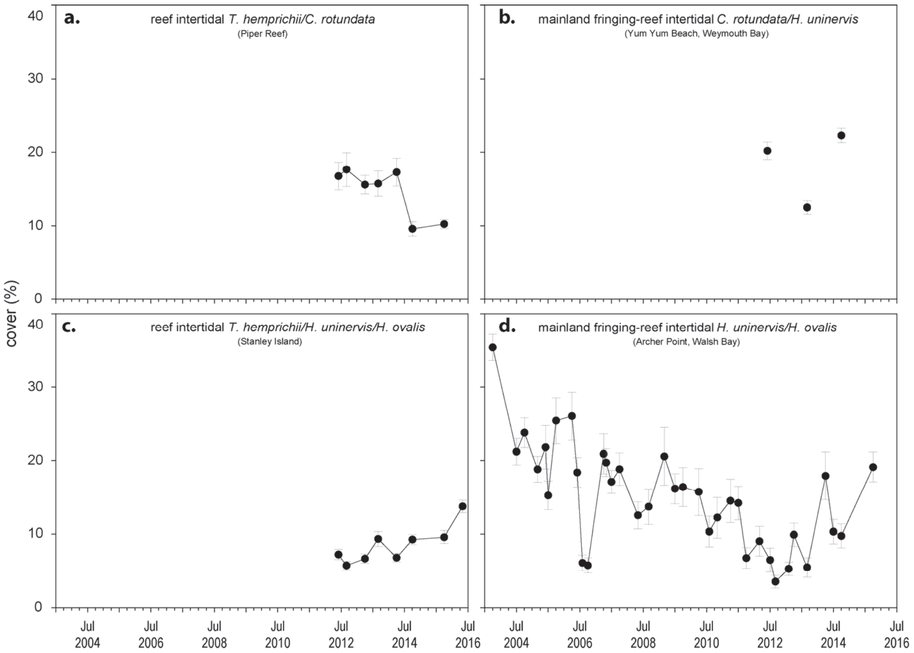

Figure 34. *Seagrass abundance (per cent cover ± Standard Error) at inshore intertidal reef habitats (replicate sites pooled) in the Cape York NRM.*

Seagrass abundance at coastal habitats in the northern Cape York NRM region decreased slightly in the late dry 2015-16, compared to the late dry 2014-15 (Figure 35). There was a slight increase in cover at Bathurst Bay when additional monitoring was undertaken in June 2016 following the heat wave and in central Cape York they increased considerably (Figure 35).

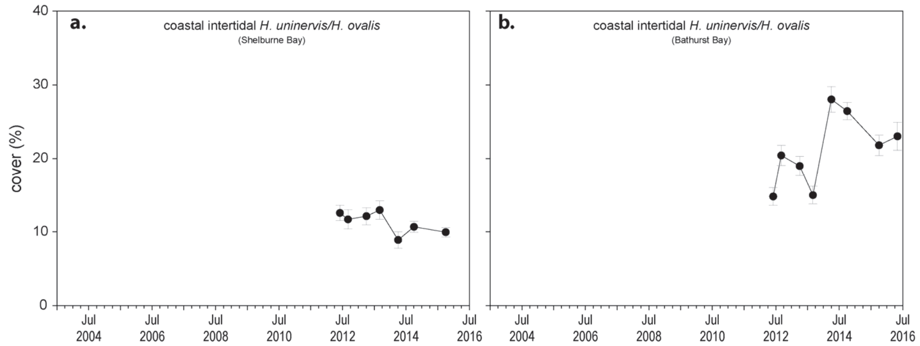

Figure 35. *Seagrass abundance (per cent cover ± Standard Error) at inshore intertidal coastal habitats (sites pooled) in the Cape York NRM region.*

An examination of the long term trend across the Cape York NRM region shows seagrass abundance (per cent cover) progressively decreased from 2003 to 2012, but has since slightly improved (Figure 36), primarily due to increases at the reef habitats (Figure 37).

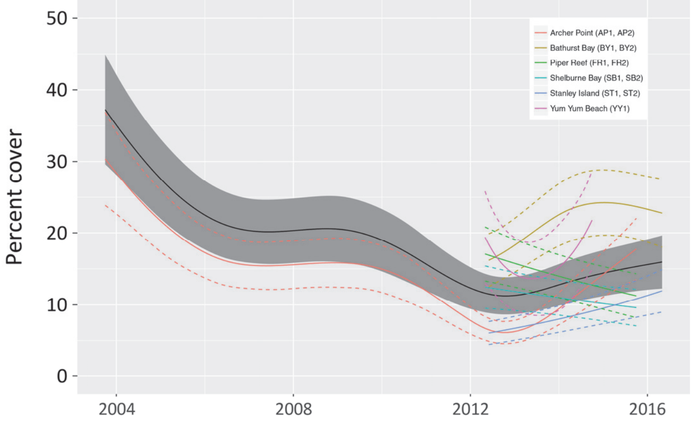

Figure 36. *Regional and location temporal trend in seagrass abundance in the Cape York NRM region represented by a GAM plot. Regional trend (all locations pooled) represented by black line with grey shaded area defining 95 per cent confidence intervals.*

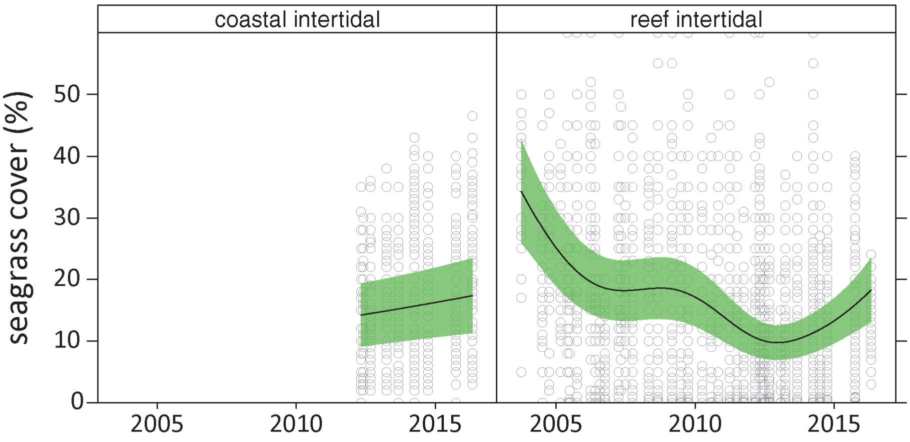

Figure 37. *Temporal trends in seagrass abundance for each habitat in the Cape York NRM region represented by a GAM plot. Regional trend (all locations pooled) represented by black line with green shaded area defining 95 per cent confidence intervals and quadrat measures represented by grey circles.*

Cape York reef meadows were dominated by *Thalassia hemprichii, Cymodocea rotundata, Halodule uninervis* and *Halophila ovalis* with varying amounts of *Syringodium isoetifolium* and *Enhalus acoroides* (Appendix 4); however, Piper Reef has relatively low diversity, being dominated by

C. rotundata. At Archer Point (the location of the longest dataset), species composition has varied since sampling began with *C. rotundata* becoming less dominant in favour of colonising (*H. ovalis*) and the opportunistic *H. uninervis* following extreme climatic conditions in 2009-2011, but *Z. muelleri* was recorded at this site in 2015-16. In contrast, seagrass at coastal habitats in the eastern Cape York NRM region were located on large shallow sand banks and dominated by *H. ovalis/H. uninervis*, with small amounts of the species typically found on reefs (*T. hemprichii* and *S. isoetifolium*). There were no substantial changes in species composition in 2015-16.

Seagrass meadows in the Cape York NRM region were composed of below GBR average (MMP sites) proportion of species displaying colonising traits in 2015-16 (Figure 38). Fluctuations over the long-term suggests the meadows are dynamic in nature, however, this appears to have stabilised over the last 12-24 months at reef habitats.

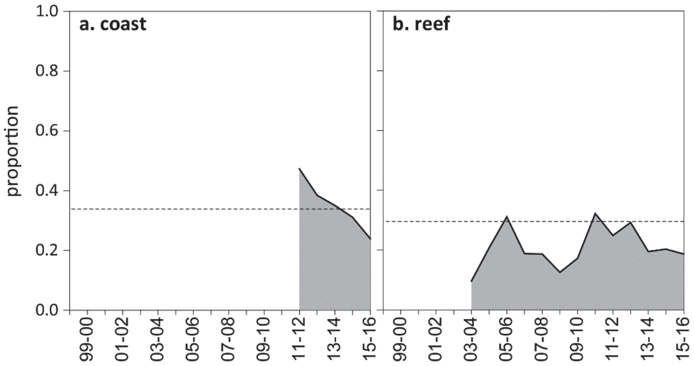

Figure 38. *Proportion of seagrass abundance composed of species displaying colonising traits at inshore habitats in the Cape York region.The dashed line represents GBR long-term average for each habitat type.*

Seagrass spatial extent mapping was conducted within all monitoring sites to determine if changes in abundance were a consequence of the meadow landscape changing and to indicate if plants were allocating resources to colonisation (asexual reproduction) (Appendix 4). Prior to 2012, the only meadow extent mapping in the Cape York NRM region was conducted at Archer Point. The meadows within monitoring sites on the reef flat at Archer Point have fluctuated within and between years (Figure 39), primarily due to changes in the landward edge and appearance of a drainage channel from an adjacent creek (data not presented). Post 2011, additional reef meadows and coastal meadows in the Cape York NRM region were included. Overall, meadow extent has been relatively stable in 2015-16 (Figure 39; Appendix 4).

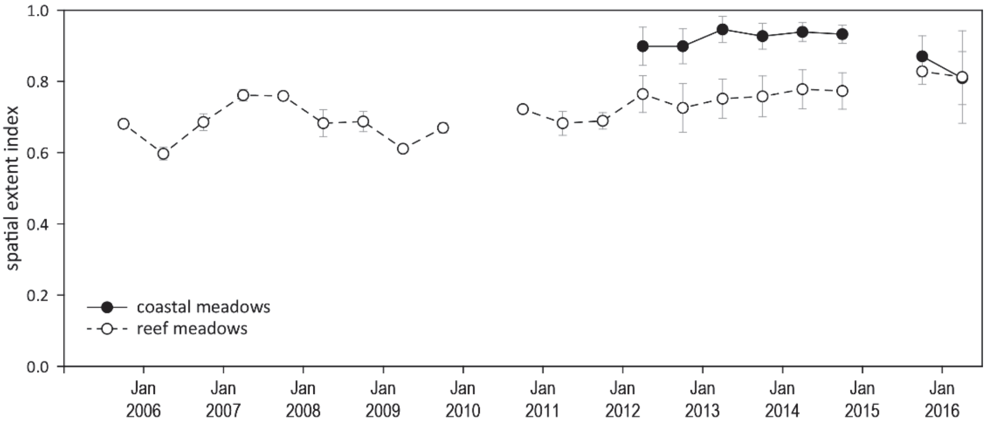

Figure 39. *Change in spatial extent of seagrass meadows within monitoring sites for each habitat and monitoring period across the eastern Cape York NRM region.*

Seagrass reproductive status

Seagrass seed banks in Cape York meadows were often larger in the late dry than late wet (Figure 40). Seed banks were also higher at coastal than reef habitats (Figure 40). A seed bank of predominately *Halodule uninervis* persists at reef habitat meadows (Figure 40), however late dry abundances in 2015-16 were lower than the previous year. As in previous years, seed banks were considerably higher at coastal sites than at reef sites. Although *Cymodocea* plants were present across reef meadows, no seeds have been found since monitoring commenced. Total reproductive effort across the region remains low with a report card rating of very poor (Figure 30), and declined compared to the previous monitoring period; significantly below the 2009 peak (Figure 40). Low seed bank density and poor reproductive effort at reef meadows indicates a low capacity to recover following disturbance, while at coastal meadows, the greater seed bank density suggests a higher capacity to recover.

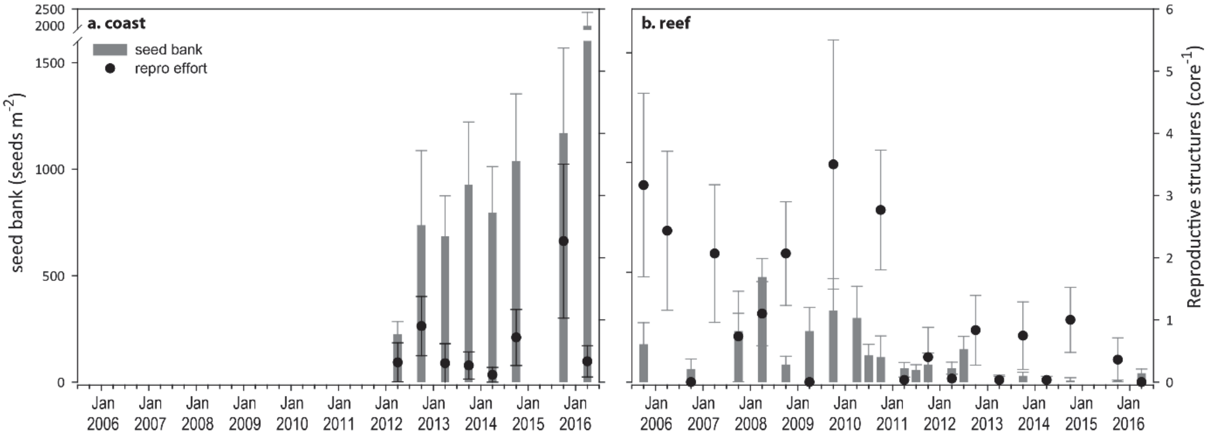

Figure 40. *Seed banks and reproductive effort at inshore intertidal coastal (a) and reef (b) habitats in the Cape York region (species and sites pooled). Seed banks (bars ± Standard Error) presented as the total number of seeds per m^2 sediment surface. Reproductive effort for late dry season (dots ± Standard Error) presented as the average number of reproductive structures per core.*

4.2.4 Indicators of environmental condition

Seagrass tissue nutrients

Seagrass leaf molar C:N ratios were largely unchanged and remained below 20 at all Cape York habitats and locations in late dry season 2015 (Figure 41; Appendix 4). Leaf molar C:P ratios in 2015 were just above 500, indicating that the plants were growing in a relatively moderate P pool that was slightly depleted (Figure 42; Appendix 4), while leaf molar N:P ratios indicate a slight enrichment of N, relative to P.

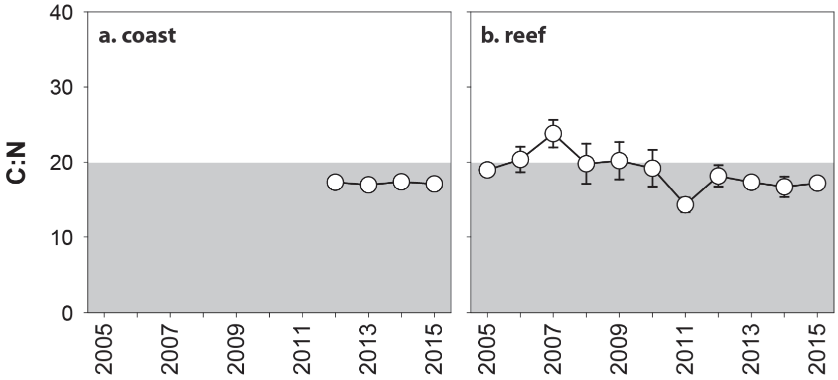

Figure 41. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation species in inshore intertidal coastal (a) and reef (b) habitats in the Cape York region from 2005 to 2015 (species pooled) (mean and SE displayed). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

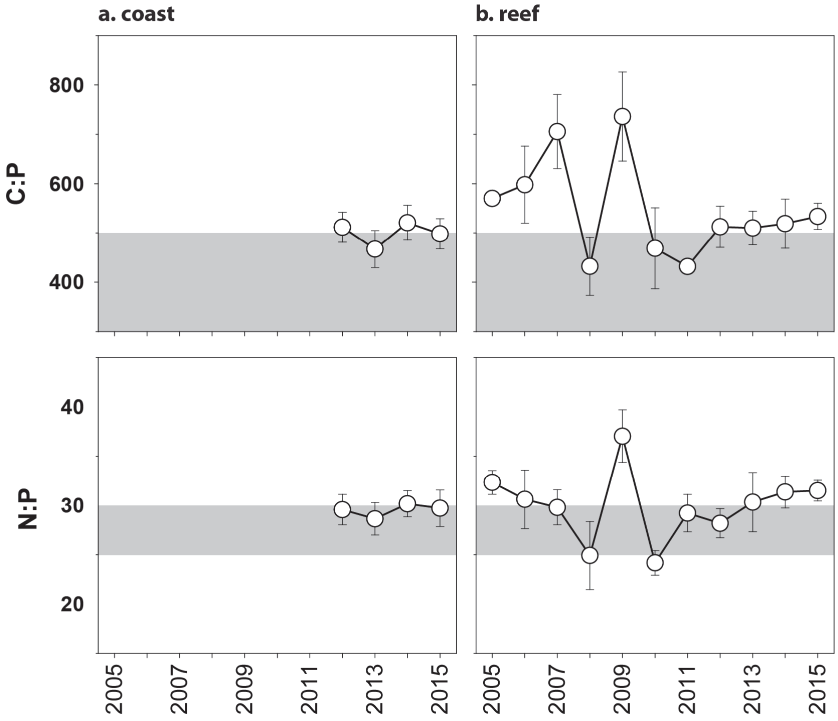

Figure 42. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation species in inshore intertidal reef (a, c) and coastal (b, d) habitats in the Cape York region from 2005 to 2015 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Seagrass meadow sediments

Reef habitats were dominated by sands and coarser sediments, while coastal habitats contained a greater proportion of mud (Appendix 4). During the late wet each year, the proportion of finer sediments (i.e. mud) increased in reef habitats, relative to the late dry season. In 2015-16, the proportion of mud at reef habitats was similar to the previous monitoring period, and no long-term trends are apparent. Similarly at coastal habitats, no long term trends are apparent.

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades over the long-term was generally higher in the wet season at coastal habitats and in the dry season at reef habitats (Figure 43). During the 2015-16 dry season, epiphyte abundances at reef habitats were slightly higher than the GBR long-term average, but still lower than 2009-2012 (Figure 43; Appendix 4, Figure 191). At coastal sites, epiphytes were lower than the GBR average in the dry season, but epiphytes in the late wet season (May 2016) at the southern coastal sites (Bathurst Bay), were higher than in the previous dry season. Percentage cover of macroalgae was variable between locations, and remained above the GBR long-term average for reef habitats in the central and north of the region throughout 2015-16 (Figure 43; Appendix 4, Figure 191). Macroalgae cover at coastal sites has varied little and in 2015-16 it remained near to the GBR long-term average (Figure 43).

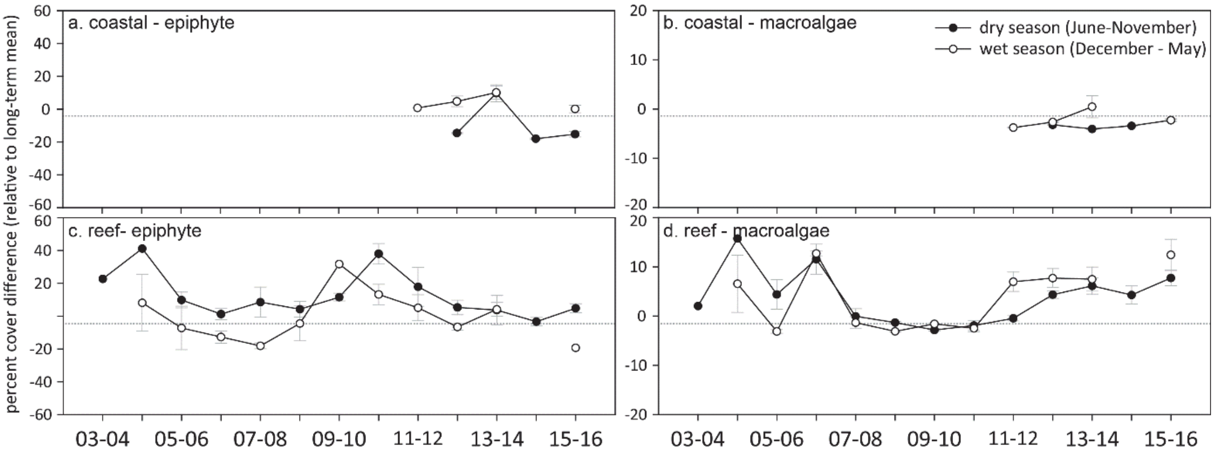

Figure 43. *Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) at monitoring sites in the Cape York region, relative to the long-term average for each inshore GBR intertidal seagrass habitat (sites pooled, ±SE).*

4.2.5 Report card for inshore seagrass status

In the 2015-16 monitoring period, the seagrass index for Cape York region was similar to the previous period (Table 15). The slight improvement is a consequence of improved abundance across all habitats but this was offset to a degree by the lower reproductive effort in reef habitats. Overall, the Cape York seagrass index is the highest since 2011-12, but remains well below the 2005-06 baseline.

Table 15. *Long-term report card scores for seagrass abundance, reproductive and leaf tissue nutrient status for each habitat in the Cape York NRM region: June 2005 – May 2016. Values are indexed scores scaled from 0-100; 🟩 = very good (81-100), 🟩 = good (61 - 80), 🟨 = moderate (41 - 60), 🟧 = poor (21 - 40), 🟥 = very poor (0 - 20). NB: Scores are unitless.*

Indicator	Habitat	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Abundance	coastal intertidal							63	81	63	75	75
	coastal subtidal											75
	reef intertidal	75	35	45	44	44	20	14	22	29	25	40
Reproductive effort	coastal intertidal								0	0	0	6
	reef intertidal	63	0	25	38	63	63	13	17	17	21	5
Leaf tissue nutrient	coastal intertidal								30	36	37	35
	reef intertidal	45	52	69	49	51	46	21	36	35	33	37
Seagrass Index		**61**	**29**	**46**	**43**	**52**	**43**	**21**	**28**	**29**	**30**	**34**

4.3 Wet Tropics

4.3.1 2015-16 Summary

The Wet Tropics includes two World Heritage Areas, however increases in intensive agriculture, coastal development and declining water quality have been identified as significant across the region. In 2015-16 rainfall and river discharge were again below the long-term average; similarly wind exposure was below the long-term average and lower than the previous monitoring period. Despite this, coastal sites and Dunk Island (which is the reef site closest to shore) were exposed to primary or secondary water types for 90-100 per cent of the wet season (December 2014 to April 2015) and canopy daily light was slightly lower than the long-term average across the entire region. The number of days that seawater temperature was above 35°C in February (18 d) was an equal record for exceedance within one month. However, the total days above 35°C for the monitoring period was equal to the long-term median (44 d), and there were no days that temperatures exceeded 40°C. Therefore, while water temperatures may contribute to cumulative impacts, particularly in February when light levels are also low, there was no indication of extreme temperature stress.

Seagrass meadows in the region remain in a vulnerable state in 2015-16 with an overall abundance rating of poor increasing from very poor in the previous year. The trends in abundance vary among locations reflecting a complex range of environmental and biological processes affecting recovery rates. Abundance continued to decline at the Green Island subtidal site, while at Yule Point there were large increases in abundance and the proportion of species displaying colonising traits remained low in favour of persistent species. Other meadows in the northern Wet Tropics remained relatively stable, leading to a region-wide stable population, but with large variability. At the coastal location (Yule Point), there were large increases in reproductive effort, and small increases in the seed bank, while at other locations seed banks remain low. At southern Wet Tropics locations, recovery after 2011 has been marginal at Dunk Island, and there has been no recovery at Lugger Bay. Furthermore, reproductive effort and seed banks remain low at all locations. Therefore, the overall rating for reproductive effort declined to very poor suggesting capacity to recover from major disturbances remains weak at most sites. Analysis of seagrass leaf tissue suggests an excess of nitrogen relative photosynthetic C uptake (C:N <20), which is consistent with the high frequency of exposure to secondary water. Nutrient status therefore remained poor.

Overall, the status of seagrass condition in the Wet Tropics NRM region has remained **poor** in 2015-16 (Figure 44). On average, Wet Tropics seagrass meadows remain in a vulnerable condition with low resilience, however, some sites are showing signs of improvement, while others have deteriorated.

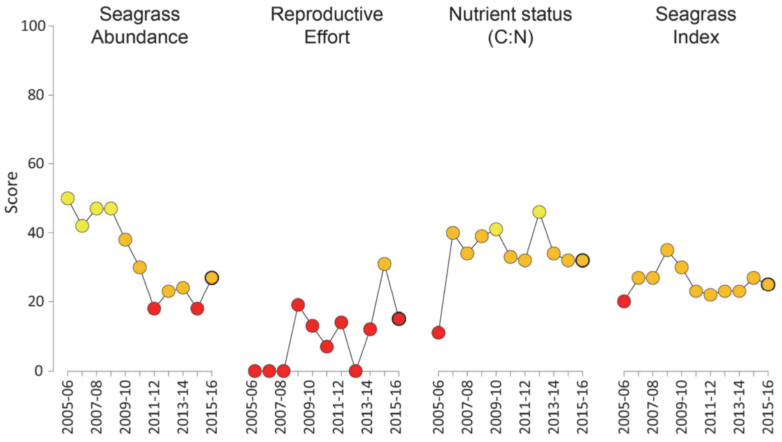

Figure 44. Report card of seagrass indicators and index for the Wet Tropics NRM region *(average across habitats and sites). Values are indexed scores scaled 0-100; 🟩 = very good (81-100), 🟩 = good (61 - 80), 🟨 = moderate (41 - 60), 🟧 = poor (21 - 40), 🟥 = very poor (0 - 20). NB: Scores are unitless.*

4.3.2 Climate and environmental pressures

Annual rainfall, river discharges and wind speeds were slightly below the long-term average (Table 16). Exposure to water types was highly variable among Wet Tropics sites. The southern Wet Tropics sites had the greatest level of exposure to turbid or green water: Lugger Bay (LB) was exposed to primary water (52 per cent) and secondary water (48 per cent), while Dunk Island (DI) was exposed to secondary water (90 per cent). In the north, the coastal sites at Yule Point (YP) were exposed to secondary water (90 per cent), while the reef sites at Low Isles (LI) and Green Island (GI) had low exposure to either (Figure 45, Table 17). Within canopy temperatures were slightly higher in 2015-16 due to the thermal anomaly in Cape York extending (albeit to a lesser extent) into the Wet Tropics.

Table 16. *Summary of environmental conditions at monitoring sites in the Wet Tropics region in 2014-15 compared to the long-term average (long-term range indicated for each data set).*

	Long-term average	2015-16
Rainfall (1887-2016)	2423 mm	2222 mm
River discharge (1970-2016)	20,978,805 L yr^{-1}	15,534,448 L yr^{-1}
Turbid water exposure (2006-2016)	*unavailable*	55 per cent
Daytime tidal exposure (1999-2016)	109.19 hrs yr^{-1}	110.28 hrs yr^{-1}
Wind (1998-2016)	118.6 days yr^{-1}	100.7 days yr^{-1}
Within canopy temperature – *intertidal* (2003-2016)	26.8°C *(41.5°C)*	27.2°C *(40.0°C)*
subtidal (2008-2016)	26.4°C *(35.7°C)*	*insufficient data*
Within canopy light (2012-2016)	12.6 mol m^{-2} d^{-1}	12.2 mol m^{-2} d^{-1}

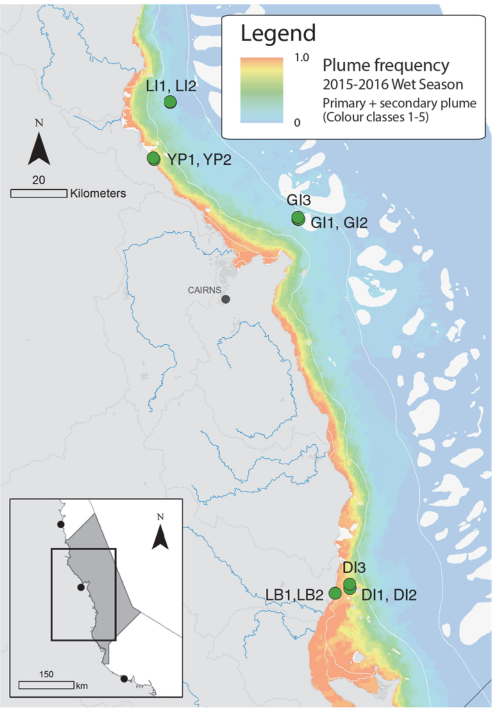

Figure 45. *Frequency of exposure to turbid water (colour classes 1-5) in the Wet Tropics NRM, wet season (22 weeks from December 2015 – April 2016) composite. Frequency calculated as number of weeks in wet season exposed to primary or secondary water (colour classes 1 – 5). Each colour class category is described by mean water quality values for TSS, CDOM, chlorophyll a and K_d (PAR) (Devlin, et al. 2015;Waterhouse, et al. 2017). For site details, see* Table 18.

Table 17. *Water type at each location in the Wet Tropics region derived from MODIS true colour images as colour classes of turbid primary water (class 1 – 4, red/brown), nutrient/chlorophyll-enriched secondary water (class 5, green), and tertiary (some freshwater/CDOM influence) or no plume influence (class 6 and 7 respectively, blue), for 22 weeks from December 2015 – April 2016. Also shown, median wet season colour class (Med), frequency of primary water as $f_{(P)}$, the frequency of secondary water as $f_{(S)}$, and the frequency of primary or secondary as $f_{(P+S)}$. *denotes data obtained from adjacent pixel.*

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Med	$f_{(P)}$	$f_{(S)}$	$f_{(P+S)}$
LI1,LI2	7	6	7			6	5	6	6	7	6	6	6	6	6	5	5	5	6	6	5		**6**	**0.00**	**0.26**	**0.26**
YP1,YP2*	5	5	5		6	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	**5**	**0.05**	**0.90**	**0.95**
GI1,GI2	7	7	7	7	5	7	7	7	7	7	7	7	6	7	7	5	6	6	6	6	6	6	**7**	**0.00**	**0.09**	**0.09**
GI3	7	7	7	7	5	7	7	7	7	7	7	7	6	7	7	5	6	6	6	6	6	6	**7**	**0.00**	**0.09**	**0.09**
DI1,DI2	5	5	6	5	5	5	5	5	5	6	5	5	5	5	5	4	5	5	5	5	5		**5**	**0.05**	**0.86**	**0.90**
DI3	5	5	6	5	5	5	5	5	5	6	5	5	5	5		4	5	5	5	5	5		**5**	**0.05**	**0.85**	**0.90**
LB1,LB2*	5	4	5	5	5	4	4	5	5	5	4	4	4	5	5	4	4	4	5	4	4		**4**	**0.52**	**0.48**	**1.00**

Daily light (I_d) at Wet Tropics sites has been monitored since 2008 or 2009. I_d in 2015-16 (12.2 mol m^{-2} d^{-1}) was slightly lower than the long-term average (12.5 mol m^{-2} d^{-1}), largely due to conditions in the southern Wet Tropics (at Dunk Island, loggers not deployed at Lugger Bay). Other sites in the Wet Tropics were at or around the long-term average in 2015-16.

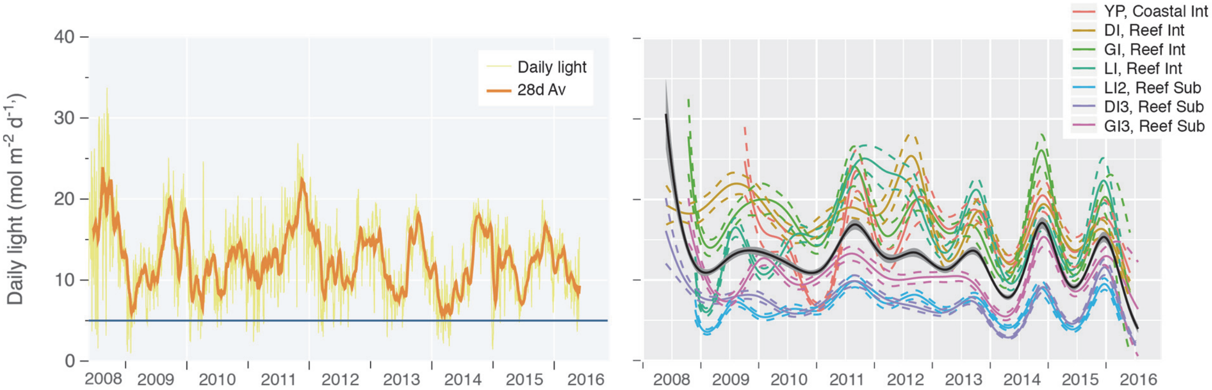

Figure 46. *Mean daily light at Wet Tropics sites with 28-d rolling average from 2008 to 2016 (left) and GAM plots (right) with the black line showing mean trend for all sites (±95 per cent confidence interval in grey shade) and coloured lines (with CI's) showing the trend for each site. Results of statistical analysis (GAM) and site-specific graphs (site-level daily light data plus 28-d rolling average) are shown in Appendix 4.*

The 2015-16 year was warmer than the long-term average at Wet Tropics seagrass sites. High temperatures (>35°C) were recorded from mid-2015 to June 2016 across the region, with the highest temperature at intertidal sites (38.4°C and 38.8°C) recorded in February, while in the previous year (2014-15), water temperature had exceeded 40°C (Figure 47). Within canopy water temperatures exceeded 35°C for a record 18 d in one month (February), and an annual total of 45 d (12.3 per cent), which is close to the median level (44 d) since 2003 when monitoring was established. Water temperature at subtidal sites rarely exceeds thresholds (Figure 48); however, for the first time since monitoring began there were no weeks that were cooler than the baseline (Figure 48).

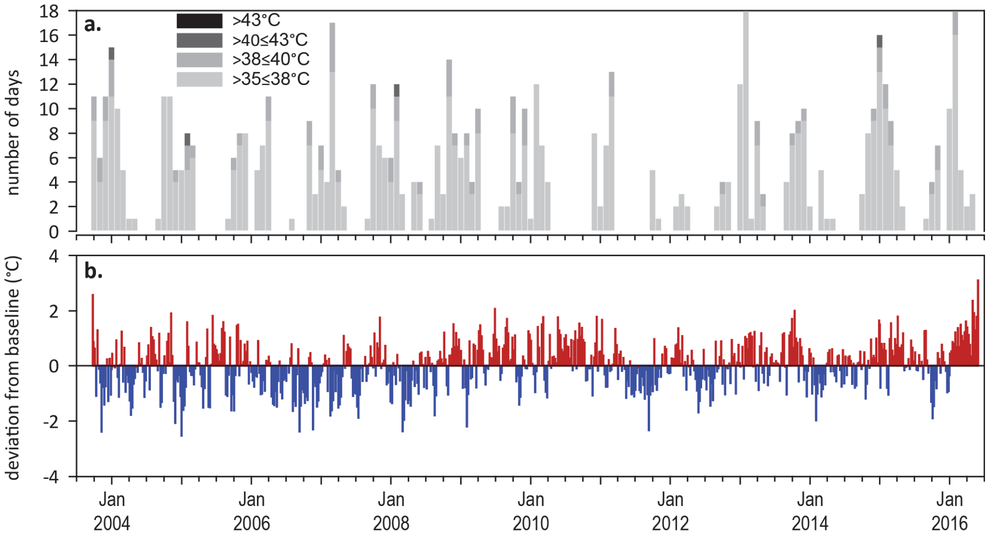

Figure 47. *Inshore sea temperature for intertidal seagrass habitats in the Wet Tropics NRM region from August 2001 to June 2016: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006a); b) deviations from 13-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations). Dashed line represents period when monitoring not established.*

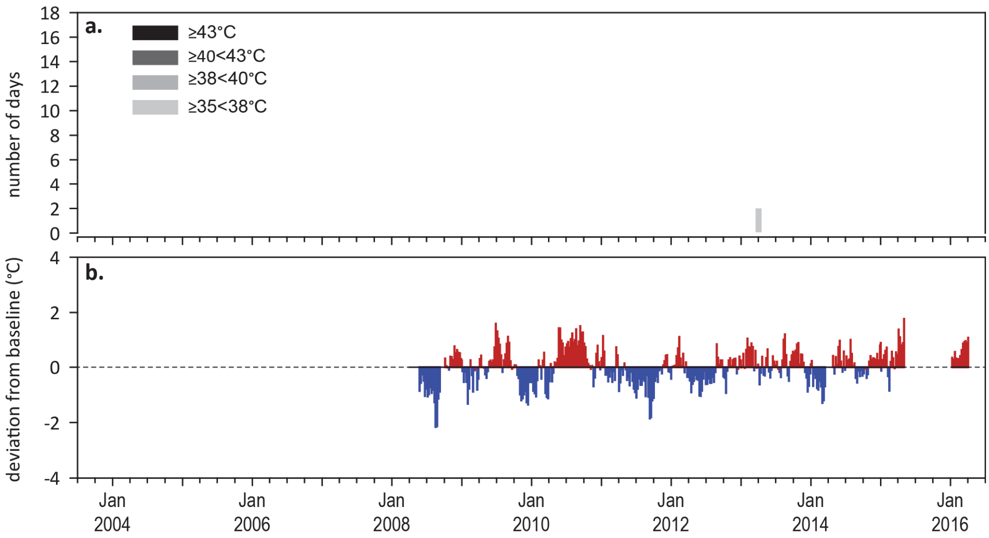

Figure 48. *Inshore sea temperature for subtidal seagrass habitats in the Wet Tropics NRM region from October 2008 to June 2016: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006a); b) deviations from 7-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations). Dashed line represents period when monitoring not established or no data available.*

4.3.3 Indicators of seagrass condition

Four seagrass habitat types were assessed across the Wet Tropics region in 2015-16, with data from 15 sites (Table 18).

Table 18. *List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Wet Tropics NRM region. † drop camera sampling (QPWS), *Seagrass-Watch. For site details see Table 3 and Table 4.*

Habitat	Site		abundance	composition	distribution	Reproductive effort	seed banks	Leaf tissue nutrients	Meadow sediments	Epiphytes	Macroalgae
coastal intertidal	LB1	Lugger Bay	■	■	■	■	■	■	■	■	■
	LB2	Lugger Bay	■	■	■	■	■	■	■	■	■
	YP1	Yule Point	■	■	■	■	■	■	■	■	■
	YP2	Yule Point	■	■	■	■	■	■	■	■	■
coastal subtidal	MS1†	Missionary Bay	■	■							■
	MS2†	Missionary Bay	■	■							■
reef intertidal	DI1	Dunk Island	■	■	■	■	■	■	■	■	■
	DI2	Dunk Island	■	■	■	■	■	■	■	■	■
	GI1	Green Island	■	■	■	■	■	■	■	■	■
	GI2	Green Island	■	■	■	■	■	■	■	■	■
	GO1*	Goold Island	■	■			■		■	■	■
reef subtidal	LI1	Low Isles	■	■	■	■	■	■	■	■	■
	DI3	Dunk Island	■	■	■	■	■	■	■	■	■
	GI3	Green Island	■	■	■	■	■	■	■	■	■
	LI2	Low Isles	■	■	■	■	■	■	■	■	■

Seagrass abundance, composition and extent

The seagrass abundance score across the region was rated as poor in 2015-16 (Figure 34). The long-term average seagrass cover at coastal habitats in the Wet Tropics NRM region varied greatly between seasons: 6.2 ±0.7 per cent in the dry and 18.8 ±0.7 per cent in the wet season. Changes in seagrass abundance were variable among sites, but generally, recovery rates stabilised or in some cases reversed. Seagrass abundance more than doubled at the northern Wet Tropics site at Yule Point (2014-15 average 8.4 per cent, 2015-16 average 17.4 per cent). Abundance remained very poor at Lugger Bay (Figure 35) after declines in early 2010 followed by complete loss in early 2011 after Tropical Cyclone Yasi. A few isolated shoots/plants established at Lugger Bay in late dry 2012, but they have failed to recolonise.

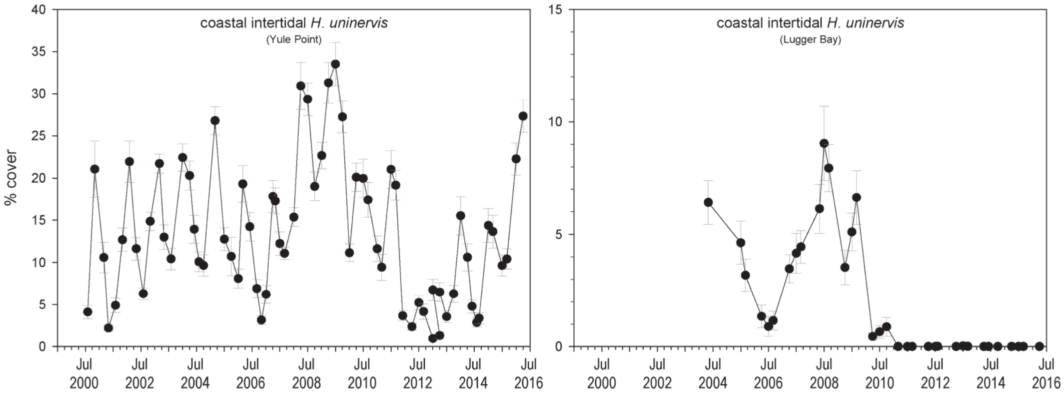

Figure 49. *Changes in seagrass abundance (per cent cover ±Standard Error) at inshore intertidal coastal habitats in the Wet Tropics NRM region, 2000 - 2015.*

Abundances at Low Isles are seasonally variable, but remain much lower than the baselines in 2008. Seagrass abundance (per cent cover) stabilised at Green Island reef platform (intertidal) sites, but have remained low at the subtidal site in 2015-16 (Figure 36). At Dunk Island, recovery trajectories observed in 2014-15 have abated and seagrass abundance remained low at subtidal (<6 per cent) and intertidal sites (<2 per cent). Recovery at Dunk Island after the crossing of TC Yasi in 2011 has most likely been limited by availability of recruits (e.g. seeds and propagules).

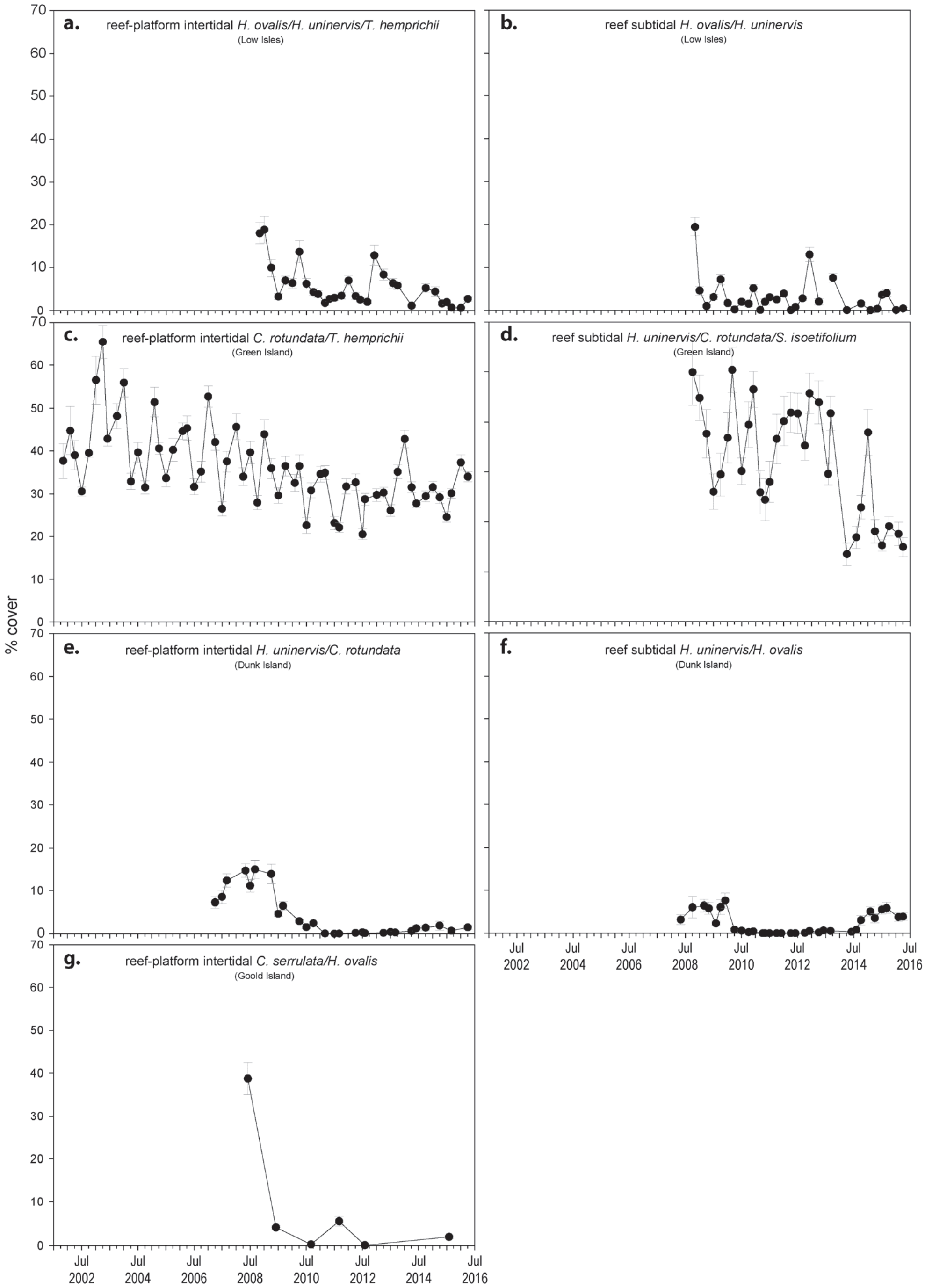

Figure 50. *Changes in seagrass abundance (per cent cover ±Standard Error) for inshore intertidal and subtidal reef habitats (left and right respectively) in the Wet Tropics NRM region, 2001 – 2016.*

An examination of the long term trends across the Wet Tropics NRM region suggests seagrass abundance (per cent cover) has remained relatively stable in the northern section (with variable trajectories among habitats leading to large variation) (Figure 51). In the southern Wet Tropics, although recovery is very slow and abundances are in very poor condition, there have been increases since 2011 at the reef sites (Figure 53) leading to marginal recovery overall, but the rate of recovery arrested in 2015-16 (Figure 51).

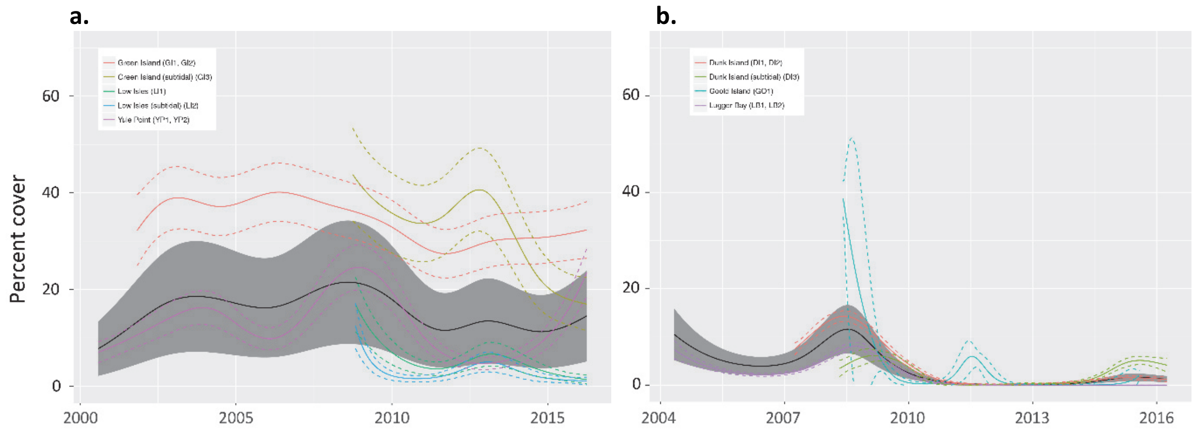

Figure 51. *Temporal trends in seagrass abundance for each monitoring location in the northern (a) and southern (b) Wet Tropics region represented by a GAM plot, 2001-2016. Northern and southern section trends (locations pooled) represented by black line with grey shaded area defining 95 per cent confidence intervals.*

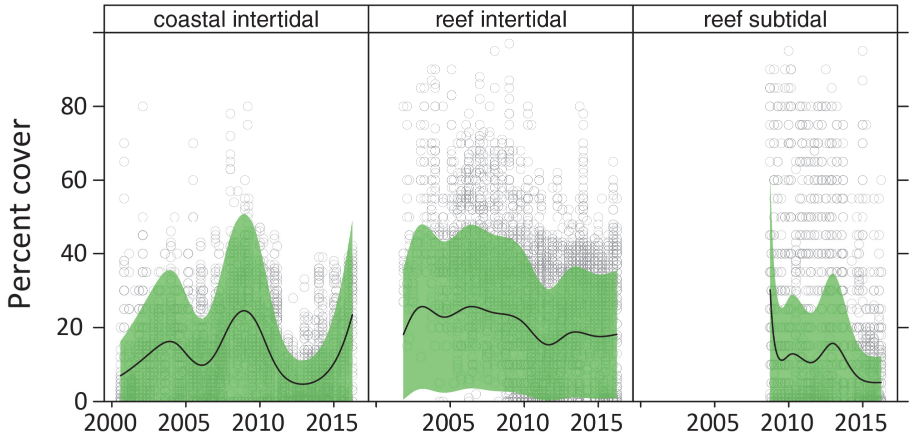

Figure 52. *Temporal trends in seagrass abundance for seagrass habitat in the northern Wet Tropics region represented by a GAM plot, 2001-2016. Trends (locations pooled) represented by black line with green shaded area defining 95 per cent confidence intervals, and quadrat data displayed as grey circles.*

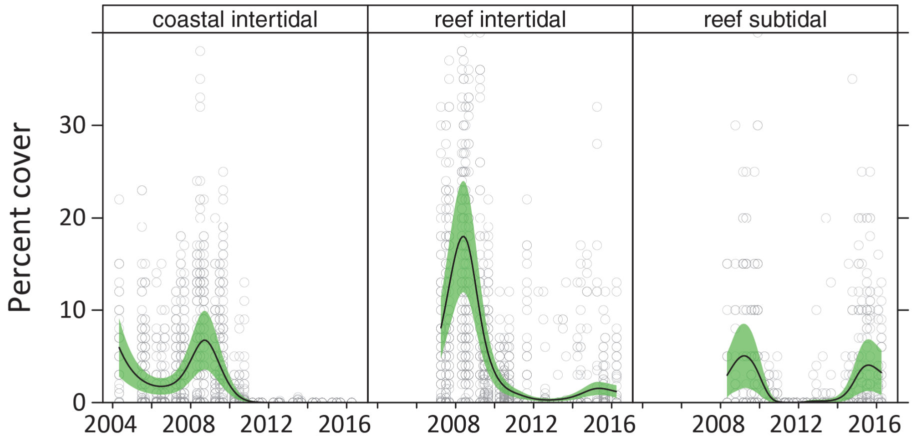

Figure 53. *Temporal trends in seagrass abundance for seagrass habitat in the southern Wet Tropics region represented by a GAM plot, 2001-2016. Trends (locations pooled) represented by black line with green shaded area defining 95 per cent confidence intervals, and quadrat data displayed as grey circles.*

The proportion of seagrass species displaying colonising traits at coastal habitats (Yule Point, Lugger Bay) had been above GBR average from 2004 to 2014, however, since 2014 the proportion declined (due to trends at Yule Point, as no seagrass remains at Lugger Bay); with colonising species replaced by opportunistic species (*Halodule uninervis*) (Figure 54). The reef subtidal habitats, in particular Low Isles and Dunk Island, have had greater than average proportion of colonising species since the extreme weather events of 2011 (Figure 54). While a similar trend (peak density of colonising species post 2011) occurred at reef intertidal sites, the magnitude of change was not as great in reefs compared to coastal habitats (Figure 54).

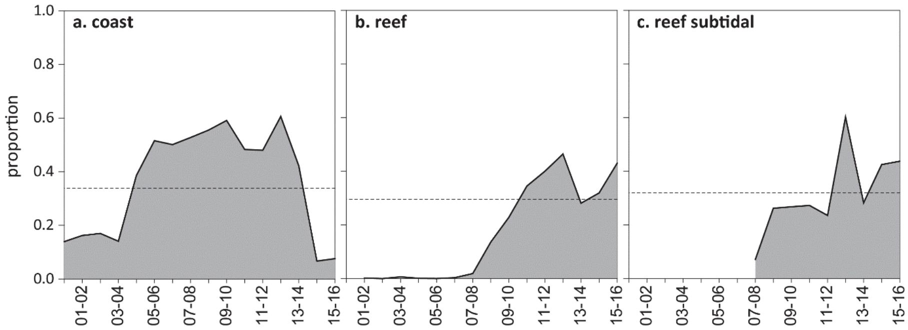

Figure 54. *Proportion of seagrass abundance composed of colonising species at inshore habitats in the Wet Tropics region, 2001 - 2016. The dashed line represents the GBR-wide average for each habitat type.*

Seagrass meadow extent within all intertidal monitoring sites has fluctuated within and between years (Figure 55), primarily due to losses and subsequent recolonisation. At coastal meadows, the extent has gradually improved since 2012, but still remains below the greatest extent in 2009. Intertidal meadows on reef habitats similarly continued to improve over the last 4 years; however, while subtidal meadows have been increasing in extent over the past 2 years there have been seasonal declines in the late-wet, which saw 60 per cent reduction in extent in the late wet season 2016 (Figure 55).

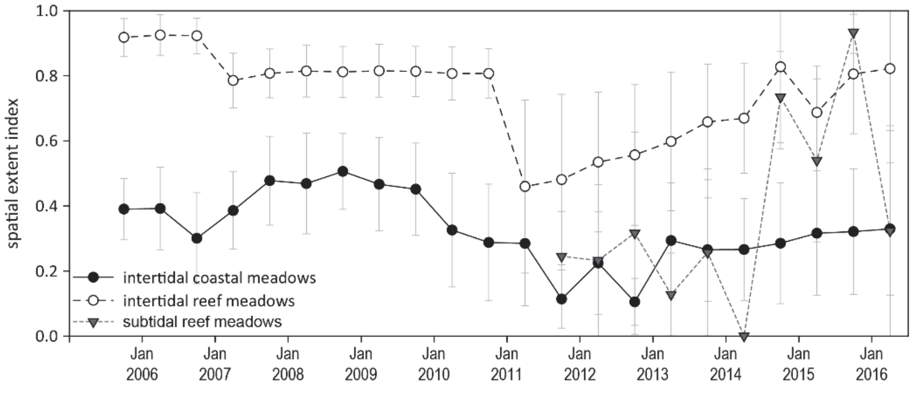

Figure 55. *Change in relative spatial extent (±SE) of seagrass meadows within monitoring sites for each habitat and monitoring period across the Wet Tropics NRM region.*

Long-term monitoring in places where cumulative anthropogenic impacts to seagrass are highest (e.g. Ports) (Grech *et al.* 2011) reported similar trends to the MMP during 2015-16, with poorer seagrass condition in the southern section of the region. Annual monitoring for Ports North reported that recovery from the large scale declines in biomass and distribution of estuarine meadows in the Ports of Cairns and Mourilyan Harbours between 2009 and 2012, either continued or reversed during 2015 (Reason *et al.* 2016; York *et al.* 2016). An assessment of 6 meadows (predominately aggregated patches) in Cairns Harbour and Trinity Inlet between September and December 2015, reported substantial increases in biomass (50 per cent increase in visually estimated above-ground biomass from a helicopter or CCTV) and extent (3.4 fold increase) since 2014 (York*, et al.* 2016). Despite the positive signs of recovery in Cairns Harbour, mean biomass and areal extent of all monitoring meadows remain below long-term averages (Figure 56).

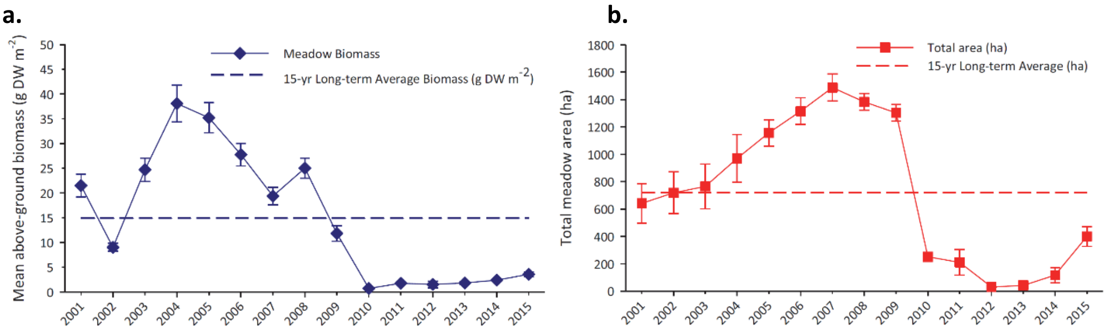

Figure 56. *Change in visually estimated above-ground biomass (a.) and total extent (b.) of all monitoring meadows combined in Cairns Harbour and Trinity Inlet from 2001 – 2015 (from York, et al. 2016). Error bars are SE for g DW m^2 and "R" reliability estimate for ha. Dashed line indicates long-term average.*

Conversely, an assessment of 5 seagrass meadows in Mourilyan Harbour in September-December 2015 reported seagrass in a lesser state than the year previous (Reason*, et al.* 2016). Similar to 2014, the only monitoring meadow remaining in 2015 was subtidal, however it declined by more than 50 per cent in both abundance (visual estimate of above-ground biomass from CCTV) and areal extent (Figure 57) (Reason*, et al.* 2016). The foundation species (*Zostera muelleri* and *Halodule uninervis*) were absent from the monitoring meadows for the sixth consecutive year. The authors attributed the decline in seagrass status in late 2015 to above average air temperatures, solar radiation and daytime tidal exposure in the months preceding the survey, coupled with an absent seed bank (Reason*, et al.* 2016).

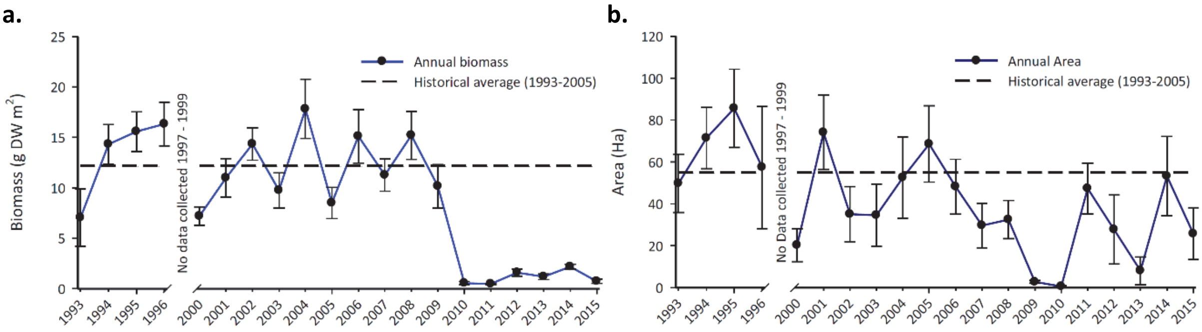

Figure 57. *Change in visually estimated above-ground biomass (a.) and total extent (b.) of all monitoring meadows combined in Mourilyan Harbour from 1993 – 2015 (from Reason, et al. 2016). Error bars are SE for g DW m^2 and "R" reliability estimate for ha. Dashed line indicates long-term average.*

Seagrass reproductive status

There was a large increase in reproductive effort in coastal intertidal habitats (at Yule Point) during 2015-16, with a corresponding increase in the seedbank; however seed density remains well below historical peaks. Reef intertidal and subtidal habitats maintained low reproductive effort, following a slight increase at subtidal habitats in 2014-15. To date, seed banks remained very low across the region in reef habitat (Figure 58). Some possible explanations for the low seed bank include failure to set seed, particularly in low density dioecious species (Shelton 2008), or rapid loss of seeds after release from germination or grazing (Heck and Orth 2006). Wet Tropics meadows may be at risk from further disturbances, as recovery potential remains very low without a substantial seed bank.

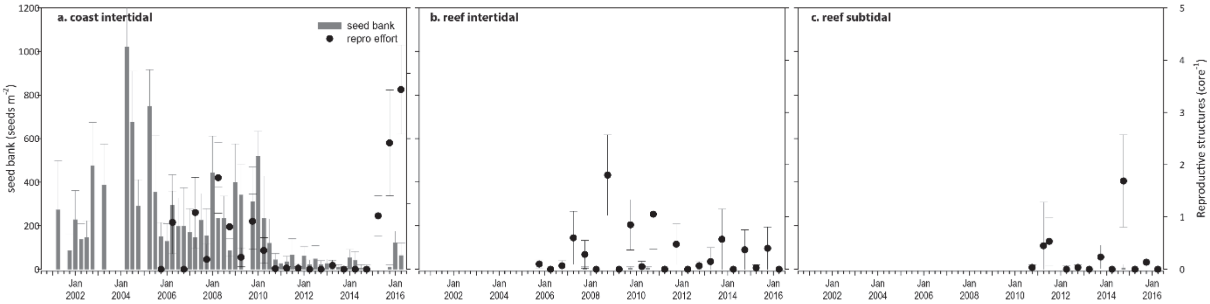

Figure 58. *Seed bank and late dry season reproductive effort for inshore intertidal coast and reef habitats in the Wet Tropics region, 2001 - 2016.Seed banks presented as the total number of seeds per m^2 sediment surface (bars ±SE), and reproductive effort presented as the average number of reproductive structures per core (species and sites pooled) (dots ±SE).*

York*, et al.* (2016) reported that although *Zostera muelleri* seed banks persist in Cairns Harbour, they have declined since quarterly monitoring for Ports North was established in June 2014. They also reported that the viability of the seeds within the seed bank was extremely low and varied between 0 and 14 per cent throughout the 2014-2016 quarterly sampling periods.

4.3.4 Indicators of environmental condition

Seagrass tissue nutrients

C:N ratio in the leaves of the foundation seagrass species (in the late dry season 2014) at the coastal sites was 11.7 (Figure 59; Appendix 4), which is well below the guideline value (20) and C:N ratios at the coastal sites were particularly low compared to other sites throughout the GBR. This indicates that nitrogen loads are in excess of growth requirements, due possibly to light limitation. Although river discharge was below average in the past year, there was high exposure to secondary water, which indicates availability of N in overlying waters, and light reducing effects from phytoplankton. Increasing N:P ratios in all habitats (Figure 60) provides further evidence of excess nitrogen loads at this site. Seagrasses in reef habitats (intertidal and subtidal) had higher leaf molar C:N ratios than those in coastal habitats (Figure 59), which has remained consistent across all years of monitoring. C:N ratios have remained relatively unchanged across all intertidal seagrass habitats over the last 6 years (Figure 59; Appendix 4), while at subtidal sites, other than a sharp increase at Green Island in 2012, C:N ratios at reef subtidal habitats have been relatively stable since monitoring commenced in 2008 (Appendix 4).

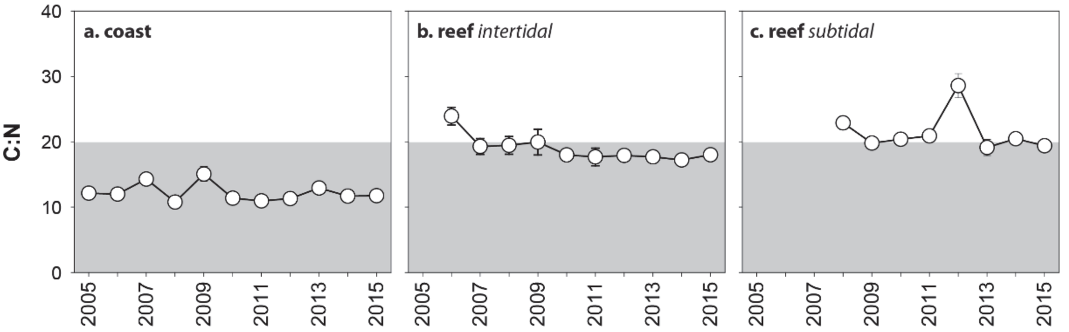

Figure 59. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each inshore habitat in the Wet Tropics region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1. C:N ratios below this line indicate reduced light availability and/or N enrichment.*

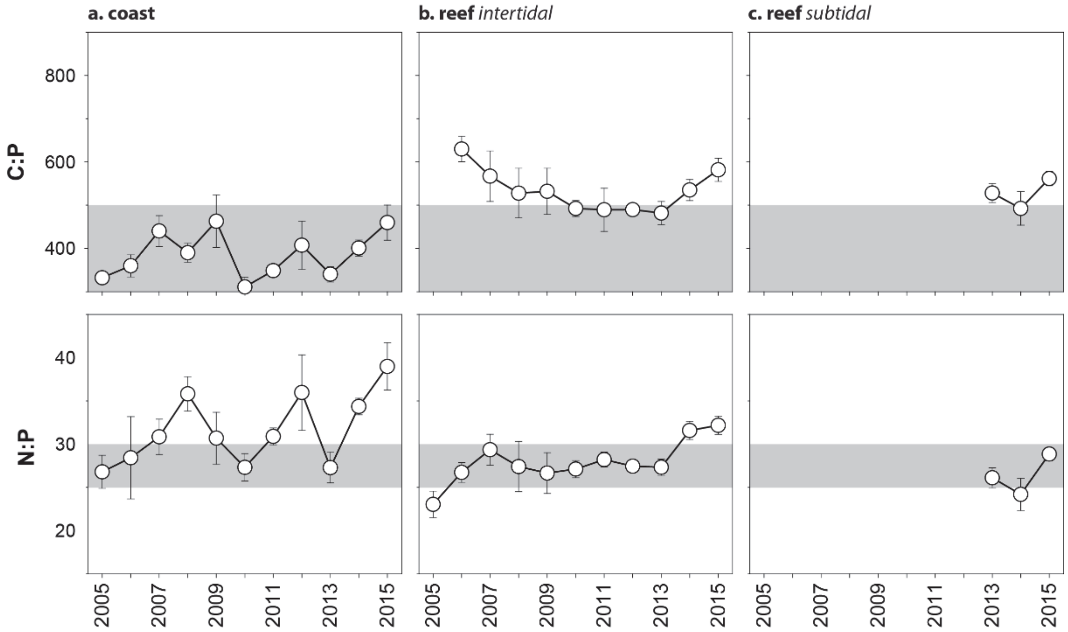

Figure 60. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each inshore habitat in the Wet Tropics region (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues. N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

The $\delta^{15}N$ values in the leaf tissue of all foundation seagrass species across reef habitats (intertidal and subtidal) were similar or slightly higher in 2015 than previously measured in the MMP, suggesting that their primary source of N was influenced by anthropogenic N sources (i.e. $\delta^{15}N$ >0<1 per cent, Udy and Dennison 1997b, see also Appendix A2.3) (Appendix 4).

Seagrass meadow sediments

Coastal sediments were composed primarily of fine sand, while reef habitats were composed of sand and coarser sediments; although finer sediments have been observed on occasion during 2012 and 2013 (Appendix 4). In 2015-16, sediments appeared similar to the long-term and the proportion of fine sediments (i.e. mud) was well below the GBR long-term average.

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades has historically been higher in the wet season across all habitats in the Wet Tropics region (Figure 61); however, in 2015-16 epiphyte loads were slightly reduced in the wet season at reef subtidal and coastal habitats. Epiphyte abundance varied across habitats and locations in 2015-16, but was much higher at reef habitats, in particular subtidal (e.g. Green Island and Dunk Island) (Appendix 2, Figure 192, Figure 193, Figure 194). Percentage cover of macroalgae generally remained around the GBR average (Figure 61; Appendix 2, Figure 192,Figure 193). Previous increases in 2014-15 at Low Isles (reef intertidal and subtidal), have abated over the 2015-16 period (Figure 61; Appendix 2, Figure 194).

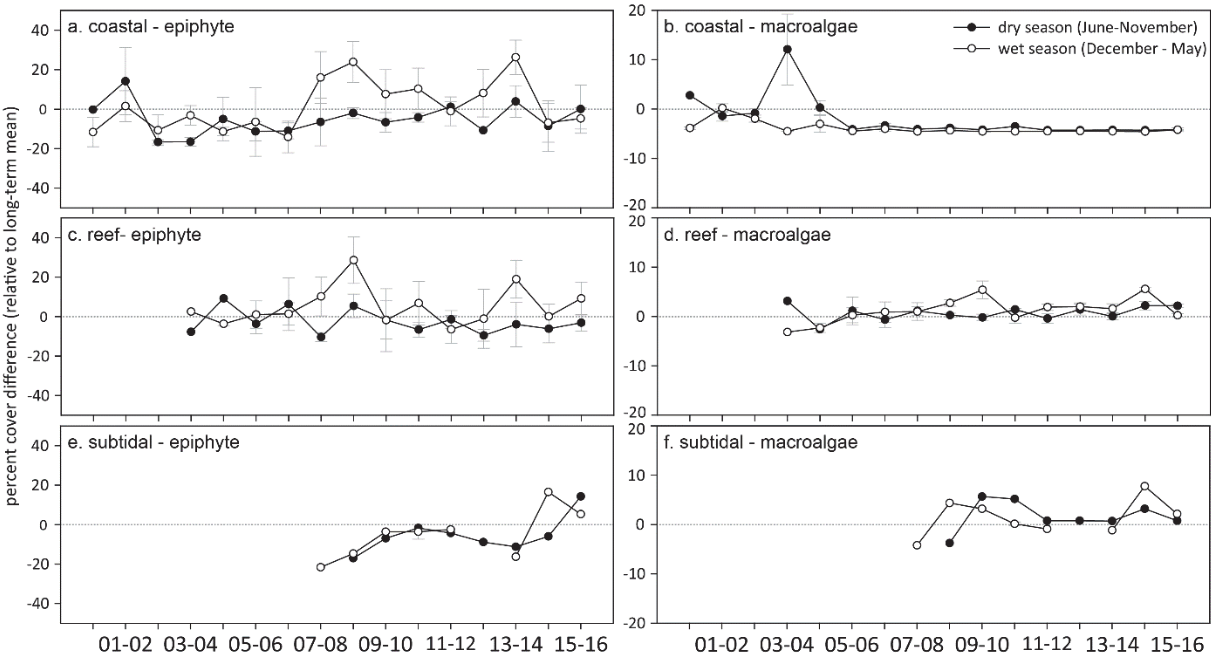

Figure 61. *Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore seagrass habitat in the Wet Tropics region, 2001 - 2016 (sites pooled, ±SE).*

4.3.5 Report card for inshore seagrass status

In the 2015-16 monitoring period, the seagrass index for the Wet Tropics region decreased relative similar to the previous period (Table 19). The decrease appears a consequence of poorer reproductive effort and leaf tissue content in subtidal reef habitats, rather than abundance; which increased or remained stable across habitats. Overall, the Wet Tropics seagrass index in 2015-16 remained in a poor state, below the 2008-09 peak.

Table 19. *Long-term report card scores for seagrass abundance, reproductive and leaf tissue nutrient status for each habitat in the Wet Tropics NRM region: June 2005 – May 2015. Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

Indicator	**Habitat**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**
Abundance	coastal intertidal	38	30	55	70	54	46	7	13	21	19	38
	coastal subtidal											33
	reef intertidal	72	58	43	35	35	19	17	21	28	20	20
	reef subtidal			0	33	23	27	34	37	22	15	17
Reproductive effort	coastal intertidal	0	0	0	0	6	0	0	0	0	0	19
	reef intertidal	0	0	0	38	19	20	10	0	10	8	10
	reef subtidal						0	33	0	25	83	17
Leaf tissue nutrient	coastal intertidal	11	10	21	6	25	7	4	7	16	8	9
	reef intertidal		70	46	47	50	40	38	40	40	36	40
	reef subtidal				64	48	52	54	93	46	52	47
Seagrass Index		**20**	**27**	**27**	**35**	**30**	**23**	**22**	**23**	**23**	**27**	**25**

4.4 Burdekin

4.4.1 2015-16 Summary

Inshore seagrass meadows in the Burdekin region are primarily structured by wind-induced turbidity (re-suspension) in the short term and by episodic riverine delivery of nutrients and sediment in the medium term. 2015-16 was a dry year with below average rainfall and river discharge was well below median discharges from the major rivers. Seagrass sites were covered in primary or secondary water types for 100 per cent of the wet season (November 2015-April 2016), which would contribute to the below average daily light observed. Although the total number of days exceeding 35°C was similar to the long-term median, seagrasses across the region experienced frequent temperature anomalies and 2 days at temperatures exceeding 40°C, which has not occurred since 2008. The low frequency of day time tidal exposure compared to long-term average may have minimised exposure to temperature extremes.

Seagrass meadows in the Burdekin NRM region decreased in abundance over 2015-16, following a period of rapid recovery since 2011, but remained in moderate condition. Reef subtidal sites had the largest reduction in abundance, while abundance at reef intertidal and coastal sites was relatively stable. Seagrass extent was stable at reef subtidal and coastal habitats, but decreased slightly at reef intertidal sites. Annual monitoring as part of the Queensland Ports Seagrass Monitoring Program (QPSMP) in the Cleveland Bay region showed a similar trend, with declining biomass, but relatively stable meadow extent in the late dry 2015 (Davies *et al.* 2015). However, at the port of Abbot Point in the southern Burdekin region, the dynamic deep-water seagrass meadows increased in biomass, while inshore meadows showed little improvement (McKenna *et al.* 2015).

Reproductive effort was increased substantially at coastal sites, and this has led to a gradual accumulation of seeds in the seed bank to be at the highest densities among all GBR sites; however, it remains lower than the historical peaks observed in 2004-2008. At reef subtidal sites, reproductive effort was relatively stable but the seed bank was highly variable. At reef intertidal sites, the seed bank and reproductive effort remains very low making them highly vulnerable to further disturbances. The overall score for reproductive effort has increased to moderate in 2015-16 after a poor rating in 2014-15, due to the good rating at subtidal site and the improved index at coastal sites. The C:N ratio of seagrass leaves declined 2015-16 at reef sites (intertidal and subtidal) for the second year after increases in prior years. Light availability was not particularly high over the past year and there was a high exposure to both primary and secondary water types, suggesting an increase in N availability and potentially reduced photosynthesis and carbon uptake.

Over the past decade, seagrass meadows of the Burdekin region have demonstrated high resilience particularly through their capacity for recovery. This may reflect a conditioning to disturbance (high seed bank, high species diversity), but also reflects the nature of the disturbances which are acute and episodic dominated by Burdekin River flows while in the adjacent Wet Tropics, multiple and ongoing disturbances tend to occur. Burdekin regional seagrass state declined in 2014-15 and remains **moderate** in 2015-16 due largely to reduced reproductive effort (Figure 62).

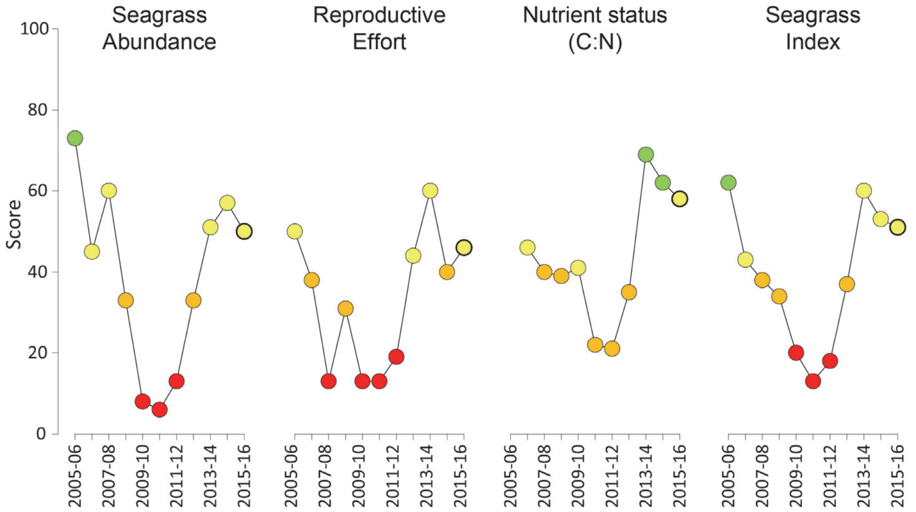

Figure 62. *Report card of seagrass status indicators and index for the Burdekin NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

4.4.2 Climate and environmental pressures

Rainfall and river discharge were again low with discharge from the Burdekin River being less than 50 per cent of the long-term average (Table 20, Figure 146) and wind, which can resuspend fine sediments and nutrients adsorbed to their surface, was lower than the long-term average. Despite this, seagrass monitoring sites were exposed to primary or secondary water for 100 per cent (f_{P+S} = 1.00) of the wet season. Coastal sites were exposed to turbid, sediment laden, primary waters, and reefs sites were exposed largely to high nutrient secondary waters, for the duration of the 2015-16 wet period (Figure 63, Table 21).

Table 20. *Summary of environmental conditions at monitoring sites in the Burdekin in 2015-16 compared to the long-term average (long-term range indicated for each data set) including climate, discharge, plume, and within seagrass canopy conditions.*

	Long-term average	**2015-16**
Rainfall (1940-2016)	1040 mm	659 mm
River discharge (1970-2016)	5,976,064 L yr^{-1}	2,306,435 L yr^{-1}
Turbid water exposure (2006-2016)	*unavailable*	100 per cent
Daytime tidal exposure 2000-2016)	120.81 hrs yr^{-1}	86.40 hrs yr^{-1}
Wind (1998-2016)	142.8 days yr^{-1}	119.5 days yr^{-1}
Within canopy temperature – *intertidal* (2003-2016)	26.5°C (46.6°C)	26.9°C *(40.5°C)*
subtidal (2008-2016)	26.3°C *(36.2°C)*	27.8°C *(32.7°C)*
Within canopy light (2012-2016)	10.3 mol m^{-2} d^{-1}	9.9 mol m^{-2} d^{-1}

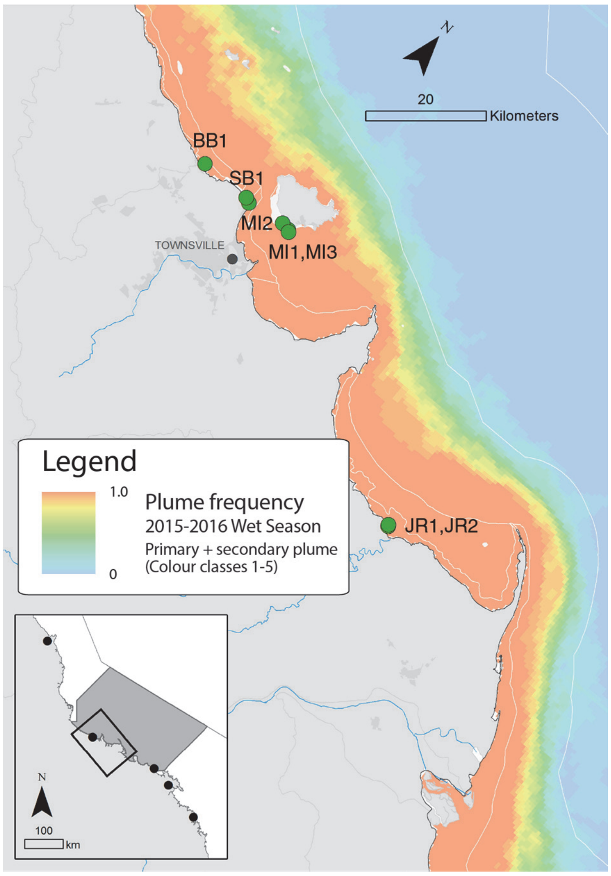

Figure 63. *Frequency of exposure to turbid water (colour classes 1-5) in the Burdekin NRM region, wet season (December 2015 – April 2016) composite. Frequency calculated as number of weeks in wet season exposed to primary or secondary water (colour classes 1 – 5). Each colour class category is described by mean water quality values for TSS, CDOM, chlorophyll a and K_d (PAR) (Devlin, et al. 2015;Waterhouse, et al. 2017). For site details, see* Table 22.

Table 21. *Water type at each seagrass monitoring site in the Burdekin NRM region, derived from MODIS true colour images as colour classes of turbid primary water (class 1 – 4, red/brown), nutrient/chlorophyll-enriched secondary water (class 5, green), and tertiary (some freshwater/CDOM influence) or no plume influence (class 6 and 7 respectively, blue), for 22 weeks from December 2015 – April 2016. Also shown, median wet season colour class (Med), frequency of primary water as $f_{(P)}$, the frequency of secondary water as $f_{(S)}$, and the frequency of primary or secondary as $f_{(P+S)}$.*

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	**Med**	$f_{(P)}$	$f_{(S)}$	$f_{(P+S)}$
BB1	1	1	2	2	4	1	2	2	2	2	2	2	2	4	3	2	2	2	3	4	2	3	**2**	**1.00**	**0.00**	**1.00**
JR1	3	2	2	1	2	1	3	1	3	2	3	1	4	1	4	1	2	1	2	2	2	4	**2**	**1.00**	**0.00**	**1.00**
MI1	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	**5**	**0.05**	**0.95**	**1.00**
MI3	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	**5**	**0.05**	**0.95**	**1.00**
SB1	3	1	2	2	3	2	3	3	4	3	4	3	3	4	4	5	3	4	5	2	3	4	**3**	**0.91**	**0.09**	**1.00**

Daily light (I_d) has been monitored at some Burdekin Dry Tropics sites since 2008 (Figure 64). I_d is highly seasonal at some sites, with the peak occurring in the late dry season (usually October-December). The seasonal signal in I_d is most pronounced at Picnic Bay intertidal (MI1) and subtidal (MI3) sites (Figure 64). In 2015-16, average I_d was lower than average due to conditions at the Magnetic Island sites and due to particularly low I_d late in the senescent season (February to May) (Figure 64).

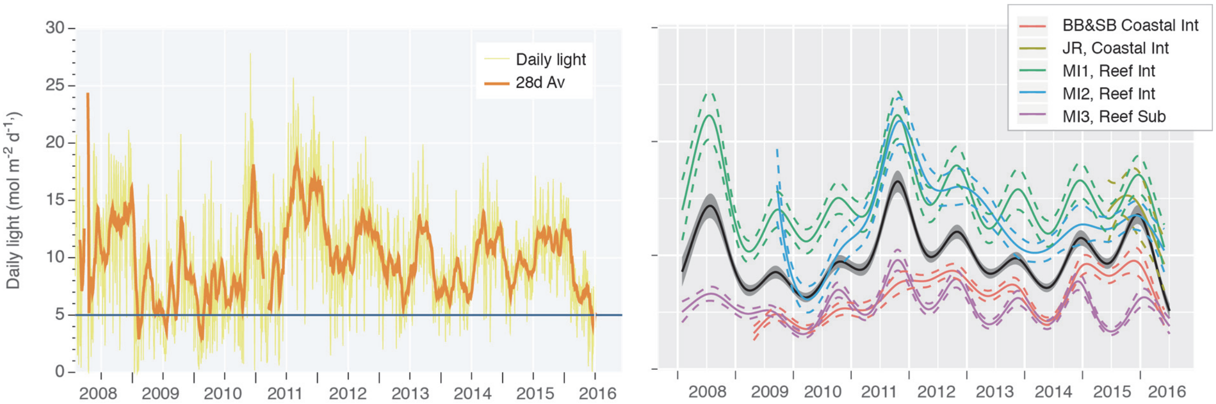

Figure 64. *Mean daily light at Burdekin sites with 28-d rolling average from 2008 to 2016 (left) and GAM plots (right) with the black line showing mean trend for all sites (±95 per cent confidence interval in grey shade) and coloured lines (with CI's) showing the trend for each site. Results of statistical analysis (GAM) and site-specific graphs (site-level daily light data plus 28-d rolling average) are shown in Appendix 4.*

Water temperature was generally very warm, but there were fewer days above 35°C in 2015-16 (44d) compared to 2014-15 (53 d) (Figure 65a), but for the second year in row there was frequent deviation from the thermal baseline, even at subtidal sites (Figure 65b). There were also 2 days of extreme temperature (>40°C) in February 2015-16, which is the greatest number since 2008-09. These temperatures can rapidly reduce photosynthetic rates and cause leaf "burn-off" (Campbell et al 2006).

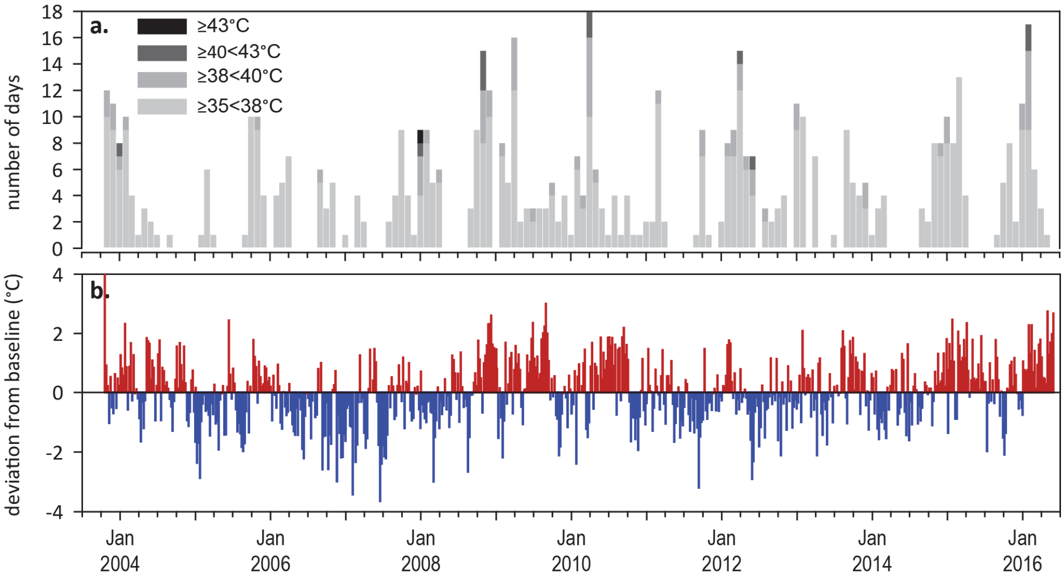

Figure 65. *Inshore sea temperature at intertidal seagrass habitats in the Burdekin region, January 2008 - May 2016: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006a); b) deviations from 11-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

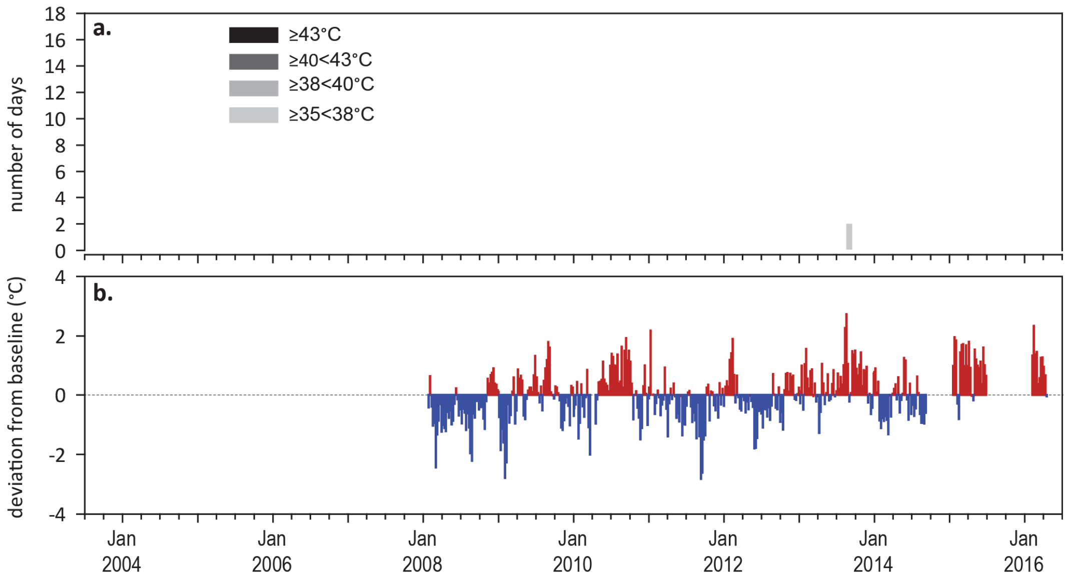

Figure 66. *Inshore sea temperature at inshore subtidal seagrass habitat at Magnetic Island (Burdekin region), January 2008 - May 2016: a) number of days when temperature exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006a); b) deviations from 7-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations). Dashed line represents no data.*

4.4.3 Indicators of seagrass condition

Three seagrass habitat types were assessed across the Burdekin region in 2015-16, with data from 8 sites (Table 22).

Table 22. *List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Burdekin NRM region. *Seagrass-Watch. For site details see Table 3 and Table 4.*

Habitat	Site code and location		Seagrass abundance	Seagrass composition	Seagrass distribution	Reproductive effort	seed banks	Leaf tissue nutrients	Meadow sediments	Epiphytes & macroalgae
coastal intertidal	SB1	Shelley Beach (Townsville)	■	■	■	■	■	■	■	■
	SB2*	Shelley Beach (Townsville)	■	■			■		■	■
	BB1	Bushland Beach (Townsville)	■	■	■	■	■	■	■	■
	JR1	Jerona (Barratta CK, Bowling Green Bay)	■	■	■	■	■	■	■	■
	JR2	Jerona (Barratta CK, Bowling Green Bay)	■	■	■	■	■	■	■	■
reef intertidal	MI1	Picnic Bay (Magnetic Island)	■	■	■	■	■	■	■	■
	MI2	Cockle Bay (Magnetic Island)	■	■	■	■	■	■	■	■
reef subtidal	MI3	Picnic Bay (Magnetic Island)	■	■	■	■	■	■	■	■

Seagrass abundance, composition and distribution

The overall status for seagrass abundance has remained **moderate** in 2015-16 (Figure 62). Seagrass abundance (per cent cover) declined over the past 12 months at reef sites while fluctuating abundance at coastal sites has resulted in relatively unchanged abundance on average (Figure 67).

Since monitoring was established, coastal and reef intertidal meadows in the region have displayed a seasonal pattern in abundance; high in wet and low in the dry season (McKenzie*, et al.* 2012a). This, however, was not apparent over the last 4 years, as variability has not followed typical seasonal trends while seagrass has been recovering from losses experienced in early 2011. Seagrass abundances in 2015-16 were higher in reef subtidal than in reef intertidal or coastal habitats (Figure 67). Reduction in abundance at the reef sites coincided the period of high temperatures and low light (February and May). At the coastal sites (BB, SB) the lowest recent abundances occurred in June 2015, following similar conditions (low light, high temperatures), but they did not decline during the 2015-16 wet.

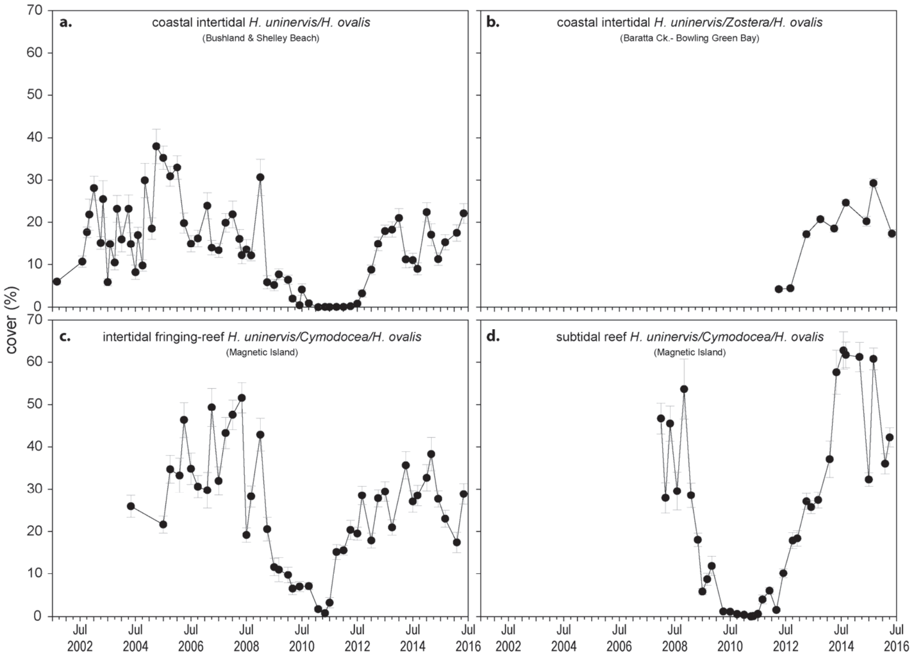

Figure 67. *Changes in mean seagrass abundance (per cent cover ±Standard Error) at inshore coastal intertidal (a, b), reef intertidal (c) and reef subtidal (d) meadows in the Burdekin region, 2001 - 2016.*

An examination of the long term trends across the Burdekin NRM habitats and region suggests seagrass abundance (per cent cover) has stabilised, and are below levels that occurred in 2005-08 in some meadows (Figure 68, Figure 69).

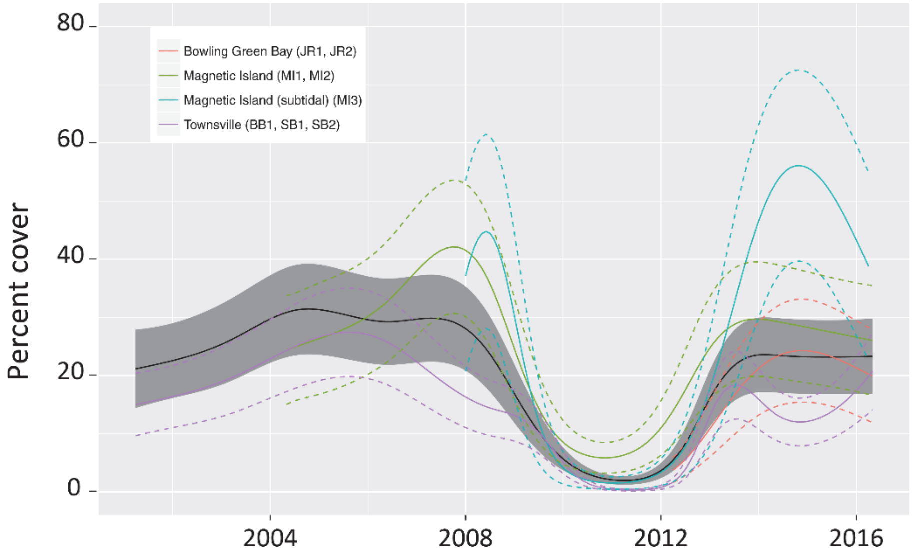

Figure 68. *Temporal trends in seagrass abundance for each location in the Burdekin region represented by a GAM plot. Regional trend (all habitats pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals.*

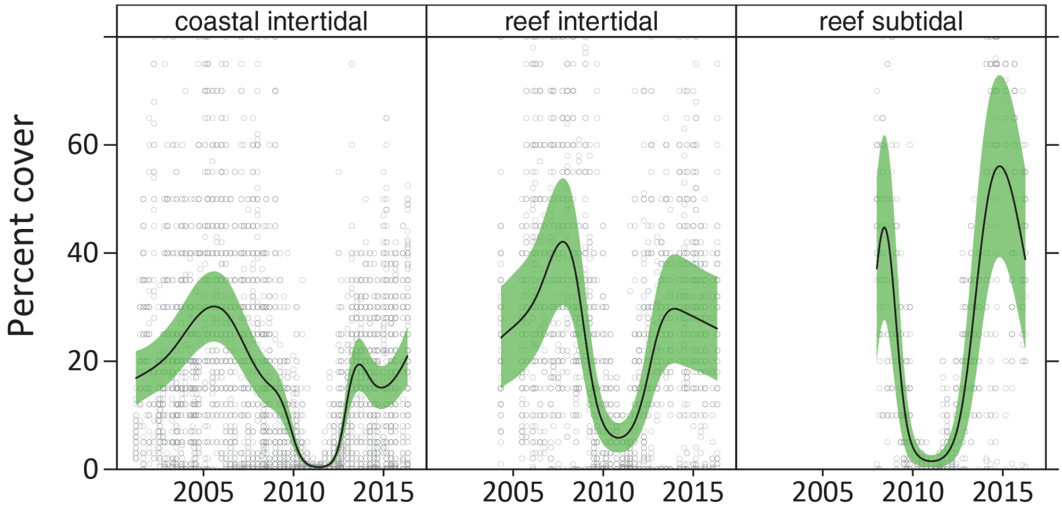

Figure 69. *Temporal trends in seagrass abundance for each habitat in the Burdekin region represented by GAM plots. Trends (locations pooled) represented by black line with green shaded area defining 95 per cent confidence intervals, and quadrat data displayed as grey circles.*

There has also been a lower proportion of species displaying colonising traits (*Halophila ovalis*), instead being dominated by opportunistic species (*H. uninervis, Z. muelleri, C. serrulata*) in coastal and reef sites or persistent species in intertidal reef habitat (*T. hemprichii*, though *C. serrulata* can also behave like a persistent species) in 2015-16 than in the previous 4 years (Figure 70; Appendix 4). This is a sign of meadow progression following near decimation after the events leading up to and including 2011. Opportunistic and persistent foundation species also have a capacity to resist stress (survive, through reallocation of resources) caused by acute disturbances (Collier *et al.* 2012c), and therefore, current species composition provides greater overall resilience in Burdekin meadows.

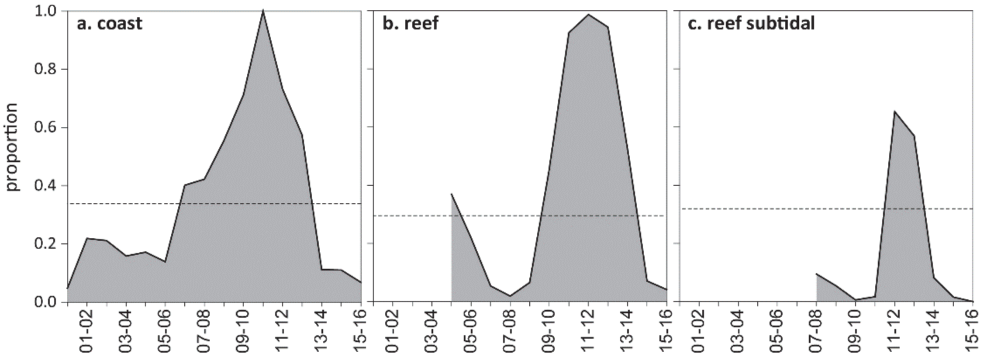

Figure 70. *Proportion of seagrass abundance composed of colonising species at inshore habitats in the Burdekin region, 2001 - 2016. Grey area represents GBR long-term average proportion of colonising species for each habitat type.*

Seagrass meadow extent within all intertidal monitoring sites has fluctuated within and between years (Figure 71), primarily due to losses and subsequent recolonisation. In the two to three years prior to 2011, significant changes occurred across the region with all seagrass meadows reducing in size and changing in landscape from continuous, to patchy, to isolated patches and finally to isolated shoots with the loss of meadow cohesion (Figure 71). That trend was also replicated at the Bay-wide scale in Cleveland Bay, with considerable loss of meadow area and meadow fragmentation (Petus *et al.* 2014a). This was caused by the high rainfall and riverine discharge that affected much of the GBR. Since 2011, meadow extents have increased in both coastal and reef habitats to pre-2009 levels (Figure 71) and have remained stable. In early 2014, however, seagrass extent declined at the subtidal habitat, to the lowest in 2 years but subsequently recovered. By early 2016, seagrass extent at coastal and reef subtidal monitoring sites had fully recovered and were at or above baseline values, while reef intertidal sites declined slightly.

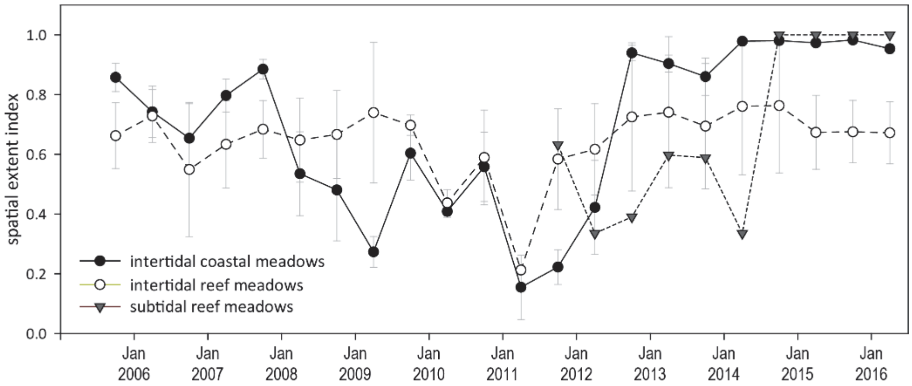

Figure 71. *Change in spatial extent of seagrass meadows within monitoring sites for each inshore intertidal habitat and monitoring period across the Burdekin region, 2005 - 2016.*

Apart from the MMP, seagrass monitoring within the Burdekin NRM region is also conducted in places where cumulative anthropogenic impacts to seagrass are highest as part of the Queensland Ports Seagrass Monitoring Program (QPSMP). Annual monitoring in September 2015 of 10 seagrass meadows in the Port of Townsville reported minor, but not significant, increases in overall extent and significant losses in abundance (Davies and Rasheed 2016, Figure 72). The increased extent was largely due to the temporary expansion of a subtidal *Halophila spinulosa* dominated meadow adjacent to Cape Pallarenda, with a smaller contribution from an intertidal *Zostera* dominated meadow in Cockle Bay. With the exception of the meadow at Shelley Beach, which deceased in extent, all other changes (increase or decrease) were not significant as they were within the estimates of reliability (see Appendix 2 in Davies and Rasheed 2016). Unfortunately, no comparison is made to the GBR historical baseline from 1987 (Coles *et al.* 1992; Coles*, et al.* 2001a). Although the authors report climatic condition in 2015 were more favourable for seagrass growth and expansion, meadow abundances (visually estimated from helicopter or boat based free diving surveys) declined by more than 20 per cent overall compared to the previous year, with several meadows declining >80 per cent in biomass (Davies and Rasheed 2016). Most declines in abundance were reported from monitoring meadows at Magnetic Island and Cape Cleveland.

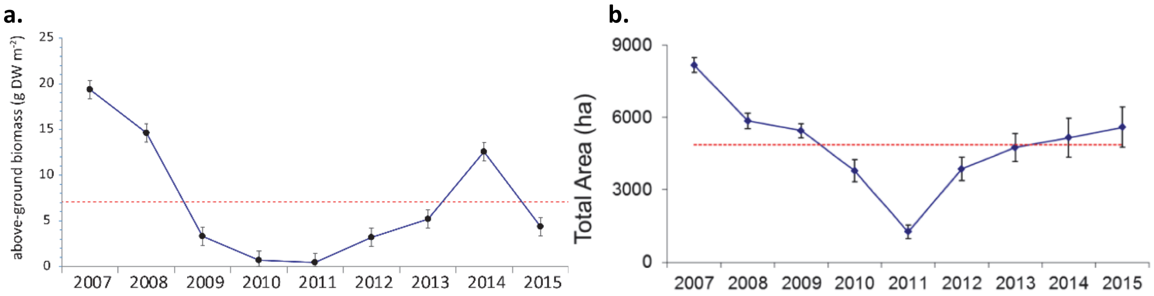

Figure 72. *Change in visually estimated above-ground biomass (a.) and total extent (b.) of all monitoring meadows combined in Port of Townsville from 2007 – 2015 (fromDavies and Rasheed 2016; a. reproduced from Appendix 2 values). Error bars are SE for g DW m^{-2} and "R" reliability estimate for ha. Dashed line indicates long-term average.*

In the southern part of the Burdekin NRM region, the findings from annual monitoring for the North Queensland Bulk Ports Corporation in the Port of Abbot Point remain less clear, as discerning seagrass state at the coastal and subtidal locations is challenged by the extremely dynamic nature of the meadows. The Port is positioned in a highly weather (e.g. wind and wave action) exposed area which place substantial environmental pressures on the seagrass and benthic communities (Rasheed *et al.* 2005a). The dynamic deeper water seagrass continued to increase in abundance (visually estimated from boat based free diving and CCTV surveys) in late 2015 following the impacts of Tropical Cyclone Oswald (January 2013) (McKenna *et al.* 2016b) (Figure 73). During the recovery phase, the deepwater sites were dominated by the structurally smaller *Halophila* species, however during 2015 the sites have returned to their pre-disturbed state being dominated by the structurally larger *Halophila spinulosa*. In the coastal meadows, the variable, isolated to aggregated patches of seagrass, continue to be dominated by colonising *Halophila* species, rather than *Zostera muelleri* and *Halodule uninervis*. The authors attribute the slow recovery to a lack of seed banks (data not presented) coupled with the high reliance on asexual reproduction, however as the location is highly disturbed by weather and waves, a closer examination of the environmental pressures is warranted. Nevertheless, in 2015 the seagrass abundance and distribution at all inshore monitoring meadows was near to, or above, long-term averages (McKenna*, et al.* 2016b).

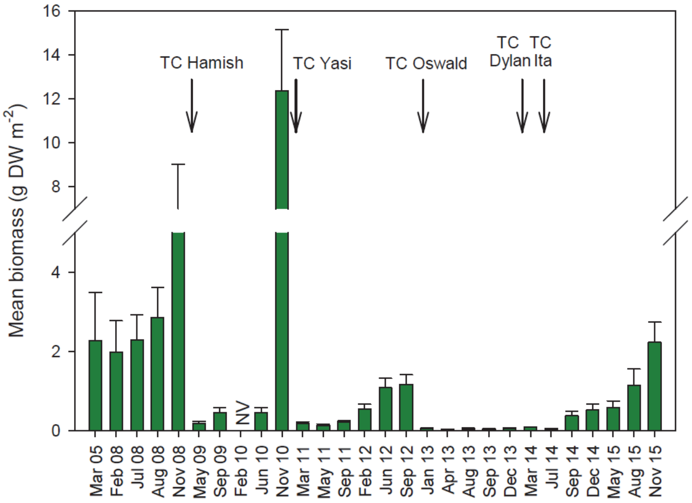

Figure 73. *Change in visually estimated above-ground biomass at offshore monitoring sites adjacent to Abbot Point from 2005 – 2015 (from McKenna, et al. 2016b; a. reproduced from Appendix 2 values). Error bars are SE for g DW m^2.*

Seagrass reproductive status

Reproductive effort in Burdekin region meadows had been on an increasing trajectory but the reproductive score declined to low in 2014-15, and increased to moderate again in 2015-16. Reproductive effort has increased at coastal sites to within range of historical records as seed banks continue to build and are the largest among all sites in the GBR. At reef intertidal sites, reproductive effort has remained low in 2015-16, however a seed bank is gradually building. At reef subtidal sites, reproductive effort and seed bank density are highly variable but the seed bank has been exceeding historical records (from 2011 onwards) on a seasonal basis (Figure 74).

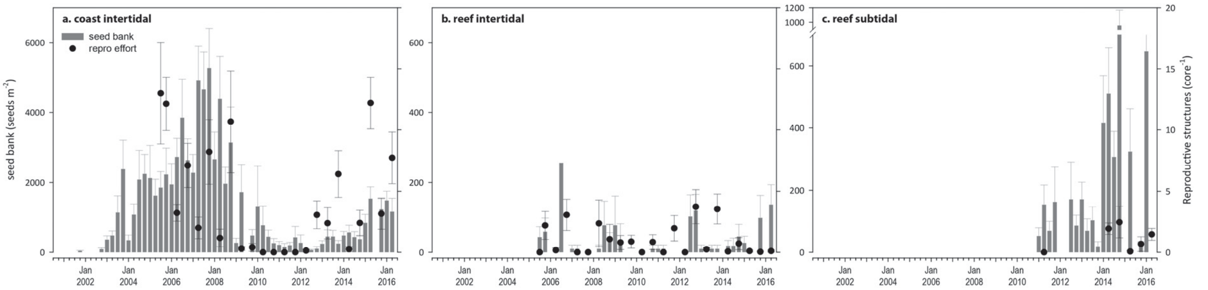

Figure 74. *Seed bank and late dry season reproductive effort at inshore intertidal coast and reef and subtidal reef habitats in the Burdekin region. Seed bank presented as the total number of seeds per m^2 sediment surface (bars ±SE), and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled) (dots ±SE). NB: Y-axis scale for seed banks differs between habitats.*

4.4.4 Indicators of environmental condition

Seagrass tissue nutrients

Seagrass leaf tissue molar C:N ratios continued to reduce in 2015-16 after increases from 2011-2013 at reef sites and remained relatively stable at coastal sites (Figure 75). All sites were around the threshold value (C:N <20) that indicates light limitation/reduced carbon incorporation relative to N availability, except at coastal sites where high turbidity (primary water, Table 11) and low light conditions prevail the C:N ratio was below the threshold (15.6), and even lower at the Townsville sites (14.1) (Figure 64). However, an increase in N:P at all sites in the past two years also suggest that increasing N may also be contributing to the falling C:N ratios (Figure 76); however these N:P ratios suggest balanced nutrient supply for seagrasses.

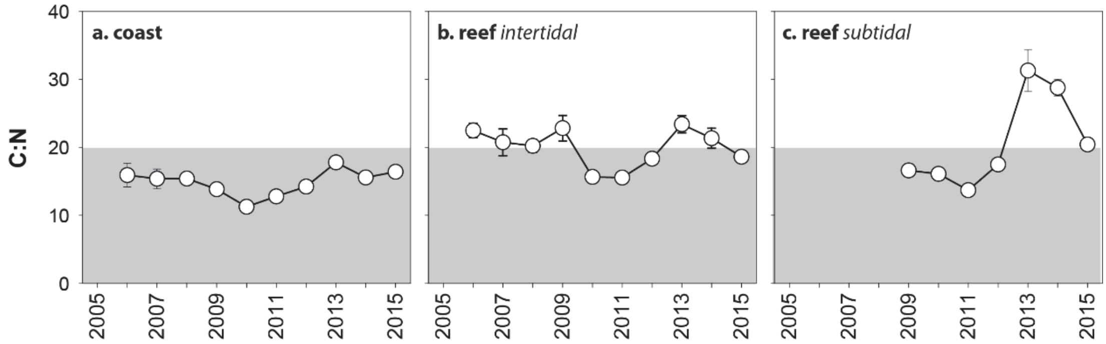

Figure 75. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each inshore habitat in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line indicate reduced light availability and/or N enrichment.*

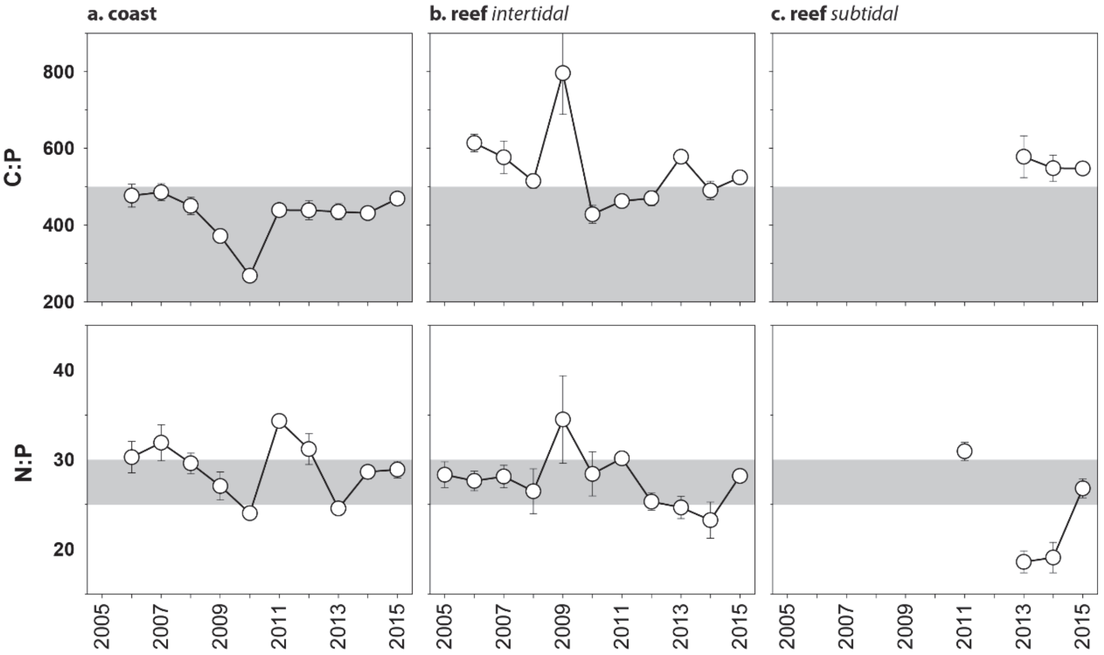

Figure 76. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at each inshore intertidal habitat in the Burdekin region each year (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues. N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Seagrass meadow sediments

The proportion of mud at Jerona (Barratta Creek) coastal habitat was much higher than Townsville sites (Bushland Beach and Shelley Beach) and has remained well above the GBR long-term average. Townsville sites were dominated by fine sediments, although the proportion of mud has declined post 2011. Conversely, reef habitats which were dominated by coarser sediment prior to 2009-10, having since gradually increased in composition of fine sand and mud. More fine sediments were present at the Cockle Bay than the Picnic Bay reef habitats meadows.

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades are generally higher in the wet- than the dry-season as was observed in 2015-16, except at reef subtidal sites where they remained elevated relative to historical records in both seasons (Figure 77; Appendix 2, Figure 195). Epiphyte cover at intertidal reef habitats remained elevated in the wet-season, after reaching slightly lower levels in the dry-season (Figure 77c; Appendix 2). Epiphyte cover at the Townsville coastal sites (BB, SB) were generally low in 2015-16, but at Bowling Green Bay, large seasonal variation in epiphytes, reaching over 90 per cent cover drove the increases observed in the wet-season. Macroalgae cover remained stable at coastal sites, but elevated at reef intertidal sites in the dry-season, and reef subtidal sites in both seasons. Both epiphytes and macroalgae cover can increase following nutrient enrichment (Cabaço *et al.* 2013; Nelson 2017), as appears to have occurred at the Burdekin seagrass sites in 2015-16; however, due to complex ecological and biological factors (e.g. grazing Heck and Valentine 2006), their abundance may not necessarily correlate to nutrient loading.

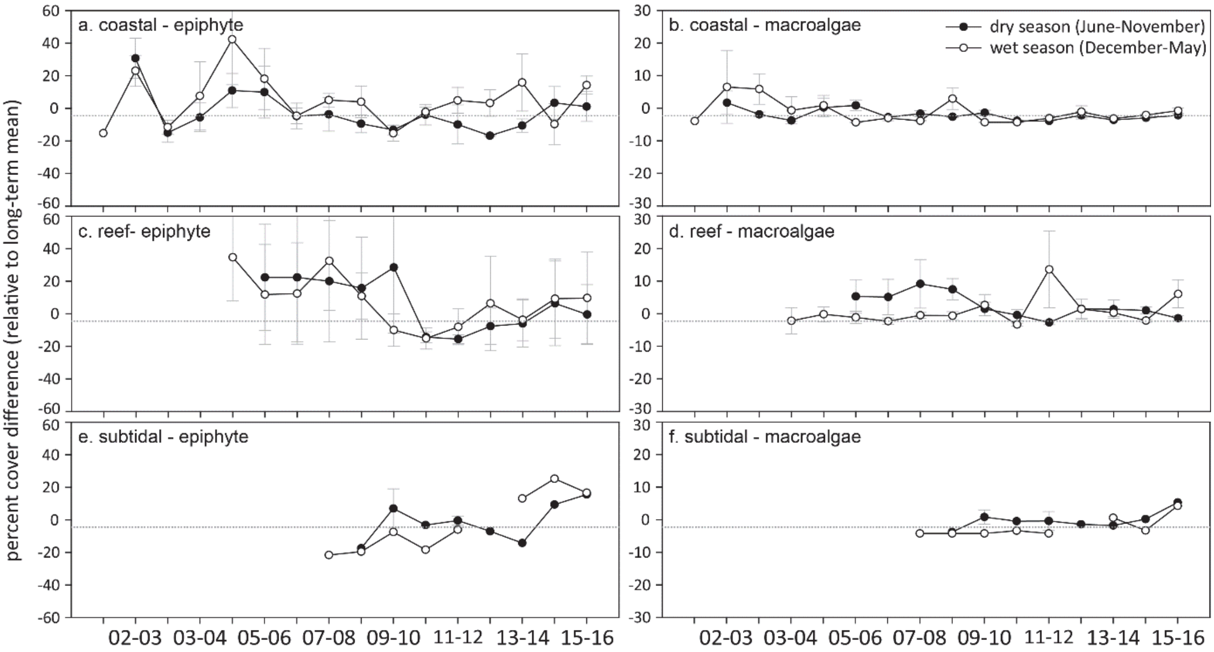

Figure 77. *Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term GBR average for each inshore seagrass habitat in the Burdekin region (sites pooled, ±SE).*

4.4.5 Report card for inshore seagrass status

In the 2015-16 monitoring period, the seagrass index for the Burdekin region was again lower than the previous period. The decrease is a consequence of reduced reproductive effort and leaf tissue nutrient in the intertidal reef habitats as well as reduced abundances across all habitats.

Table 23. *Long-term report card scores for seagrass abundance, reproductive and leaf tissue nutrient status for each habitat in the Burdekin region: June 2015 – May 2016. Values are indexed scores scaled from 0-100; 🟩 = very good (81-100), 🟩 = good (61 - 80), 🟨 = moderate (41 - 60), 🟧 = poor (21 - 40), 🟥 = very poor (0 - 20). NB: Scores are unitless.*

Indicator	**Habitat**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**
Abundance	coastal intertidal	88	31	34	25	11	6	5	29	44	49	47
	reef intertidal	59	59	75	31	6	9	25	41	50	56	38
	reef subtidal			100	50	8	0	8	31	75	100	88
Reproductive effort	coastal intertidal	50	25	25	38	0	0	0	13	19	6	38
	reef intertidal	50	50	0	25	25	25	38	75	63	13	0
	reef subtidal									100	100	100
Leaf tissue nutrients	coastal intertidal		30	27	27	19	6	14	26	39	28	32
	reef intertidal		62	54	51	64	28	28	42	69	57	43
	reef subtidal					39	30		37	100	100	100
Seagrass Index		**62**	**43**	**38**	**34**	**20**	**13**	**18**	**37**	**60**	**53**	**51**

4.5 Mackay Whitsunday

4.5.1 2015-16 Summary

The Mackay Whitsunday region is characterised by episodic flows from adjacent catchments, as well as urban and marina development, tourism and is also vulnerable to temperature extremes in shallow habitats. As in 2013-15, climatic conditions in 2015-16 were more conducive to seagrass growth than in previous years. There was low rainfall and below average river flows; however, above-average wind conditions provide risk of exposure to re-suspension of sediments and nutrients. Most meadows were exposed to primary or secondary water for the majority of the time during December to April and within canopy daily light was below average. Above average seawater temperatures exposed meadows to warm conditions throughout the year, with a record number of days exceeding 35°C, and extreme temperatures (>40°C) recorded on 2 days.

During 2014-15 seagrass abundance continued to increase at all sites except Hamilton Island increasing the score to **moderate** after an increase to poor in the previous year, compared to very poor in 2013-14. Meadows extent remained high and stable at estuarine and coastal sites, and increased at reef sites. The proportion of opportunistic species remained stable and high at coastal and estuarine sites, while the reef sites, which are still in a phase of recovery, maintained a high proportion of colonising species.

Seagrass reproductive effort continued to recover at coastal and estuarine sites but remained **poor** due to very low reproduction at reef sites. Despite this, there has been ongoing increase in seed bank density (at all except reef sites), which enables meadows to recover from disturbances and contributes to an improvement in overall resilience. Leaf tissue C:N ratios also continued to increase to near 20 but declined at reef sites and were classed as **poor** overall. This, together with an increase in N:P indicate a surplus in availability of N, relative to demand from photosynthetic C incorporation and growth.

Mackay Whitsunday regional seagrass state improved but remained **poor** in 2015-16 (Figure 78). While the condition and resilience of these meadows show considerable signs of improvement, they remain highly vulnerable to further disturbances, particularly at reef sites.

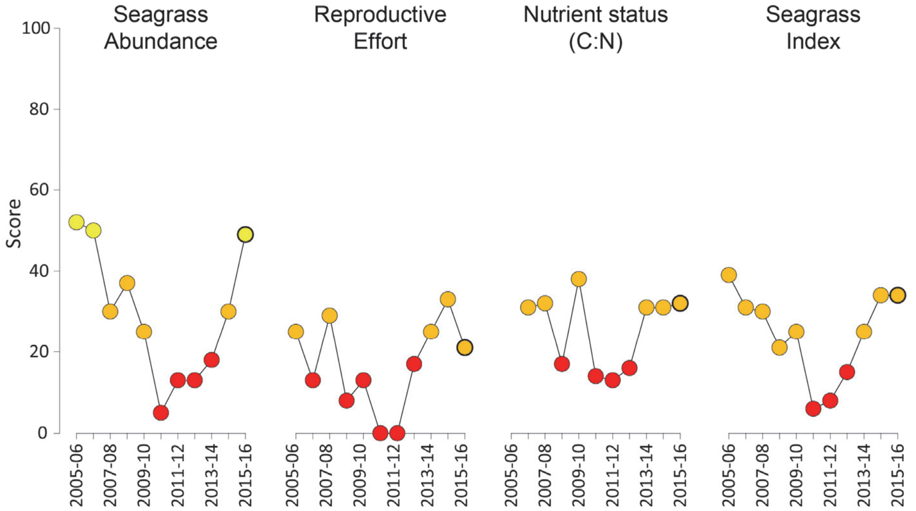

Figure 78. *Report card of seagrass status indicators and index for the Mackay Whitsunday NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20).*

4.5.2 Climate and environmental pressures

Rainfall and river discharge was considerably lower than the long-term average in 2015-16 (Table 24). However wind speeds were well above average, which increases risk of exposure to resuspension of sediments and nutrients delivered in previous flows (Fabricius, *et al.* 2012). Exposed to turbid primary water or green secondary water was lower than in 2014-15 being 82 per cent to 100 per cent ($f_{(P+S)}$ = 1.00) of the wet season (Figure 79, Table 25), compared to 100 per cent in the previous year. The exception was at Hamilton Island (HM), where exposure was lower ($f_{(P+S)}$ = 0.55).

Table 24. *Summary of environmental conditions at monitoring sites in Mackay Whitsunday region in 2014-15 compared to the long-term average (long-term range indicated for each data set).*

	Long-term average	**2015-16**
Rainfall (1910-2016)	1649 mm	1277 mm
River discharge (1970-2016)	3,514,304 L yr^{-1}	2,030,444 L yr^{-1}
Turbid water exposure $f_{(P+S)}$ (2006-2016)	*not available*	86 per cent
Daytime tidal exposure (1999-2016)	50.53 hrs yr^{-1}	57.33 hrs yr^{-1}
Wind >25km hr^{-1}(1998-2016)	119.9 days yr^{-1}	178.7 days yr^{-1}
Within canopy temperature (2003-2016)	25.4°C *(42.7°C)*	25.7°C *(40.8°C)*
Within canopy light (2012-2016)	14.1 mol m^{-2} d^{-1}	14.5 mol m^{-2} d^{-1}

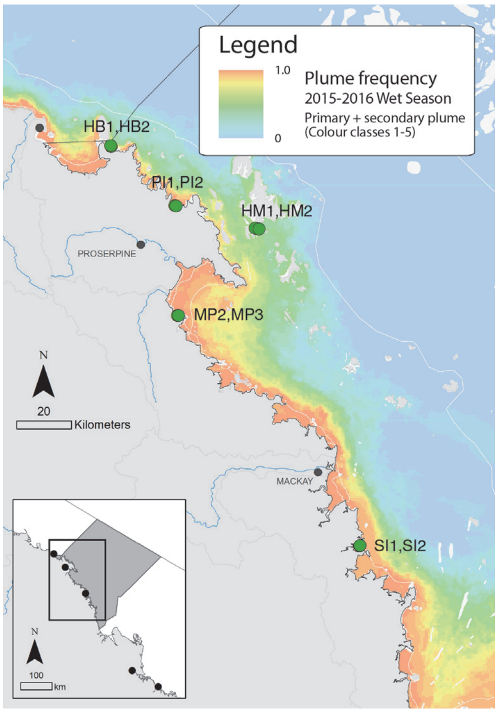

Figure 79. *Frequency of exposure to turbid water (colour classes 1-5) in the Mackay Whitsunday NRM region, wet season (December 2015 – April 2016) composite. Frequency calculated as number of weeks in wet season exposed to primary or secondary water (colour classes 1 – 5). Each colour class category is described by mean water quality values for TSS, CDOM, chlorophyll a and K_d (PAR) (Devlin, et al. 2015;Waterhouse, et al. 2017). For site details, see Tables 3 & 4.*

Table 25. *Water type at each location in the Mackay Whitsunday region derived from MODIS true colour images as colour classes of turbid primary water (class 1 – 4, red/brown), nutrient/chlorophyll-enriched secondary water (class 5, green), and tertiary (some freshwater/CDOM influence) or no plume influence (class 6 and 7 respectively, blue), for 22 weeks from December 2015 – April 2016. Also shown, median wet season colour class (Med), frequency of primary water as $f_{(P)}$, the frequency of secondary water as $f_{(S)}$, and the frequency of primary or secondary as $f_{(P+S)}$. *denotes data obtained from adjacent pixel.*

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	**Med**	$f_{(P)}$	$f_{(S)}$	$f_{(P+S)}$
HB1*	5	6	5	5	5	5	6	5	5	5	5	5	5	6	5	5	5	5	5	5	5	6	**5**	**0.00**	**0.82**	**0.82**
HM1	6	6	6	6	6	6	6	5	5	6	5	5	5	6	5	5	5	5	5	5	5	6	**5**	**0.00**	**0.55**	**0.55**
MP2*	2	4	1	2	4	2	5	2	4	4	4	2	4	5	4	4	5	2	2	2	2	4	**4**	**0.86**	**0.14**	**1.00**
PI2	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	**5**	**0.05**	**0.95**	**1.00**
SI1*	3	2	4	2	5	3	5	1	5	5	4	2	4	6	4	3	4	2	4	2	3	5	**4**	**0.73**	**0.23**	**0.95**

Daily light (I_d) at Mackay Whitsunday sites has been monitored since 2009 for some locations. In 2015-16 (14.5 mol m^{-2} d^{-1}), I_d was slightly higher than the long-term average (14.1 mol m^{-2} d^{-1}). There was low data retrieval from two out of the three sites (HM and SI), but at Midge Point where light data is available for every day in the reporting year I_d in 2015-16 (15.5 mol m^{-2} d^{-1}) was slightly higher than average (15.1 mol m^{-2} d^{-1}) (Figure 80).

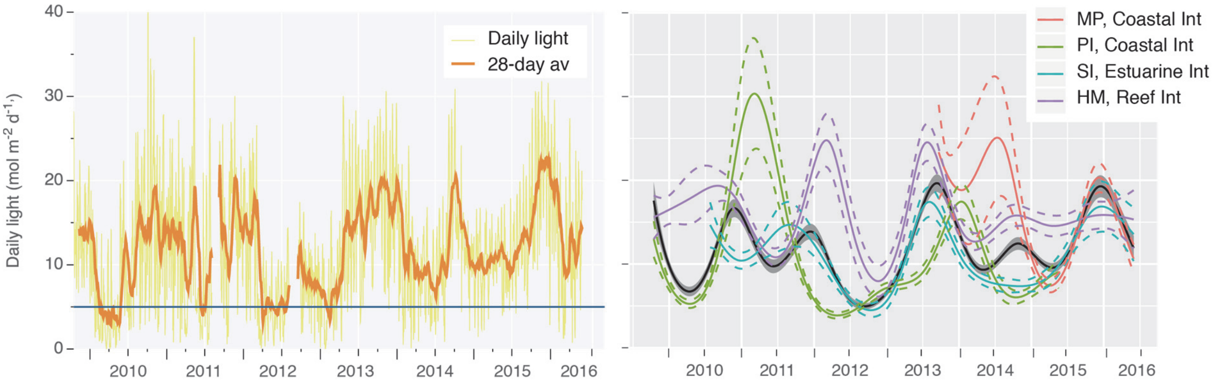

Figure 80 . *Mean daily light at Mackay Whitsunday habitats with 28-d rolling average from 2009 to 2016 (left) and GAM plots (right) with the black line showing mean trend for all sites (±95 per cent confidence interval in grey shade) and coloured lines (with CI's) showing the trend for each site. Results of statistical analysis (GAM) and site-specific graphs (site-level daily light data plus 28-d rolling average) are shown in Appendix 4.*

Water temperature was very warm in the seagrass habitats in the Mackay Whitsunday region in 2015-16 with a largest number of days above 35°C (77 days) since records began in 2003 (Figure 81), and frequent warm deviation from the baseline being sustained from November through to March (it must be noted that the greater number of days since 2013 are also a consequence of the new sites at Midge Point). In addition, there were 9 days that were 35-38°C and 2 days that were >40°C. These temperatures can cause significant photoinhibition and acute temperature stress (Campbell*, et al.* 2006a), and prolonged exposure to warm water can reduce growth in some species such as *Zostera muelleri* (Collier *et al.* 2011b; Collier *et al.* 2016b).

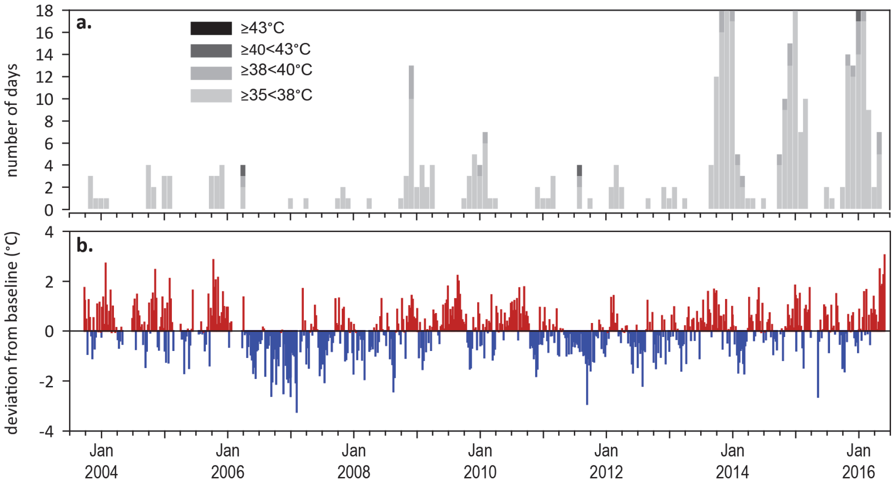

Figure 81. *Inshore sea temperatures within each intertidal seagrass habitat in the Mackay Whitsunday region, September 2003 - May 2016: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006a); b) deviations from 11-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

4.5.3 Indicators of seagrass condition

Five seagrass habitat types were assessed across the Mackay Whitsunday region in 2015-16, with data from 14 sites (Table 26).

Table 26. *List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Mackay Whitsunday NRM region. † drop camera sampling (QPWS), *Seagrass-Watch. For site details see Table 3 and Table 4.*

Habitat	**Site**		**abundance**	**composition**	**distribution**	**Reproductive effort**	**seed banks**	**Leaf tissue nutrients**	**Meadow sediments**	**Epiphytes**	**Macroalgae**
estuary intertidal	SI1	Sarina Inlet	■	■	■	■	■	■	■	■	■
	SI2	Sarina Inlet	■	■	■	■	■	■	■	■	■
coastal intertidal	MP2	Midge Point	■	■	■	■	■	■	■	■	■
	MP3	Midge Point	■	■	■	■	■	■	■	■	■
	PI2*	Pioneer Bay	■	■			■		■	■	■
	PI3*	Pioneer Bay	■	■			■		■	■	■
coastal subtidal	NB1†	Newry Bay	■	■							■
	NB2†	Newry Bay	■	■							■
reef intertidal	HM1	Hamilton Island	■	■	■	■	■	■	■	■	■
	HM2	Hamilton Island	■	■	■	■	■	■	■	■	■
	HB1*	Hydeaway Bay	■	■			■		■	■	■
	HB2*	Hydeaway Bay	■	■			■		■	■	■
reef subtidal	TO1†	Tongue Bay	■	■							■
	TO2†	Tongue Bay	■	■							■

Seagrass abundance, composition and distribution

Seagrass abundance continued to increase at all sites except at Hamilton Island where it remained low and stable in 2015-16 (Figure 74). Abundance is almost with range of historical peaks. There was an overall increase in the seagrass abundance score in 2015-16 from poor to moderate; a rapid rise after being very poor in 2013-14 (Figure 73).

An examination of the long term trends across the Mackay Whitsunday NRM region suggests seagrass abundance (per cent cover) continued to improve in 2015-16 from losses experienced in 2011 but remains below the pre-2009 levels (Figure 86).

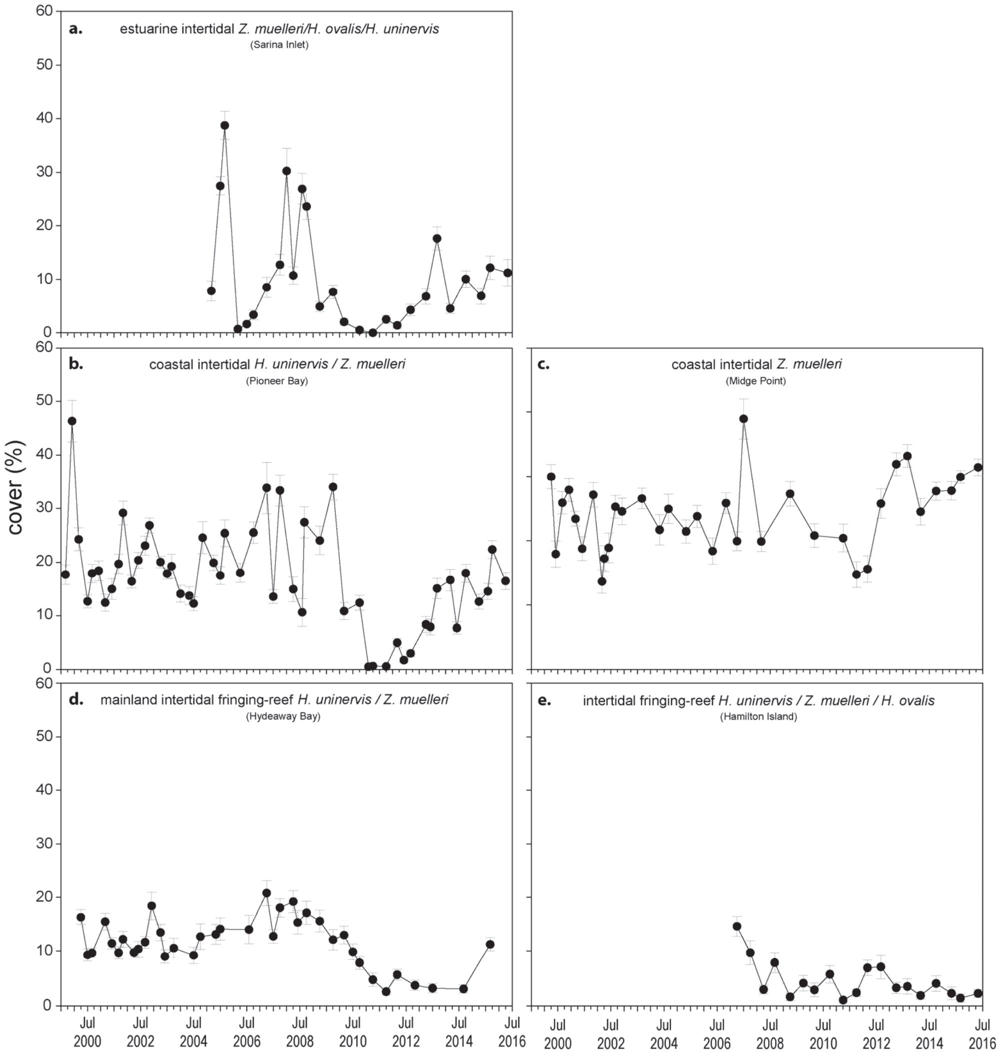

Figure 82. *Changes in seagrass abundance (per cent cover ±Standard Error) at inshore intertidal habitats in the Mackay Whitsunday region, 1999 - 2016: a). estuarine, b). coastal, and c). reef.*

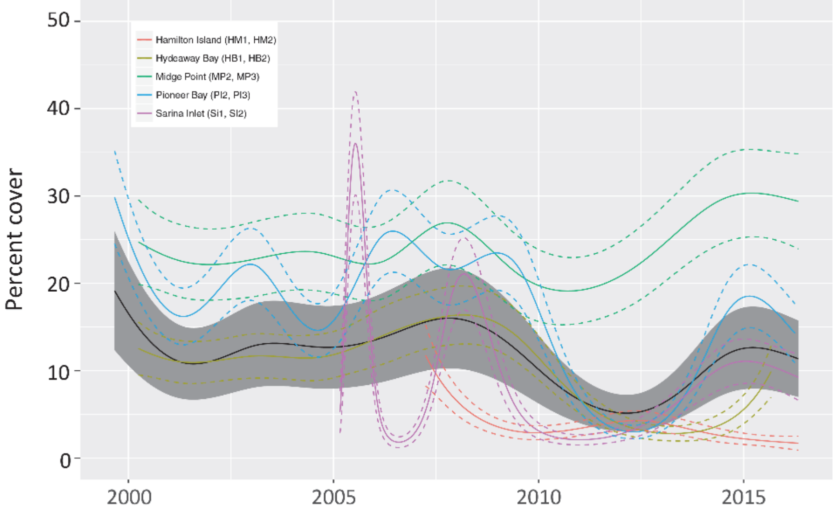

Figure 83. *Temporal trends in seagrass abundance for each location in the Mackay Whitsunday region represented by a GAM plot. Regional trend (all habitats pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals.*

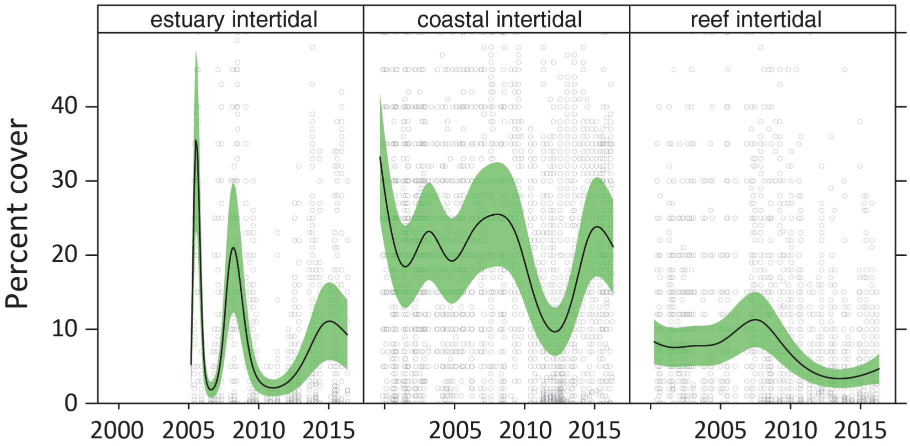

Figure 84. *Temporal trends in seagrass abundance for each habitat in the Mackay Whitsunday region represented by GAM plots. Trends (locations pooled) represented by black line with green shaded area defining 95 per cent confidence intervals, and quadrat data displayed as grey circles.*

The most common seagrass species across all habitats in the Mackay Whitsunday NRM region were *Halodule uninervis* and *Zostera muelleri*, mixed with the colonising species *Halophila ovalis*.

Colonising species have recently dominated in coastal meadows across the Mackay Whitsunday NRM following the extreme weather in 2011. As in other regions, colonising species have continued to represent a low proportion of the species diversity in favour of opportunistic foundational species (*H. uninervis* and *Z. muelleri*) which now dominate (Figure 85, Appendix 4). The dominance of the foundational (opportunistic and persistent) species in meadows across all habitats in the Mackay Whitsunday NRM region continued to improve over the last 2 monitoring periods, suggesting meadows may have an improved ecosystem resistance to tolerate disturbances (Figure 85). In contrast, in reef habitats (Hamilton Island), colonising species been steadily increasing, but declined slightly in 2015-16.

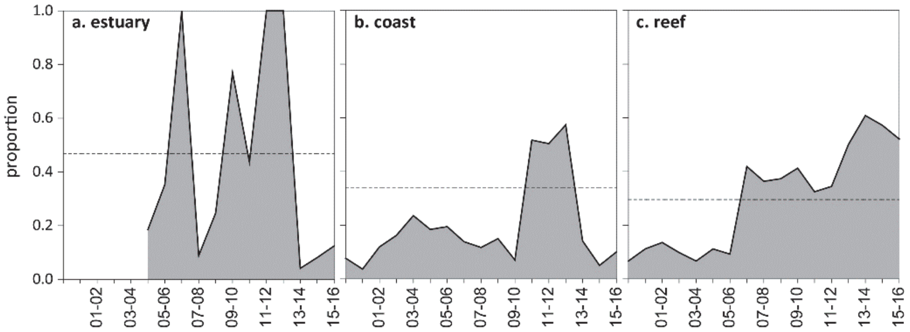

Figure 85. *Proportion of seagrass abundance composed of colonising species at inshore intertidal habitats in the Mackay Whitsunday region, 1999 - 2016. Grey area represents GBR long-term average proportion of colonising species for each habitat type*.

Seagrass meadow edge mapping was conducted within all monitoring sites in October 2015 and April 2016 to determine if changes in abundance were a consequence of the meadow edges changing and to indicate if plants were allocating resources to colonisation (asexual reproduction) (Appendix 4). Over the past 12 months, reef meadows have increased in extent, which provides an indication that reef meadows might be in recovery despite other indicators declining, while coastal and estuarine meadows have remained relatively stable (Figure 86).

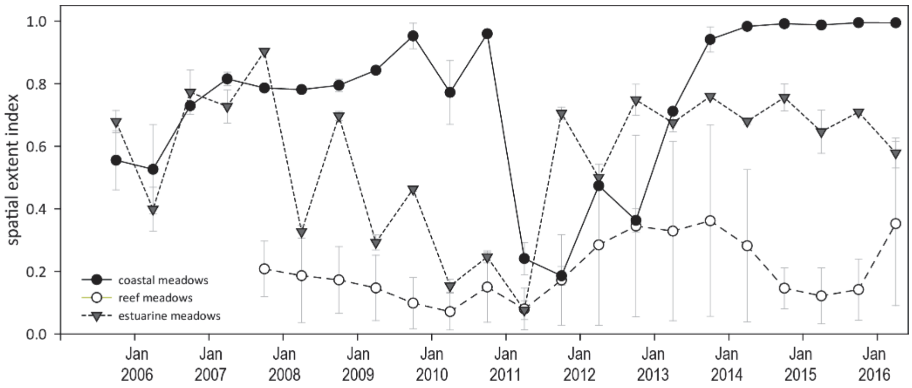

Figure 86. *Change in spatial extent of seagrass meadows within monitoring sites for each inshore intertidal habitat and monitoring period across the Mackay Whitsunday NRM region.*

Apart from the MMP, seagrass monitoring within the Mackay Whitsunday NRM region is also conducted as part of the Queensland Ports Seagrass Monitoring Program (QPSMP) in places where cumulative anthropogenic impacts to seagrass are highest. Annual monitoring in October 2015 of five offshore monitoring areas between Mackay and Hay Point, an inshore region between Dudgeon Point and Hay Point, and two subtidal meadows at the Keswick Island group for North Queensland Bulk Ports reported an improvement relative to the previous years, with overall increases in biomass and area (McKenna *et al.* 2016a). The deepwater monitoring areas improved in abundance (Figure 87), however, it should be noted that there were less *Halophila* species present and the increase in above-ground biomass (visually estimated from boat based CCTV) was minor, with values ranging from 0.02 to 0.12 ±0.05 gDWm^{-2}; which equate to values below ~3 per cent total cover (Collier *et al.* 2016d). Similarly, the increase in area of the small inshore seagrass meadows of Dalrymple Bay (between Hay Point and Dudgeon Point) was only minor and not significant (i.e. estimates of reliability/mapping precision overlap between years). In the Keswick Island group, the monitoring meadows were similar in extent, however abundances were much lower in 2015 relative to 2014 (McKenna*, et al.* 2016a). The authors attribute the improved state of deep water seagrasses to favourable climate conditions (low rainfall; below average river flow), the declines at Dudgeon Point to increased exposure (higher temperatures and desiccation), and the declines at Keswick Island to biomass allocation for sexual reproduction (McKenna*, et al.* 2016a).

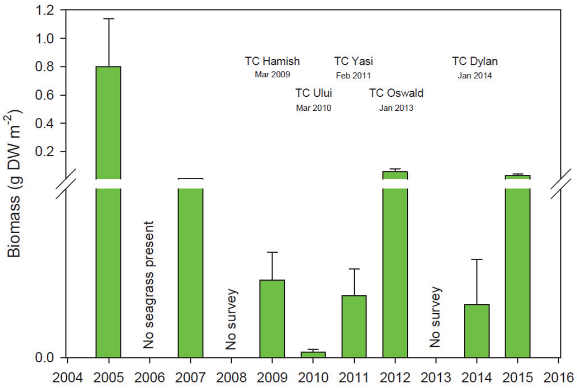

Figure 87. *Change in visually estimated above-ground biomass at Hay Point offshore monitoring sites from 2005 to 2015 (from McKenna, et al. 2016a). Error bars are SE for g DW m^{-2}.*

Seagrass reproductive status

Reproductive effort was highly variable and highly seasonal in the Mackay Whitsunday region, but increased in 2015-16 at coastal habitat, and was similar in estuarine habitats compared to 2014-15 (Figure 88). In contrast, at the reef sites, there was a large peak in 2013-14, which subsequently declined in 2014-15 and reproductive effort remained low in 2015-16. Banks of predominately *Halodule uninervis* and some *Zostera muelleri* seeds have varied greatly over the past decade, however, very few seeds have been found in reef habitat meadows (Figure 88). Seed banks increased considerably at coastal sites and were similar to the previous year at estuarine sites (Figure 88). The overall score for reproductive effort has decline and remains poor, mostly due to conditions at the reef habitat.

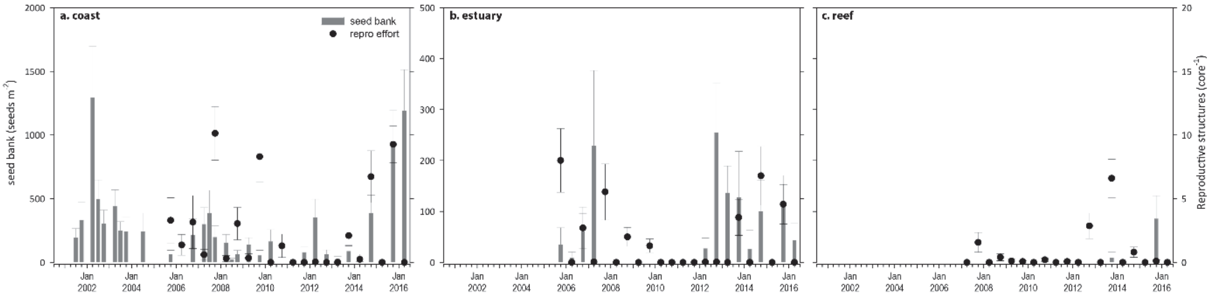

Figure 88. *Seed bank and late dry season reproductive effort at inshore intertidal coast, estuary, and reef habitats in the Mackay Whitsunday region, 2001 - 2016. Seed bank presented as the total number of seeds per m^2 sediment surface and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled). NB: Y-axis scale for seed banks differs between habitats.*

4.5.4 Indicators of environmental condition

Seagrass tissue nutrients

Seagrass leaf molar C:N ratios were similar to the previous year but slightly increased at coastal and estuarine sites and reduced at reef habitat. C:N remaining well below 20 (Figure 89) at reef habitat indicates a surplus of N relative to photosynthetic C incorporation. N:P ratios increased to at or near 30, which when coupled with the large P pool, (C:P <500), indicates surplus availability of N driving C:N (Figure 90). Across all habitats, the δ^{15}N values for the dominant species (*Zostera muelleri*) were >0 <2‰, suggesting the primary source of the elevated N was possibly influenced by fertiliser.

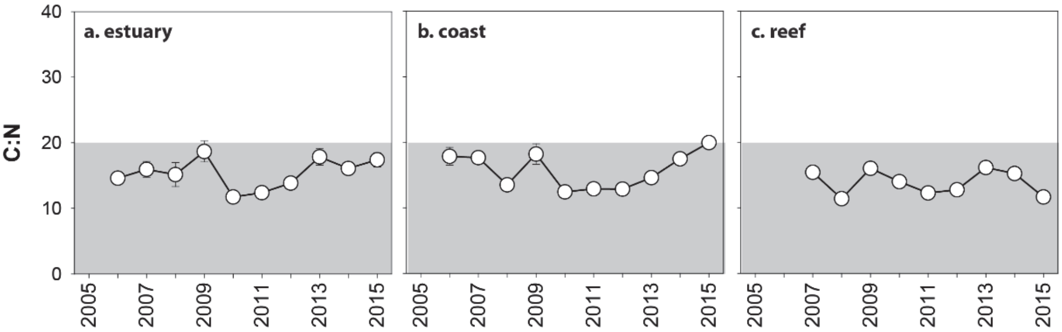

Figure 89. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at inshore intertidal habitats in the Mackay Whitsunday region, 2006 - 2015 (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

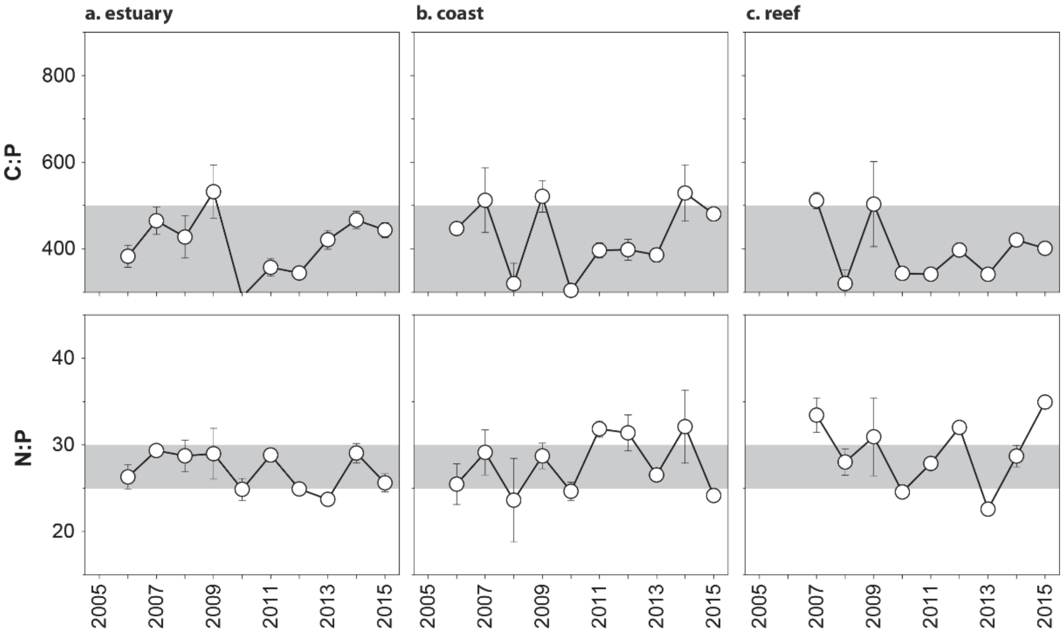

Figure 90. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at inshore intertidal habitats in the Mackay Whitsunday region, 2006 - 2015 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Seagrass meadow sediments

The proportion of fine grain sizes decreases in the sediments of the seagrass monitoring sites/meadows with distance from the coast/river mouths in the Mackay Whitsunday region. Estuarine sediments were composed of greater proportion of finer sediments, and in 2014-15 the proportion of mud was similar to the GBR long-term average with little change over the last 6 years. Coastal habitat meadows had less mud than estuarine habitats, and the meadows at Midge Point had a higher proportion of mud than those in Pioneer Bay. Sediments at Midge Point have remained stable relative to the GBR long-term average since 2007, however, at Pioneer Bay they have fluctuated greatly between sites and between years except in 2015-16, the proportion mud stayed relatively stable compared to 2014-15. Reef habitats were composed predominately of fine to medium sand, and in 2014 they contained a proportion of mud, but this was not detected in 2015-16.

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades increased in 2015-16 in estuarine habitat, and in reef habitat during the wet season. At coastal sites, epiphyte cover was consistent with the long-term trend with no seasonal difference apparent (Figure 91. In coastal habitats, epiphyte abundances had been higher at Pioneer Bay than Midge Point both in 2014-15 but epiphyte cover was comparable between the two sites in April 2016 (Figure 91; Appendix 2, Figure 198). Percentage cover of macroalgae remained unchanged and at or below the GBR long-term average for all habitats throughout 2015-16 (Appendix 4, Figure 198, Figure 199, Figure 200).

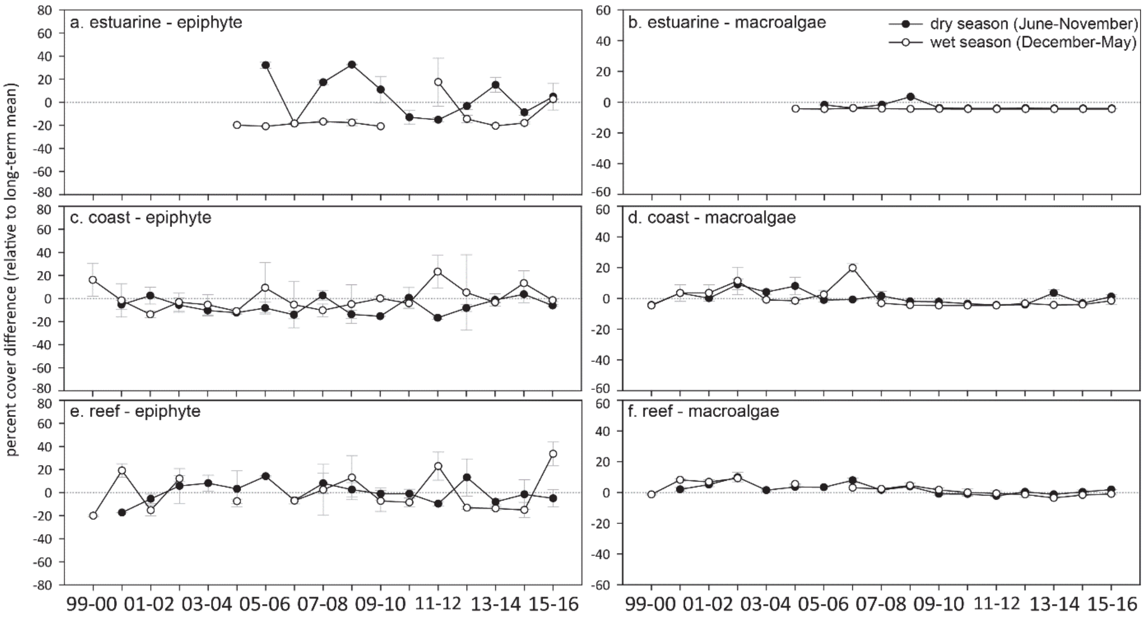

Figure 91. *Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal habitat in the Mackay Whitsunday region, 1999 - 2016 (sites pooled, ±SE).*

4.5.5 Report card for inshore seagrass status

In the 2015-16 monitoring period, the seagrass index for the Mackay Whitsunday region improved slightly above the previous period and was the highest since 2006-07. The improvement is a consequence of improved abundance and reproductive effort in coastal habitats, and improved tissue nutrients at coastal and estuarine habitats. This has provided an offset for declines in reproductive effort and tissue nutrients in reef habitat. Overall, the Mackay Whitsunday seagrass index has continued to improve since 2010-11 when it reached its lowest level since monitoring commenced.

Table 27. *Long-term report card scores for seagrass abundance, reproductive and leaf tissue nutrient status for each habitat in the Mackay Whitsunday region: June 2015 – May 2016. Values are indexed scores scaled from 0-100; 🟩 = very good (81-100), 🟩 = good (61 - 80), 🟨 = moderate (41 - 60), 🟧 = poor (21 - 40), 🟥 = very poor (0 - 20). NB: Scores are unitless.*

Indicator	Habitat	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Abundance	estuarine intertidal	40	25	20	25	6	0	13	25	13	13	13
	coastal intertidal	63	88	54	63	63	8	13	13	33	67	83
	coastal subtidal											63
	reef intertidal		25	6	13	6	6	13	0	0	3	38
	reef subtidal											25
Reproductive effort	estuarine intertidal	50	13	25	0	0	0	0	0	25	50	25
	coastal intertidal	0	13	38	13	38	0	0	0	0	25	38
	reef intertidal			25	13	0	0	0	50	50	25	0
Leaf tissue nutrients	estuarine intertidal		23	30	26	43	9	12	19	39	30	37
	coastal intertidal		39	38	18	41	12	14	14	23	37	50
	reef intertidal			27	7	30	20	11	14	31	26	8
Seagrass Index		**39**	**31**	**30**	**21**	**25**	**6**	**8**	**15**	**25**	**32**	**34**

4.6 Fitzroy

4.6.1 2015-16 Summary

The Fitzroy region has the largest catchment area draining into the GBR, and the inshore seagrass meadows are mainly located on the large shallow sand/mud banks in sheltered areas of the region's estuaries and coasts, or on the fringing reef flat habitats of offshore islands. The seagrass meadows are primarily structured by infrequent plumes of sediment-laden floodwaters, high turbidity, desiccation and elevated temperatures.

In 2015-16 climatic conditions in the region were generally more conducive to seagrass growth, but very warm conditions may have had a chronic effect on meadow condition. 2015-16 was slightly drier than the long term average at coastal monitoring stations and river discharge was again above the long-term average, which is in contrast to other regions of the GBR. Seagrass meadows were exposed to primary or secondary water for 100 per cent of wet season weeks (November 2015 to April 2016) at coast and estuarine sites, and to secondary water for 76 per cent of weeks at the reef sites. The most distinguishing environmental extremes in 2015-16 were the thermal anomalies, whereby meadows were exposed to a record number of warm water (>35°C) days (63 d). This was the fourth year in a row of above-average temperatures which could have a chronic impact on seagrass condition. However, there were no extreme temperatures (>40°C) that could cause photoinhibition and burning. Above median annual daytime tidal exposure is likely to have contributed to the warm conditions.

Trends in seagrass abundance varied across habitats in 2015-16, with an overall increase at coastal sites, and a decrease at estuarine habitats and also at reef habitats, which remain at very low abundance. The regional seagrass abundance score was unchanged and remained **poor**. However, seagrass extent remained stable in all habitats including at reef habitat which expanded substantially in the previous year; however, reef habitats increased in the proportion of colonising species at the expense of opportunistic foundation species. Reproductive effort increased at estuarine sites albeit with a very poor rating, while the seed bank remained stable. However, reproductive effort decreased coastal sites and was again absent at the reef sites. Despite this, coastal sites maintained a moderate seed bank; however, poor reproductive effort may be a precursor to seed bank limitation in the near future.

Seagrass leaf tissue nutrient concentrations and isotopic signatures across all habitats indicated a surplus in the uptake of N relative to the uptake and incorporation of carbon (i.e. C:N declined and was <20) at coastal and reef sites; suggesting either reduced light availability or elevated N. In contrast, C:N increased slightly at estuarine sites. Increasing N:P at coast and reef sites indicated that the change in C:N can be attributed to nitrogen enrichment. Leaf tissue δ^{15}N values at coastal and estuarine habitats suggests either fertiliser and/or sewage influence in the primary source of N: possibly explaining the slight increase in epiphyte loads in estuary habitats.

Seagrass across the region remain in the early stages of recovering from multiple years of climate related impacts which are more recent than in other regions, which has likely left a legacy of reduced resilience to impacts until they have further recovered. Overall, the Fitzroy regional seagrass state increased slightly from a very poor rating to **poor** in 2015-16 (Figure 92).

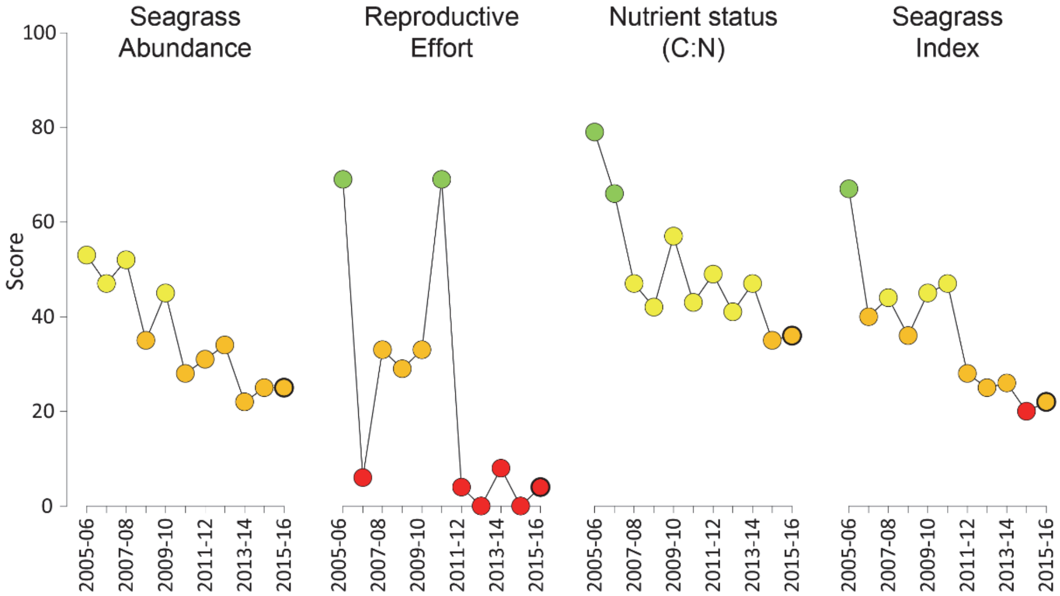

Figure 92. *Report card of seagrass status indicators and index for the Fitzroy NRM region (averages across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

4.6.2 Climate and environmental pressures

In the Fitzroy region, rainfall at coastal locations was lower than the long-term average (Table 28), but unlike other regions in the GBR, river discharge in 2015-16 was larger than the long-term average. Water quality effects, however, were not limited to this event, as seagrass sites in the Fitzroy region were exposed to mostly primary water for 100 per cent ($f_{(P+S)}$=1.00) of the wet season (November 2015 – April 2016), except at Great Keppel Island where exposure to secondary water only in the wet season was for 76 per cent (Figure 93, Table 29). This level of exposure is slightly lower than in 2014-14 which was 100 per cent at all sites, with a greater frequency of the more turbid colour classes (1-2).

Table 28. *Summary of environmental conditions at monitoring sites in the Fitzroy region in 2015-16 compared to the long-term average (long-term range indicated for each data set).*

	Long-term average	**2015-16**
Rainfall (1957-2016)	947.6 mm	645.3 mm
River discharge (1970-2016)	4,376,164 L yr^{-1}	5,799,371 L yr^{-1}
Turbid water exposure (2006-2016)	*unavailable*	95 per cent
Daytime tidal exposure (2002-2016)	105.32 hrs yr^{-1}	128.83 hrs yr^{-1}
Wind (1998-2016)	80.7 days yr^{-1}	83.3 days yr^{-1}
Within canopy temperature (2006-2016)	23.8°C *(41°C)*	24.4°C *(39.5°C)*
Within canopy light (2012-2016)	14.7 mol m^{-2} d^{-1}	15.2 mol m^{-2} d^{-1}

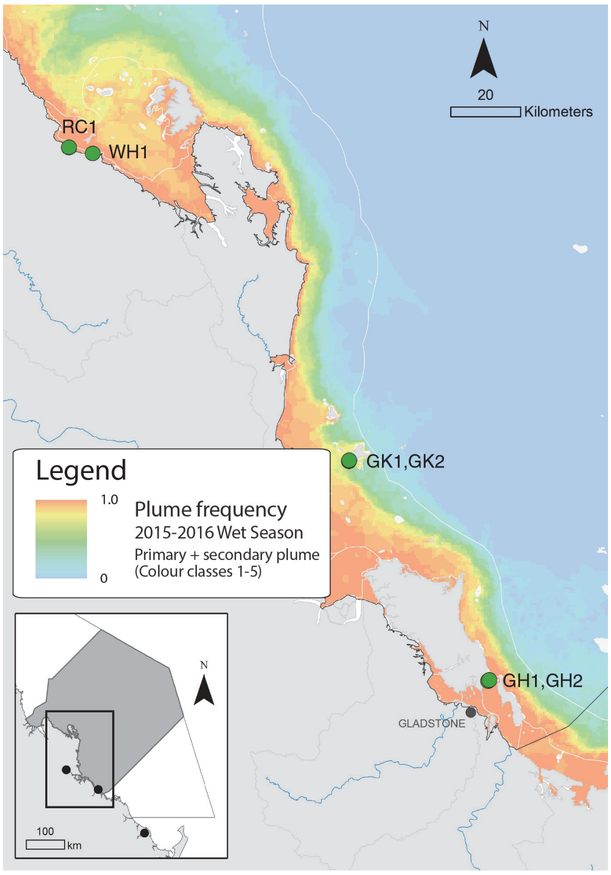

Figure 93. *Frequency of exposure to turbid water (colour classes 1-5) in the Fitzroy NRM, wet season (22 weeks from December 2015 – April 2016) composite. Frequency calculated as number of weeks in wet season exposed to primary or secondary water (colour classes 1 – 5). Each colour class category is described by mean water quality values for TSS, CDOM, chlorophyll a and K_d (PAR) (Devlin, et al. 2015;Waterhouse, et al. 2017). For site details, see Tables 3 & 4.*

Table 29. *Water type at each site in the Fitzroy region derived from MODIS true colour imagesas colour classes of turbid primary water (class 1 – 4, red/brown), nutrient/chlorophyll-enriched secondary water (class 5, green), and tertiary (some freshwater/CDOM influence) or no plume influence (class 6 and 7 respectively, blue), for 22 weeks from December 2015 – April 2016. Also shown, median wet season colour class (Med), frequency of primary water as $f_{(P)}$, the frequency of secondary water as $f_{(S)}$, and the frequency of primary or secondary as $f_{(P+S)}$.*

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	**Med**	$f_{(P)}$	$f_{(S)}$	$f_{(P+S)}$
GH1	4	4	4	2	4	3	4	2	5	5	3	4	3		3	4	4	4	3	5	4	5	**4**	**0.81**	**0.19**	**1.00**
GK1	5	5	5	5	5	5	5	5	5	6	5	4	5		5	5	5	6	5	6	6	6	**5**	**0.05**	**0.71**	**0.76**
RC1	1	2	4	1	2	2	5	2	3	3	4	2	4	4	2	2	4	2	2	2	2	4	**2**	**0.95**	**0.05**	**1.00**
WH1	1	2	4	1	3	2	5	2	2	2	4	2	4	2	2	2	4	1	2	1	2	5	**2**	**0.91**	**0.09**	**1.00**

Within canopy daily light (I_d), was slightly higher in 2015-16 than the long-term average for the region, although highly variable among habitats (Figure 94). Data retrieval has reduced at two of the three sites because they are now monitored only once per year thus there were only 27 per cent and 26 per cent of days with data in 2015-16 at RC and GKI and this is from the late dry immediately sampling when Id is higher. I_d in Gladstone Harbour (GH) where there is almost continuous data for the monitoring year (93 per cent days), I_d in 2015-16 (11.6 mol m^{-2} d^{-1}) was slightly higher than the long-term average (11.2 mol m^{-2} d^{-1}).

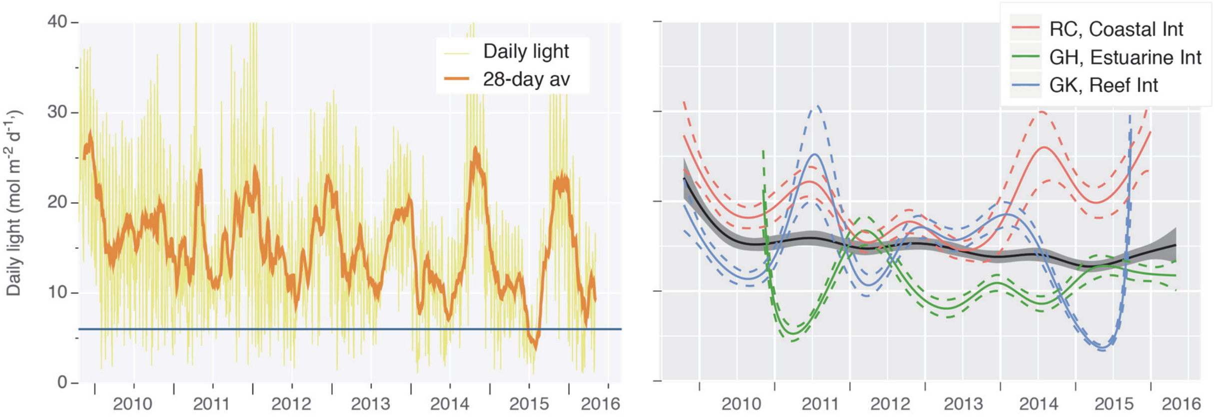

Figure 94. *Mean daily light at Fitzroy sites with 28-d rolling average from 2009 to 2016 (left) and GAM plots (right) with the black line showing mean trend for all sites (±95 per cent confidence interval in grey shade) and coloured lines (with CI's) showing the trend for each site. Results of statistical analysis (GAM) and site-specific graphs (site-level daily light data plus 28-d rolling average) are shown in Appendix 4.*

Water temperature was higher than the long-term average for this region (Figure 95). There were a record number of days (63) exceeding 35°C, but there were no days where water temperature exceeded extreme thresholds (>40°C). There was also frequent warm deviation from the baseline particularly in May 2016, when temperature deviations exceeded 2°C above the 11-year mean weekly temperature, but as this was later in the reporting year, the effects of this will be detected in the following years monitoring (2016-17). These temperatures would not be expected to cause significant photoinhibition (Campbell, *et al.* 2006a), but may cause chronic cumulative stress (Collier, *et al.* 2011b). There was daily tide exposure was also greater than the long-term average, most likely contributing to the anomalously warm conditions.

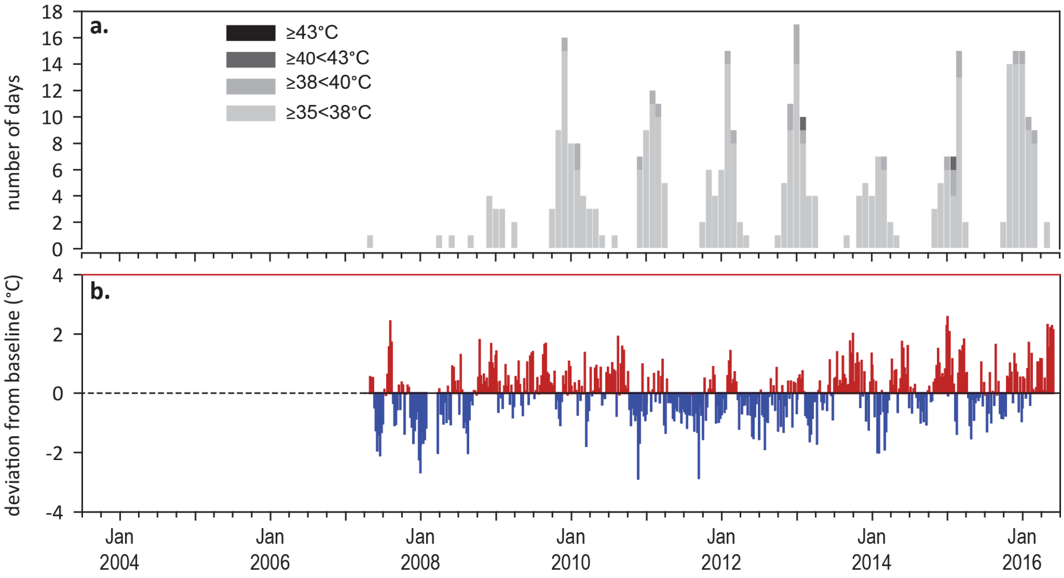

Figure 95. *Inshore sea temperatures within each intertidal seagrass habitat in the Fitzroy region, May 2007 - June 2016: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from Campbell, et al. 2006a); b) deviations from 11-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

4.6.3 Indicators of seagrass condition

Three seagrass habitat types were assessed across the Fitzroy region in 2015-16, with data from 6 sites (Table 30).

Table 30. *List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Fitzroy NRM region. For site details see* Table 3 *and* Table 4*.*

Habitat	Site		abundance	composition	distribution	Reproductive	seed banks	Leaf tissue	Meadow	Epiphytes	Macroalgae
estuary intertidal	GH1	Gladstone Hbr	■	■	■	■	■	■	■	■	■
	GH2	Gladstone Hbr	■	■	■	■	■	■	■	■	■
coastal subtidal	RC1	Ross Creek (Shoalwater Bay)	■	■	■	■	■	■	■	■	■
	WH1	Wheelans Hut (Shoalwater Bay)	■	■	■	■	■	■	■	■	■
reef intertidal	GK1	Great Keppel Is.	■	■	■	■	■	■	■	■	■
	GK2	Great Keppel Is.	■	■	■	■	■	■	■	■	■

Seagrass abundance, composition and extent

The regional seagrass abundance score was unchanged in 2015-16 but the state remained poor (Figure 92). Monitoring of habitats in the Fitzroy region has been reduced to once per year in the dry season since 2014. Seagrass abundance remained low in estuarine habitat, increased in coastal habitat, but declined slightly at reef sites. The long-term average seagrass abundances at coastal habitats in the Fitzroy region were seasonally lower in the wet (13.0 ±1.4 per cent) than the late dry (17.4 ±1.5 per cent) (Figure 96); however, as sampling has been reduced to once per year, the late wet is no longer measured. In 2015-16, coastal average abundances in the late dry were the greatest they have been since 2011, but remain 44 per cent lower than the long-term average. Estuarine abundances in late dry 2014-15 were 30 per cent lower than the long term average, while reef abundances reduced, and remain very low (1.8 per cent cover), and 28 per cent lower than the long-term mean.

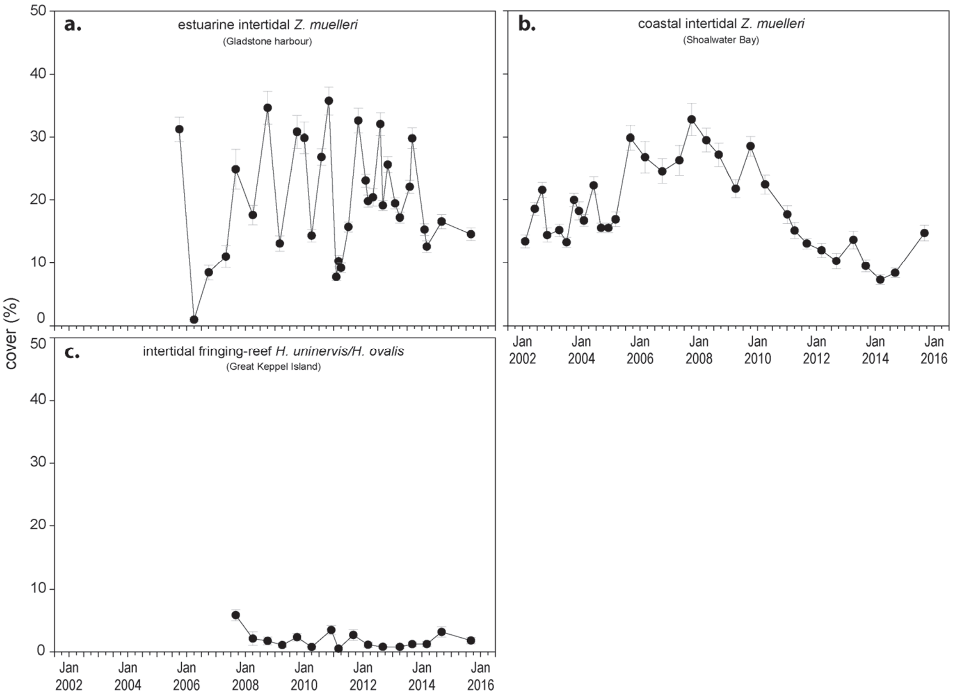

Figure 96. *Changes in seagrass abundance (per cent cover ±Standard Error) in inshore intertidal habitats of the Fitzroy region, 2001 - 2016: a) estuarine (Gladstone Harbour, b) coastal (Shoalwater Bay) and c) reef (Great Keppel Island).*

An examination of the long term trends across the Fitzroy NRM region suggests seagrass abundance (per cent cover) declined from 2002 to 2013, but are increasing (Figure 97).

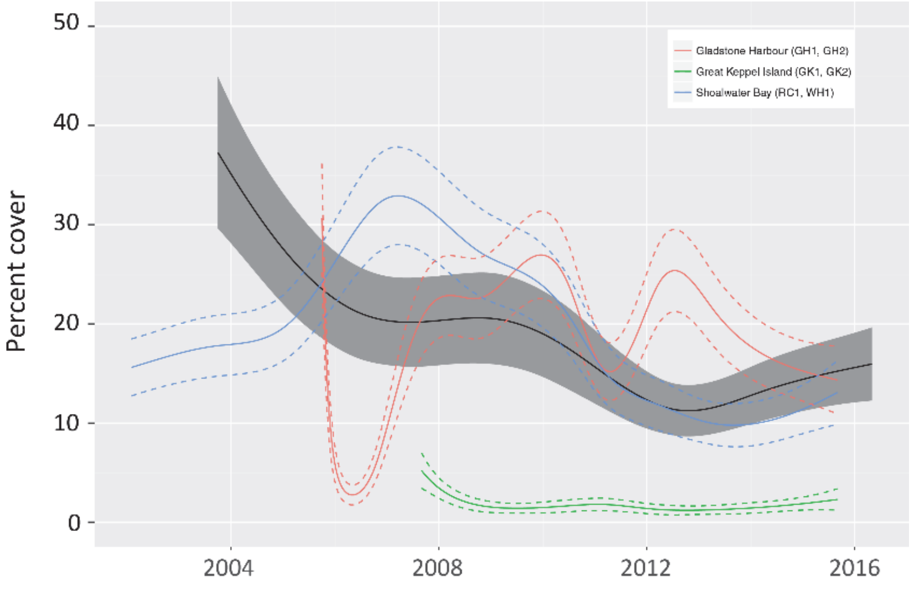

Figure 97. *Temporal trends in seagrass abundance for each habitat in the Fitzroy region, represented by a GAM plot 2001-2016. Regional trend (all habitats pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals.*

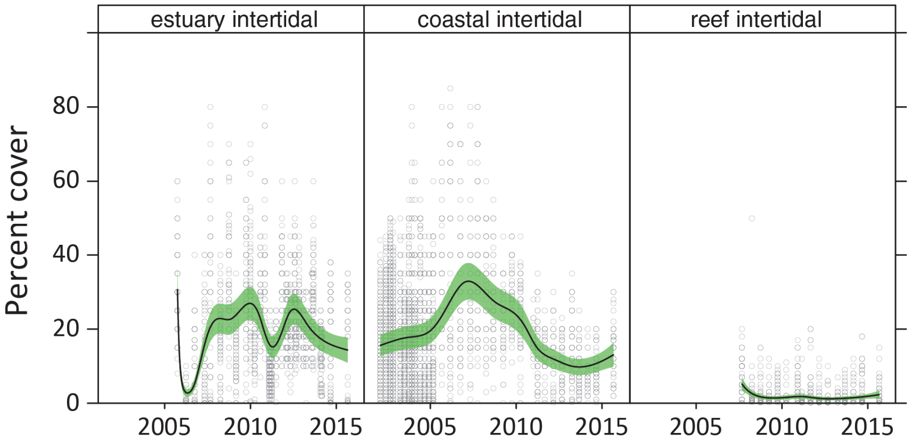

Figure 98. *Temporal trends in seagrass abundance for seagrass habitat in the Fitzroy region represented by a GAM plot, 2001-2016. Trends (locations pooled) represented by black line with green shaded area defining 95 per cent confidence intervals, and quadrat data displayed as grey circles.*

Coastal meadows in Shoalwater Bay (Ross Creek and Wheelans Hut) had an increased proportion of colonising species (*H. ovalis*) after 2011 but remained dominated (>0.5) by the opportunistic species *Z. muelleri*, and *H. uninervis* (Figure 99). In 2015-16, the proportion of these opportunistic species declined as colonising species dominance increased. Similarly, there was an increase in colonising species at the reef sites, while estuarine sites (Gladstone Harbour) continued to be dominated by the opportunistic foundational species *Zostera muelleri* in 2015-16.

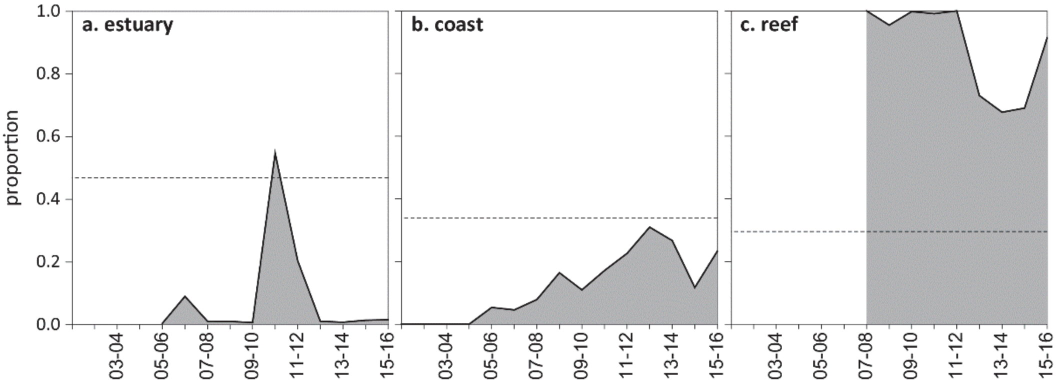

Figure 99. *Proportion of seagrass abundance composed of colonising species in inshore intertidal habitats of the Fitzroy region, 2001 - 2016. Grey area represents GBR long-term average proportion of colonising species for each habitat type.*

The extent of the coastal meadows within monitoring sites in Shoalwater Bay has remained stable at the maximum since monitoring commenced in 2005. The extent of the estuarine meadows has remained relatively stable over the past 8 monitoring periods, however, reef meadows have varied greatly. In late 2014, the extent of the reef meadows (Great Keppel Island), increased to their most extensive in 4 years, and this remained stable in the late dry in 2015 (Figure 100).

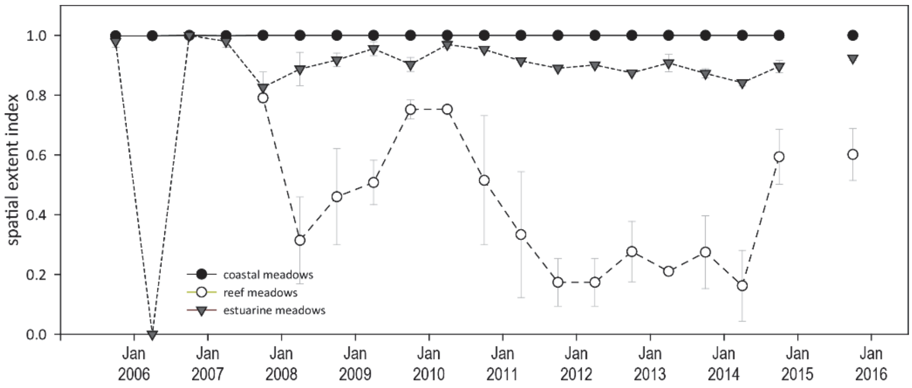

Figure 100. *Change in spatial extent of seagrass meadows within monitoring sites for each inshore intertidal habitat across the Fitzroy NRM region, 2005 - 2016.*

Apart from the MMP, seagrass monitoring within the Fitzroy NRM region is also conducted in places where cumulative anthropogenic impacts to seagrass are highest as part of the Queensland Ports Seagrass Monitoring Program (QPSMP). Annual monitoring of 14 seagrass meadows within Gladstone Harbour in November 2015 reported a decline in average meadow above-ground biomass (visually estimated using helicopter and boat-based free diving/grab) with abundances remaining below the long-term average in all but three monitoring meadows (Davies *et al.* 2016). Despite these biomass declines, there was a minor, but not significant (i.e. estimates of reliability/mapping precision overlap between years), increase in meadow area across the monitoring meadows; particularly in The Narrows and Western Basin zones (Davies*, et al.* 2016). The total area of seagrass mapped from The Narrows to the Boyne River was the second highest total area since November 2009.

The MMP monitoring sites GH1 and GH2 are located within one of the meadows monitored (Pelican Banks north) for the Gladstone Ports Corporation Limited. Although the Pelican Banks meadow extent appears to have remained relatively stable, it was reported to have become patchier and during 2015 declined to the lowest visually estimated above-ground biomass since monitoring was established (Davies*, et al.* 2016), which is consistent with the downward trend in abundance observed at the MMP sites since 2013-14. They also observed an increase in the composition of colonising species (Davies et al 2016). Associated seed bank density and biannually (February and May) seed viability assessments in 2016 also reported that although seed density was low, a relatively high proportion remained viable at the Pelican Banks meadow compared with 2015 (Bryant *et al.* 2016). Although environmental conditions were generally favourable in the twelve months preceding the survey (e.g. below average rainfall and light levels well above threshold for maintenance and growth), the authors attribute the low biomass to a combination of sustained high temperatures during the 2014 growing season and exposure-related stress caused by high total daytime tidal exposure at the beginning of the 2015 growing season (Davies*, et al.* 2016).

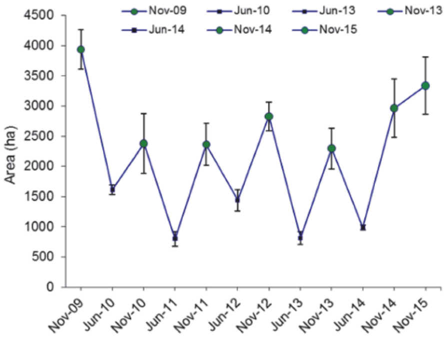

Figure 101. *Change total extent of all monitoring meadows combined in Port Curtis from 2009 – 2015 (from Davies, et al. 2016). Error bars are "R" reliability estimate for ha.*

Seagrass reproductive status

Reproductive effort has increased at estuary sites in 2015-16, and seed banks have been maintained since 2011. Seed banks of *Zostera muelleri* at estuary sites, respectively, indicate a capacity to recover following disturbance. In these sites, the reproductive score may underestimate the role of sexual reproduction and the seed bank. As such, seed banks are being considered for future inclusion in the report card metric. Reproductive effort has remained very low at coast and reef sites, however, seed banks have persisted in coast habitats over the last 3 – 4 monitoring periods, but not at reef sites (Figure 102). This limits the capacity of opportunistic species to expand in reef habitats, as well as the meadow capacity to recover following further disturbance. Furthermore, poor reproductive effort in coast and reef habitats may be a precursor to seed bank limitation in the near future.

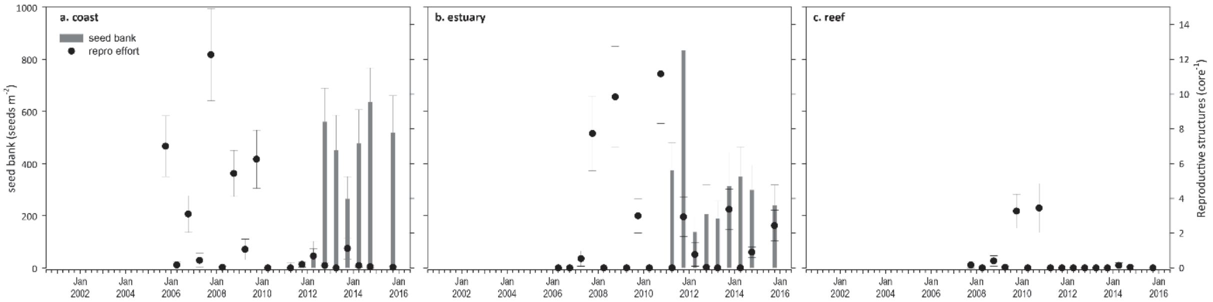

Figure 102. *Seed bank and late dry season reproductive effort for inshore intertidal coastal, estuary and reef habitats in the Fitzroy region, 2005 - 2016. Seed bank presented as the total number of seeds per m^2 sediment surface and late dry season reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

4.6.4 Indicators of environmental condition

Seagrass tissue nutrients

Seagrass growing in coast and reef habitat in the Fitzroy region were similar in the relative compositions of carbon to nitrogen (C:N = 16) in 2015-16 (Figure 103). C:N below 20, is indicative of a surplus in the uptake of N, relative to the uptake and incorporation of carbon and may indicate either reduced light availability. Leaf tissue δ^{13}C declined at reef and estuarine habitats, but were above global averages, suggesting that light limitation has abated. However the low C:N can also be caused by elevated N, and increasing N:P in both habitats (Figure 104) suggests that N loads have also contributed to the low C:N. In contrast, at estuarine habitats, C:N increased slightly, which was coincident with reduced N pools relative to P (N:P).

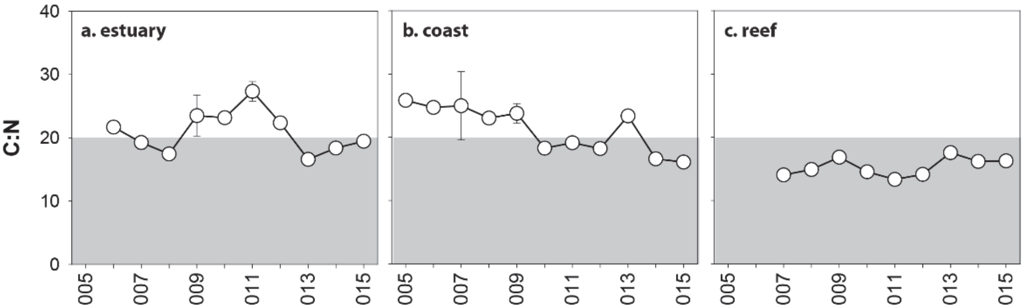

Figure 103. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at inshore intertidal habitats in the Fitzroy region, 2005 - 2015 (species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment.*

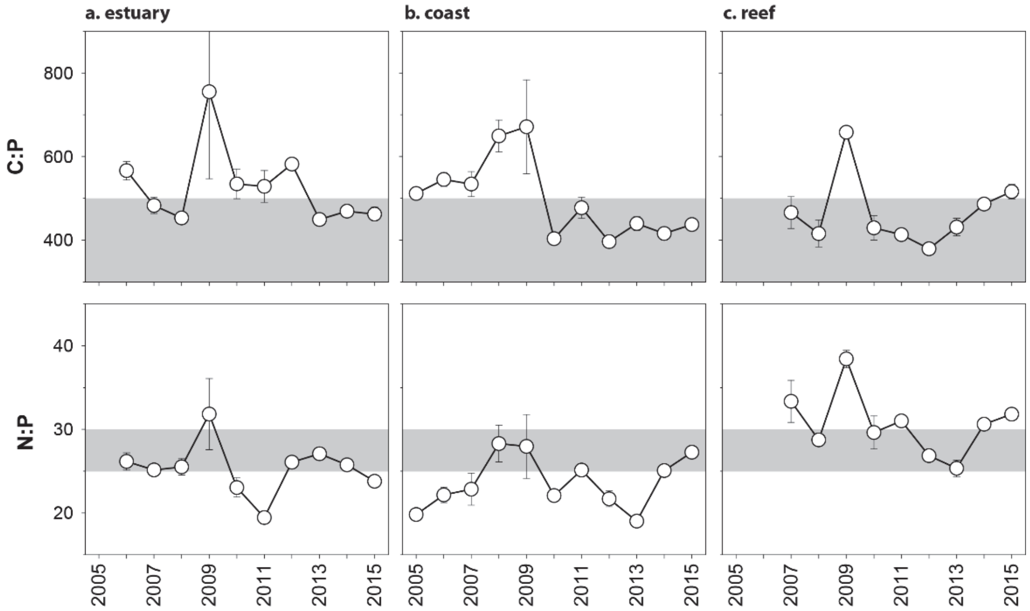

Figure 104. *Elemental ratios (atomic) of seagrass leaf tissue N:P and C:P for the foundation seagrass species examined at inshore intertidal habitats in the Fitzroy region, 2005 - 2015 (species pooled) (mean ± Standard Error). Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues. N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Seagrass meadow sediments

In the Fitzroy region, the proportion of fine grains in meadow sediments decreases with distance from the coast/river mouths and has remained stable over the last 6-7 years. Estuarine sediments were composed primarily of finer sediments, with the mud portion just below the GBR long-term average. Coastal and reef habitat sediments were dominated by fine sand/sand, but the proportion of mud in coastal habitats was higher than the GBR long-term average.

Epiphytes and Macroalgae

Epiphyte cover at coast and reef habitats in the late dry remained below the GBR long-term average over the 2015-16 monitoring period, despite increases at reef habitat (Figure 105; Appendix 4, Figure 203, Figure 205). At estuary habitats, however, epiphyte cover remaining above the GBR long-term average (Appendix 2, Figure 204), which could contribute to light limitation. Macroalgae cover remained unchanged at all habitats in the Fitzroy region (Figure 105; Appendix 4, Figure 205).

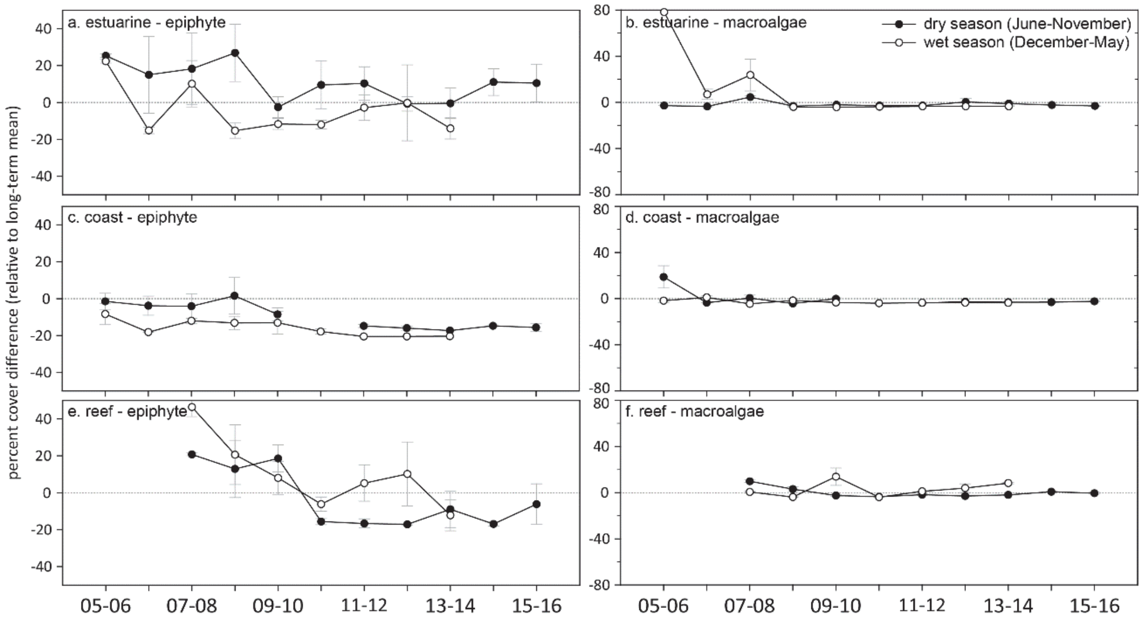

Figure 105. *Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each inshore intertidal seagrass habitat in the Fitzroy region, 2005 - 2016 (sites pooled, ±SE).*

4.6.5 Report card for inshore seagrass status

In the 2015-16 monitoring period, the seagrass index recovered slightly to poor, from its lowest level ever (very poor) in 2014-15. Very poor abundance in reef habitat, and very poor reproductive effort in all habitats are keeping are pulling the score down, while small gains in tissue nutrients at estuarine, and abundance at coastal sites have enabled the small increase. These meadows remain in a highly vulnerable state.

Table 31. *Long-term report card scores for seagrass abundance, reproductive and leaf tissue nutrient status for each habitat in the Fitzroy region: June 2005 – May 2016. Values are indexed scores scaled from 0-100; 🟩 = very good (81-100), 🟩 = good (61 - 80), 🟨 = moderate (41 - 60), 🟧 = poor (21 - 40), 🟥 = very poor (0 - 20). NB: Scores are unitless.*

Indicator	**Habitat**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**
Abundance	estuarine intertidal	25	13	44	25	42	34	47	53	34	25	25
	coastal intertidal	81	81	100	75	81	31	25	25	8	25	38
	reef intertidal			13	6	13	13	6	6	6	25	13
Reproductive effort	estuarine intertidal	100	0	50	63	25	75	13	0	25	0	13
	coastal intertidal	38	13	50	25	25		0	0	0	0	0
	reef intertidal			0	0	50	63	0	0	0	0	0
Leaf tissue nutrients	estuarine intertidal		58	46	37	67	66	85	62	33	42	47
	coastal intertidal	79	74	75	65	69	41	46	41	67	33	30
	reef intertidal			20	25	34	23	17	21	41	31	31
Seagrass Index		**67**	**40**	**44**	**36**	**45**	**47**	**28**	**25**	**26**	**20**	**22**

4.7 Burnett Mary

4.7.1 2015-16 Summary

Only intertidal estuarine and coastal seagrass meadows located in bays protected from SE winds and wave action were monitored in the Burnett Mary NRM region. The main ecological drivers in these environments are exposure to wind waves, elevated temperature, flood runoff and turbidity. Seagrasses are monitored at locations in the north and south of the Burnett Mary Region. Since monitoring was established, the meadows have come and gone on an irregular basis.

Both rainfall and river discharge were below the long-term average in 2015-16. Despite this, the estuarine and coastal sites were exposed to turbid primary water, and somewhat to secondary water) for the entire wet season (100 per cent of weeks from November to April). As a consequence, the daily light continued to decline in 2015-16 to well below the long-term average for yet another year. Water temperatures were above average with a record number of days exceeding 35°C and 3 days where water temperature was extreme (>40°C). These anomalously warm temperatures during the wet season months may have affected post-wet season seagrass condition.

Seagrass abundance increased across the region in 2015-16 to a **moderate** rating, providing the highest score since 2005. The proportion of seagrass species displaying colonising traits continued to decline slightly in estuarine habitats, and increase slightly at coastal habitats. While reproductive effort increased, seed banks remained stable, and the reason that they aren't accumulating more is not immediately apparent. The improving reproductive effort, however, suggests seed bank recovery in the near future as a result of possible increased replenishment. *Z. muelleri* leaf tissue analysis in late 2015, suggested sufficient and possibly increasing carbon available for growth but given the low light levels, this is unlikely. Instead the N:P and C:P rations suggest that the availability of nitrogen and phosphorus have declined. Leaf tissue δ^{15}N value were lower in 2014 than the previous year, but still indicated either fertiliser and/or sewage influence as the primary N source. Epiphyte abundance reduced and macroalgae abundance remained below the GBR long-term average in 2015-16.

In response to the environmental pressures over 2015-16, the seagrass state in the Burnett Mary region increased to the highest score in a decade, but remained **poor** (Figure 106).

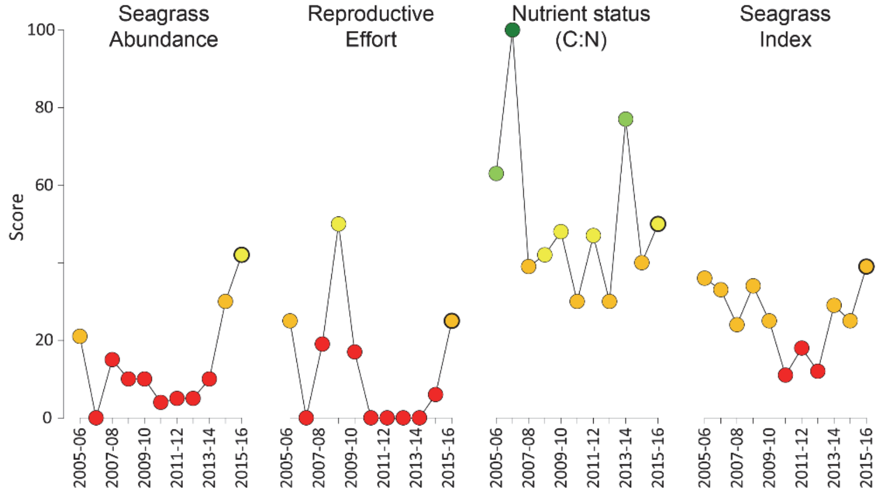

Figure 106. *Report card of seagrass status indicators and index for the Fitzroy region (averages across habitats and sites). Values are indexed scores scaled from 0-100;* 🟩 *= very good (81-100),* 🟩 *= good (61 - 80),* 🟨 *= moderate (41 - 60),* 🟧 *= poor (21 - 40),* 🟥 *= very poor (0 - 20). NB: Scores are unitless.*

4.7.2 Climate and environmental pressures

Rainfall and river discharge were below average in 2015-16, following above average conditions in the previous year (Table 32) that were related to TC Marcia which tracked down the coast bringing rainfall into the Mary River catchment in 2014-15. Burnett Mary seagrass meadows also received strong winds in 2015-16 and were exposed to almost exclusively primary water, often of very high turbidity (class 1 or 2, Figure 107 Table 33), from November 2015 to April 2016.

Table 32. *Summary of environmental conditions at monitoring sites in the Burnett Mary in 2015-16 compared to the long-term average (long-term range indicated for each data set).*

	Long-term average	**2015-16**
Rainfall (1986-2016)	1099 mm	767 mm
River discharge (1970-2016)	1,490,961 L yr^{-1}	1,307,761 L yr^{-1}
Turbid water exposure (2006-2016)	*not available*	100 per cent
Daytime tidal exposure (1999-2016)	116.58 hrs yr^{-1}	123.33 hrs yr^{-1}
Wind (1998-2016)	81.4 days yr^{-1}	24.5 days yr^{-1}
Within canopy temperature (2003-2016)	23.2°C *(40.9°C)*	23.9°C *(40.9°C)*
Within canopy light (2012-2016)	13.3 mol m^{-2} d^{-1}	10.6 mol m^{-2} d^{-1}

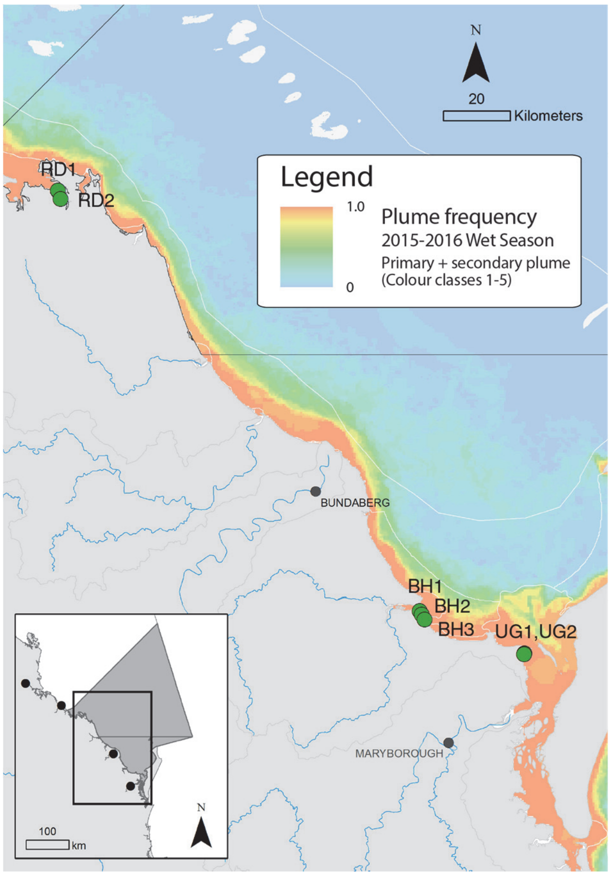

Figure 107. *Frequency of exposure to turbid water (colour classes 1-5) in the Burnett Mary NRM, wet season (22 weeks from December 2015 – April 2016) composite. The frequency is calculated as the number of weeks out of 22 weeks that are exposed to primary or secondary water (colour classes 1 – 5). Each colour class category is described by mean water quality values for TSS, CDOM, chlorophyll a and K_d (PAR) (Devlin, et al. 2015;Waterhouse, et al. 2017). For site details, see Table 34.*

Table 33. *Water type at each location in the Burnett Mary NRM derived from MODIS true colour imagesas colour classes of turbid primary water (class 1 – 4, red/brown), nutrient/chlorophyll-enriched secondary water (class 5, green), and tertiary (some freshwater/CDOM influence) or no plume influence (class 6 and 7 respectively, blue), for 22 weeks from December 2015 – April 2016. Also shown, median wet season colour class (Med), frequency of primary water as $f_{(P)}$, the frequency of secondary water as $f_{(S)}$, and the frequency of primary or secondary as $f_{(P+S)}$. *denotes data obtained from adjacent pixel.*

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	**Med**	$f_{(P)}$	$f_{(S)}$	$f_{(P+S)}$
BH1	5	1	2	1	4	2	4	1	4	1	4	2	1	4	1	2	2	4	1	4	1	4	**2**	**0.95**	**0.05**	**1.00**
BH3	5	2	2	1	4	2	4	2	4	2	4	2	4	4	2	2	4	4	2	4	2	4	**3**	**0.95**	**0.05**	**1.00**
RD1	4	4	2	1	4	2	4	1	4	4	2	2	2	4	1	3	3	4	2	5	3	5	**3**	**0.91**	**0.09**	**1.00**
UG1	4	2	3	2	4	2	4	2	4	3	2	2	2	4	2	4	4	2	2	4	1	4	**2.5**	**1.00**	**0.00**	**1.00**

Within canopy daily light (I_d), was lower than the long-term average for the region (Figure 94, Table 32). This can be attributed to considerably reduced peaks in dry season light at Urangan, and low wet season conditions at Rodds Bay, however, the acute threshold leading to loss (6 mol m^{-2} d^{-1}) was not exceeded.

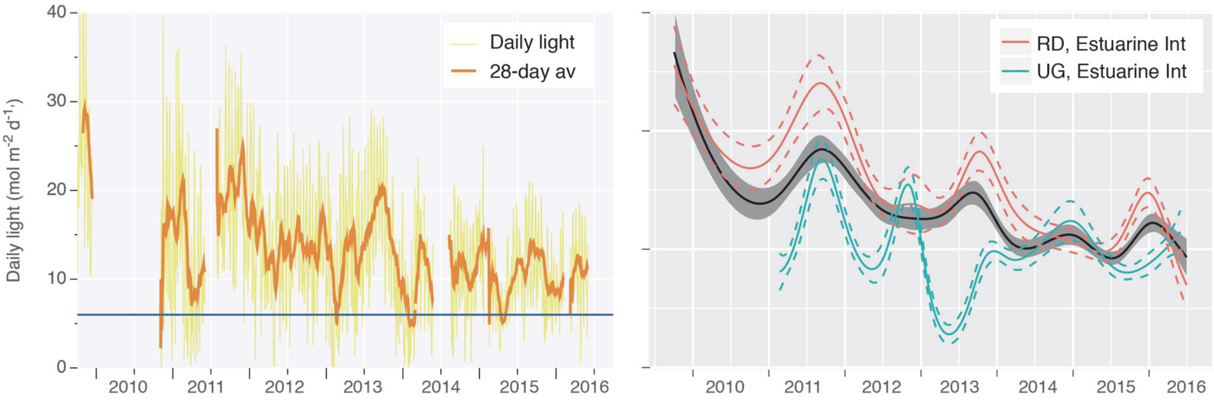

Figure 108. *Daily light at Burnett Mary locations from 2010 to 2016 (left) and GAM plots (right) with the black line showing mean trend for all sites (±95 per cent confidence interval in grey shade) and coloured lines (with CI's) showing the trend for each site. Results of statistical analysis (GAM) and site-specific graphs (raw daily light data plus 28-d rolling average) are shown in Appendix 4.*

Burnett Mary, being the southern most NRM, is inherently has cooler temperatures than the more northern regions. As a consequence there were fewer exceedances of GBR-wide temperature thresholds (>35°C). However, deviation from the region-specific baseline demonstrates that 2015-16 was an above average year for water temperature, and was above the local baseline for most of the year (Figure 109). There were a record number of days above 35°C (27 d), and 3 days exceeding 40°C, which can cause photoinhibition, reductions in net productivity and burning, particularly in the southern populations of *Z. muelleri* (Adams et al 2017, Campbell et al 2006).

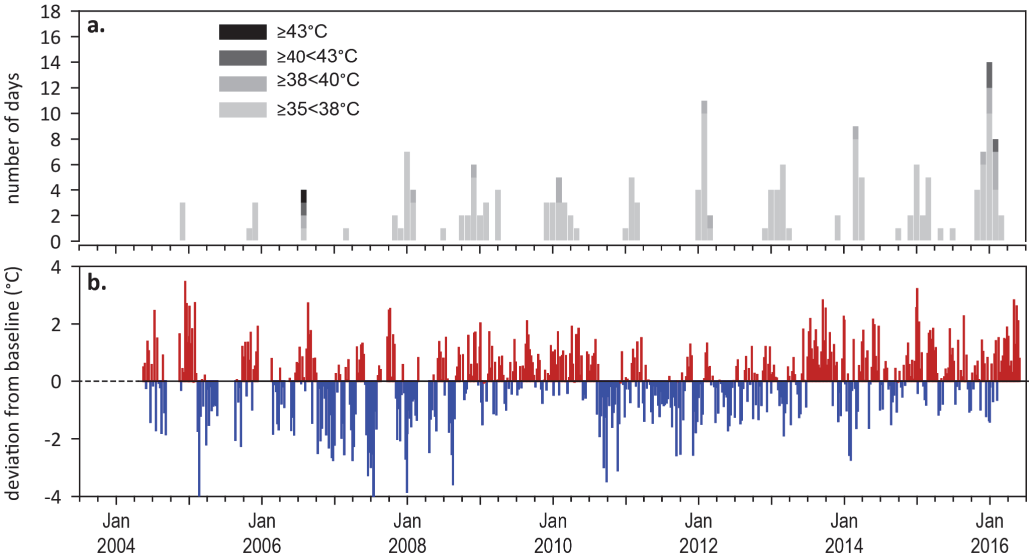

Figure 109. *Inshore sea temperature monitoring September 2005 to June 2016 for seagrass meadows in Burnett Mary NRM region: a) number of days when temperature has exceeded 35°C, 38°C, 40°C and 43°C within each season (thresholds adapted from SJ Campbell et al., 2006); b) deviations from 10-year mean weekly temperature records (weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations).*

4.7.3 Indicators of seagrass condition

Two seagrass habitat types were assessed across the Burnett Mary region in 2015-16, with data from 6 sites (Table 34).

Table 34. *List of data sources of seagrass and environmental condition indicators for each seagrass habitat type in the Burnett Mary NRM region. *Seagrass-Watch. For site details see Table 3 and Table 4.*

Habitat	**Site**		**abundance**	**composition**	**distribution**	**Reproductive effort**	**seed banks**	**Leaf tissue nutrients**	**Meadow sediments**	**Epiphytes & macroalgae**
estuary intertidal	RD1	Rodds Bay	■	■	■	■	■	■	■	■
	RD2	Rodds Bay	■	■	■	■	■	■	■	■
	UG1	Urangan	■	■	■	■	■	■	■	■
	UG2	Urangan	■	■	■	■	■	■	■	■
coastal intertidal	BH1*	Burrum Heads	■	■			■		■	■
	BH3*	Burrum Heads	■	■			■		■	■

Seagrass abundance, composition and extent

Only estuarine and coastal habitats are monitored in the Burnett Mary NRM region. Since monitoring was established, the estuarine meadows have come and gone on an irregular basis. Seagrass abundance at Urangan increased in the late dry of 2015 to the highest levels since 2004 but seasonally declined in the post wet season of 2016, while at Rodds Bay there was limited recovery following loss in 2014. At the coastal site, seagrass abundance has been on an increasing trajectory, and increased to the highest level since 2011-12. On average, abundances increased to a **moderate** rating for the first time since 2005 (Figure 106).

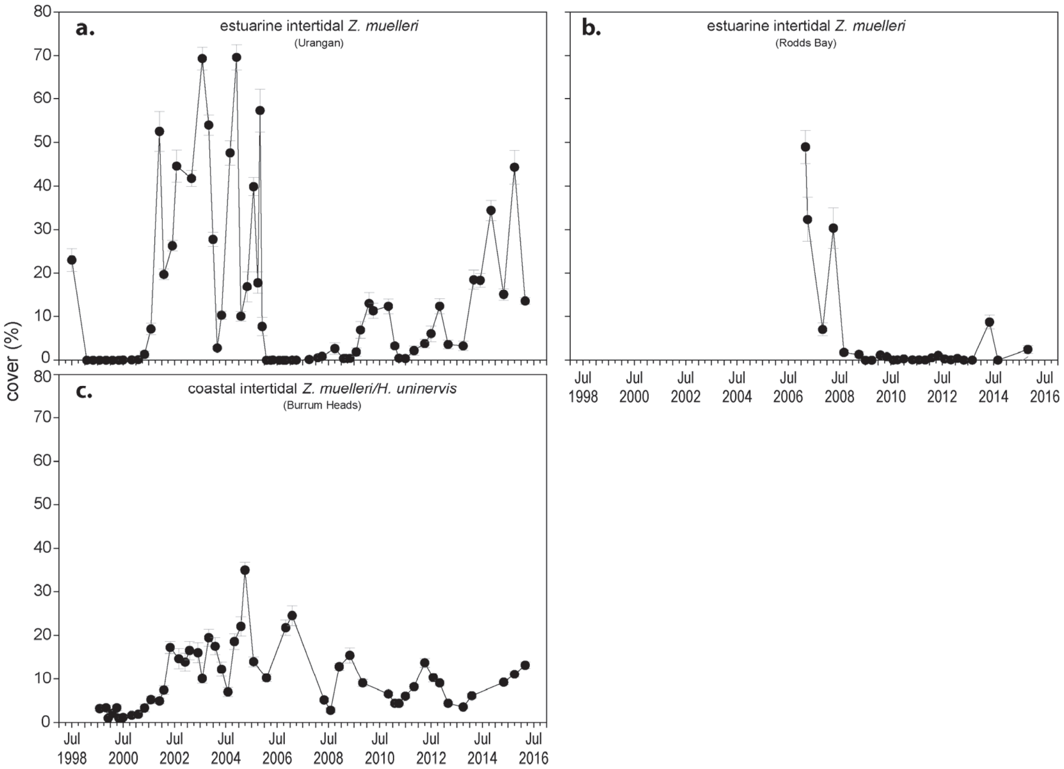

Figure 110. *Changes in seagrass abundance (per cent cover ±Standard Error) at estuarine and coastal meadows in Burnett Mary region from 1999 to 2016.*

An examination of the long term trends across the Burnett Mary NRM region suggests seagrass abundance (per cent cover) has fluctuated greatly between years, but progressively decreased from 2004 to 2012; and recent increases have placed the meadows on a pathway towards recovery to pre-2005 levels (Figure 111).

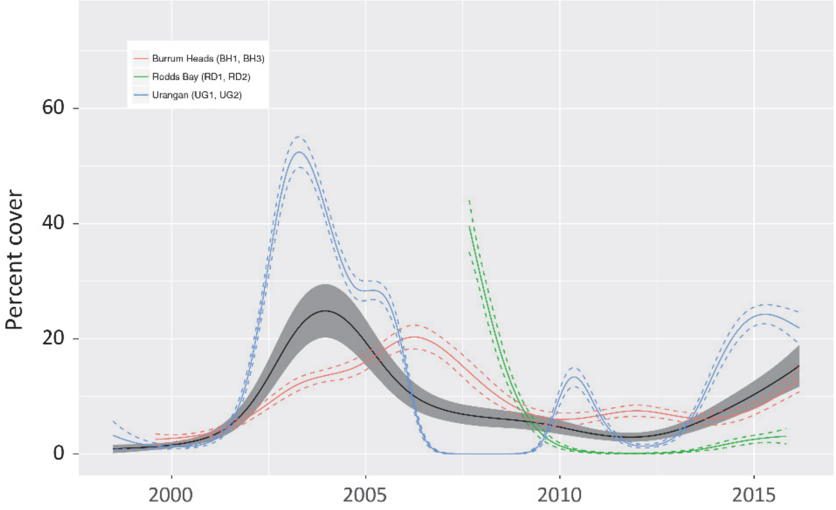

Figure 111. *Temporal trends in seagrass abundance at estuarine locations in the Burnett May region, represented by a GAM plot 1999-2016. Regional trend (all habitats pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals.*

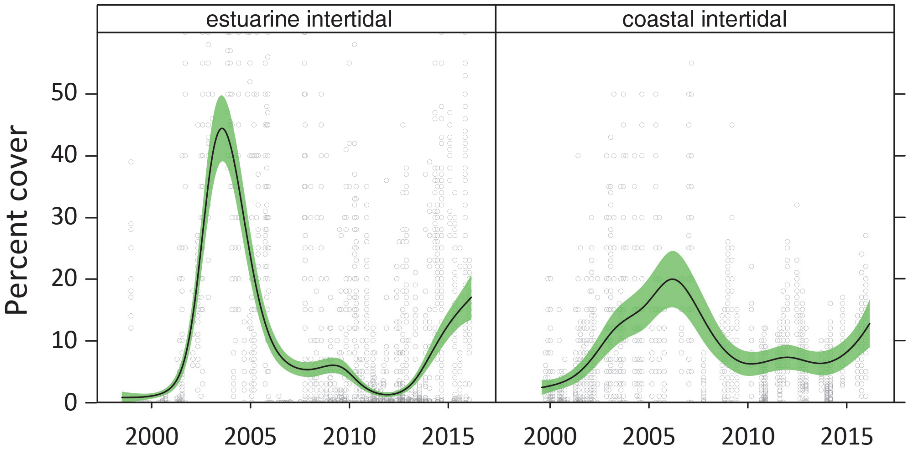

Figure 112. *Temporal trends in seagrass abundance for seagrass habitat in the Burnett Mary region represented by a GAM plot, 1998-2016. Trends (locations pooled) represented by black line with green shaded area defining 95 per cent confidence intervals, and quadrat data displayed as grey circles.*

The estuarine seagrass habitats were dominated by *Zostera muelleri* with varying components of *Halophila ovalis* over the monitoring period (Figure 113). In 2015-16, the proportion of colonising species declined in estuarine habitats and increased slightly at coastal habitats but remained below the GBR long-term average throughout the region. The reducing proportion of colonising species in the meadows suggests greater ability to tolerate/resist major disturbances, particularly as the meadows improve abundance.

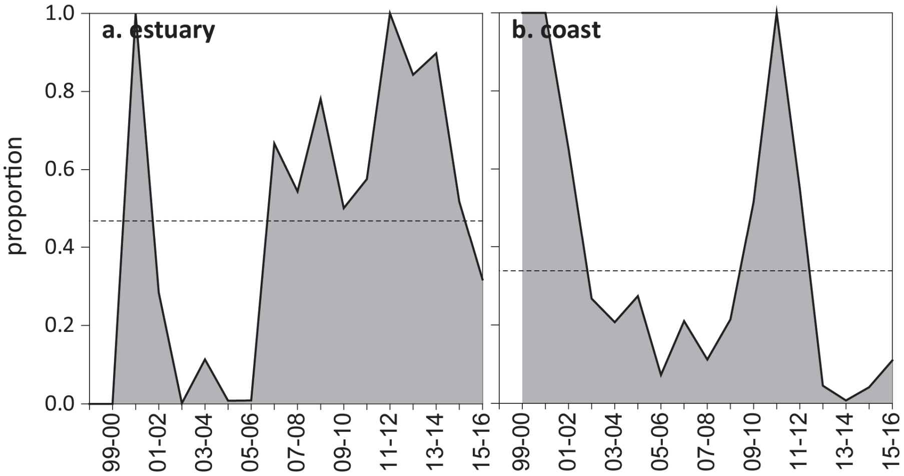

Figure 113. *Proportion of seagrass abundance composed of colonising species at: a. estuary and b. coastal habitats in the Burnett Mary region, 1998-2016. Grey area represents GBR long-term average proportion of colonising species for each habitat type.*

Seagrass meadow edge mapping was conducted at all monitoring sites in October 2015 and April 2016 (Appendix 4) to determine if changes in abundance were a consequence of the meadow edges changing and to indicate if plants were allocating resources to colonisation (asexual reproduction). Over the last 12 months meadow extent has seasonally varied, but in the post-wet in 2016 were at an equal greatest extent since 2006 (Figure 114).

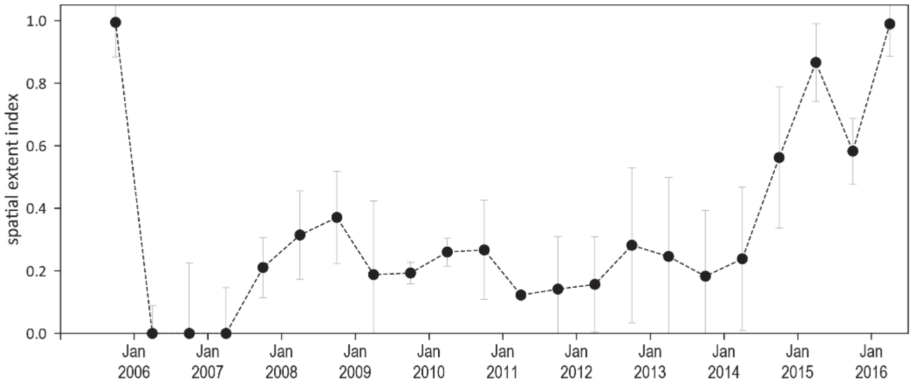

Figure 114. *Change in spatial extent of estuary seagrass meadows within monitoring sites for each habitat and monitoring period across the Burnett Mary NRM region.*

Apart from the MMP, seagrass monitoring within the Burnett Mary NRM region is also conducted in the northern section where cumulative anthropogenic impacts to seagrass are highest as part of the Queensland Ports Seagrass Monitoring Program (QPSMP). Annual monitoring of 3 seagrass meadows within Rodds Bay is conducted as a reference (low impact) comparison to the Port Curtis (Gladstone Harbour) meadows for the Gladstone Ports Corporation Limited. The MMP monitoring sites RD1 and RD2 are located within two of the meadows monitored (meadows #96 and #104, respectively). Monitoring in November 2015 reported a minor, but not significant (i.e. estimates of reliability/mapping precision overlap between years) in area of the larger intertidal *Z. muelleri* subsp. capricorni meadow (#96), however average meadow above-ground biomass (visually estimated using helicopter and boat-based free diving/grab) remained well below the long term average, with a higher than average composition of colonising species (Davies*, et al.* 2016). Seed bank density and viability studies conducted in meadow #96, reported a persistent seed bank where a relatively high proportion remained viable compared with 2015 (Bryant*, et al.* 2016).The adjacent *Z. muelleri* subsp. capricorni dominated meadow (#104) not only declined in abundance and species composition (dominated by colonising species), but also area (Davies*, et al.* 2016). Although environmental conditions were generally favourable in the twelve months preceding the survey (e.g. below average rainfall and light levels well above threshold for maintenance and growth), the authors attribute the low biomass to a combination of sustained high temperatures during the 2014 growing season and exposure-related stress caused by high total daytime tidal exposure at the beginning of the 2015 growing season (Davies*, et al.* 2016).

Seagrass reproductive status

Seagrass reproductive effort increased to the second highest levels recorded in the late dry, but seasonally declined in the late wet, in estuarine habitat of the Burnett Mary. *Zostera muelleri* seed banks in Burnett Mary region meadows have remained relatively stable but low in 2015-16 following declines in 2013-14 (Figure 115); potentially indicating a reduced capacity to recover following disturbance. However, the improving reproductive effort suggests seed bank recovery could occur in the near future.

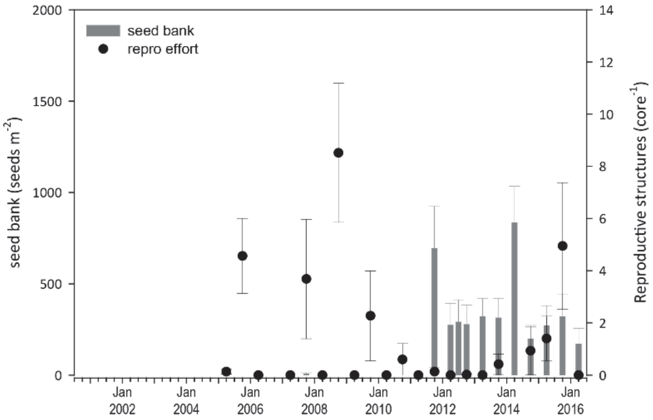

Figure 115. *Burnett Mary estuary seed bank and reproductive effort. Seed bank presented as the total number of seeds per m^2 sediment surface and reproductive effort presented as the average number of reproductive structures per core (species and sites pooled).*

4.7.4 Indicators of environmental condition

Seagrass tissue nutrients

In 2015, *Zostera muelleri* leaf molar C:N ratios increased slightly to 20 (Figure 116); primarily due to the high C:N ratios at Urangan (23), rather than Rodds Bay (14). This has occurred despite lower than average light levels at Urangan at the time of collection and suggests a change in the nutrient supply. *Zostera muelleri* leaf molar C:P ratios have gradually increased over the last 4 years, with the regional average exceeding 500 in 2015 for the second year, indicating that the plants were growing in an environment with a relatively small P pool (Figure 116). As both the C:P increased and N:P ratio decreased, it would appear that there is a reduced supply of both nitrogen and phosphorus in 2015-16 (Appendix 4, Figure 221). δ^{13}C values were higher than global ranges, and higher than the previous 3 years (Appendix 4), also suggesting that the changing tissue nutrients could be due to sufficient carbon available for growth (i.e. light availability for carbon uptake). However, light levels have been low and contradict this interpretation, therefore, reducing nitrogen and phosphorus is the most likely explanation for changing C:N

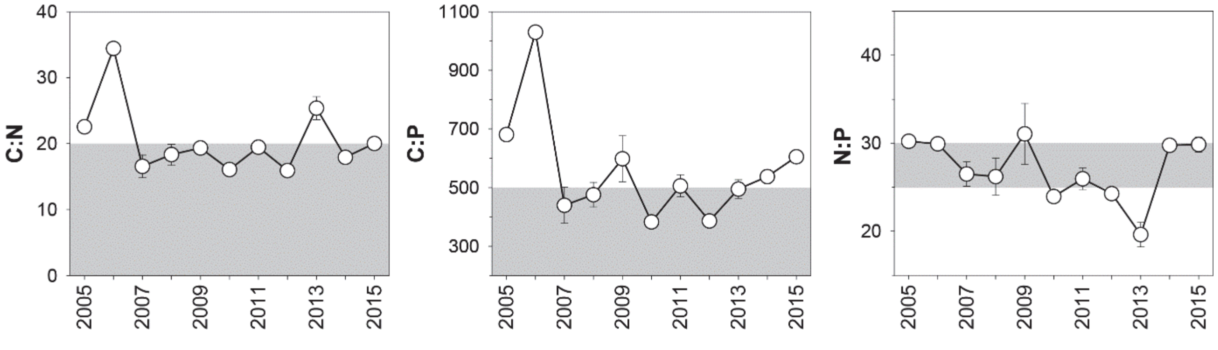

Figure 116. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at estuarine habitats in the Burnett Mary region each year (sites and species pooled) (mean ± Standard Error). Horizontal shaded band on the C:N ratio panel represents the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal, et al. 1994; Grice, et al. 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment. Horizontal shaded band on the N:P ratio panel represents the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean, et al. 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).*

Leaf tissue δ^{15}N values were lower in 2015 than 2014 (Appendix 4.2.6, Table 61), but still at levels which suggest either fertiliser and/or sewage may be influencing the primary source of N.

Seagrass meadow sediments

Sediments in the estuary seagrass habitats of the Burnett Mary region are dominated by mud, and in 2015-16, this has remained relatively stable, albeit with seasonal variability (Appendix 4, Figure 189).

Epiphytes and macroalgae

Epiphyte cover on seagrass leaf blades was high in the wet but reduced during the dry season, but remained above the GBR long-term average in 2015-16 (Figure 117; Appendix 4, Figure 205). Percentage cover of macroalgae was very low in both the wet dry seasons of 2015-16 (Figure 117; Appendix 4, Figure 205).

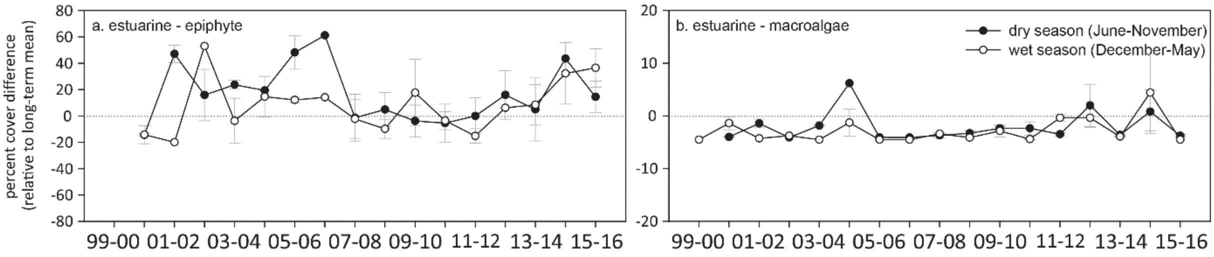

Figure 117. *Long-term trend in mean epiphyte and macroalgae abundance (per cent cover) relative to the long-term average for each seagrass habitat in the Burnett Mary NRM region (sites pooled, ±SE).*

4.7.5 Report card for inshore seagrass status

Since reporting was established in 2005, the seagrass index score for the Burnett Mary has been poor or very poor. In the 2015-16 monitoring period, the seagrass index for the Burnett Mary region was the highest since reporting was established, but it remains **poor**. Reproductive effort and tissue nutrients had the greatest improvements, but abundance at the estuarine sites increased only slightly.

Table 35. *Long-term report card scores for seagrass abundance, reproductive and leaf tissue nutrient status for each habitat in the Burnett Mary region: June 2005 – May 2016. Values are indexed scores scaled from 0-100; 🟩 = very good (81-100), 🟩 = good (61 - 80), 🟨 = moderate (41 - 60), 🟧 = poor (21 - 40), 🟥 = very poor (0 - 20). NB: Scores are unitless.*

Indicator	Habitat	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Abundance	estuarine intertidal	21	0	15	10	10	4	5	5	10	26	28
	coastal intertidal										38	69
Reproductive effort	estuarine intertidal	25	0	19	50	17	0	0	0	0	6	25
Leaf tissue nutrients	estuarine intertidal	63	100	39	42	48	30	47	30	77	40	50
Seagrass Index		**36**	**33**	**24**	**34**	**25**	**11**	**18**	**12**	**29**	**25**	**39**

5 Conclusions

In 2015-16, inshore seagrass across the GBR remained in a vulnerable state, particularly in the Fitzroy and southern Wet Tropics, with weak resistance (low abundance and low diversity, or abundance dominated by colonising species) and a low capacity to recover (low seed bank and/or low reproductive effort). Climatic conditions throughout 2015-16 were relatively moderate with the lowest cyclone activity on records and below median river discharge. However, during 2015-16 seagrass received below average daily irradiance which appears a consequence of exposure to turbid sediment and plankton laden waters (primary and secondary water) for much of the wet season and slightly higher than average wind speeds throughout the year. This coupled with above average water temperatures and increasing epiphyte loads may have resulted in C limitation and less than optimal growth conditions for seagrass recovery in some meadows in central and northern GBR regions.

2015-16 was the second year data from other seagrass monitoring programs in the GBR were integrated into the report card improving the spatial resolution of monitoring. Abundance data from 8 long-term Seagrass-Watch monitoring sites in the Cape York, Burdekin, Mackay Whitsunday and Burnett Mary regions were included. Similarly, abundance data collected using drop-cameras from 4 subtidal locations (Lloyd Bay, Missionary Bay, Tongue Bay, Newry Bay) by QPWS were also included in 2015-16 report card. As Seagrass-Watch and QPWS drop-camera monitoring use similar methodologies to the MMP, data integration was seamless. The only other seagrass monitoring program of significance in the Great Barrier Reef WHA is the QPSMP which monitors seagrass at a number of industrial ports from Cairns in the north to Gladstone in the south (http://bit.ly/2m0mOSC). Due to the alternative monitoring approach implemented through the QPSMP, a thorough examination of data compatibility as well as levels of uncertainty and sensitivity, is required prior to integration. It is anticipated such analysis will occur in 2017-18 as part of the Reef 2050 Integrated Monitoring Modelling and Reporting Program (RIMMReP) (http://bit.ly/2myDYrK).

Long-term monitoring through the MMP and related programs (e.g. QPSMP) has demonstrated that the tropical seagrass ecosystems of the GBR are a mosaic of different habitat types comprised of multiple seagrass species in which timing and mechanisms that capture their dynamism (i.e. declines and subsequent recovery) are complex and spatially diverse. The report card of inshore seagrass state for the Great Barrier Reef shows that the declines occurring in 2006 and then from 2009 to 2012 (from Cooktown south) abated in late 2012 and seagrass state improved; but remained poor in 2015-16 (Figure 118). More specifically, although some locations in the Wet Tropics and Burdekin regions experienced declines in early 2006 as a consequence of TC Larry, most recovered within 1-2 years; with the exception of the coastal sites in southern Wet Tropics where recovery was protracted. In late 2008, locations in the northern Wet Tropics and Burdekin regions were in a moderate state of health with abundant seagrass and seed banks. In contrast, locations in the southern GBR in Mackay Whitsunday and Burnett Mary regions were in a poor state, with low abundance, reduced reproductive effort and small or absent seed banks. In 2009 with the onset of the La Niña, the decline in seagrass state steadily spread across the Burdekin region and to locations within the Fitzroy and Wet Tropics where discharges from large rivers and associated catchments occurred (McKenzie *et al.* 2010b; McKenzie*, et al.* 2012b). The only locations of better seagrass state were those with relatively little catchment input, such as Gladstone Harbour and Shoalwater Bay (Fitzroy region), Green Island (Wet Tropics), and Archer Point (Cape York) (McKenzie*, et al.* 2012b). By 2010, seagrasses of the GBR were in a poor state with declining trajectories in seagrass abundance, reduced meadow extent, limited or absent seed production and increased epiphyte loads at most locations. These factors would have made the seagrass populations particularly vulnerable to large episodic disturbances, as demonstrated by the widespread and substantial losses documented after the floods and cyclones of early 2011.

Following the extreme weather events of early 2011, seagrass habitats across the GBR further declined, with severe losses reported from the Wet Tropics, Burdekin, Mackay Whitsunday and Burnett Mary regions. By 2011-12, the onset of seagrass recovery was observed across some regions, however a state change had occurred and colonising species dominated many habitats. The majority of meadows appeared to allocate resources to vegetative growth rather than reproduction, indicated by the lower reproductive effort and seed banks. In 2015-16, recovery continued to progress across most of the regions, although some regions meadows recovery appears to have stalled.

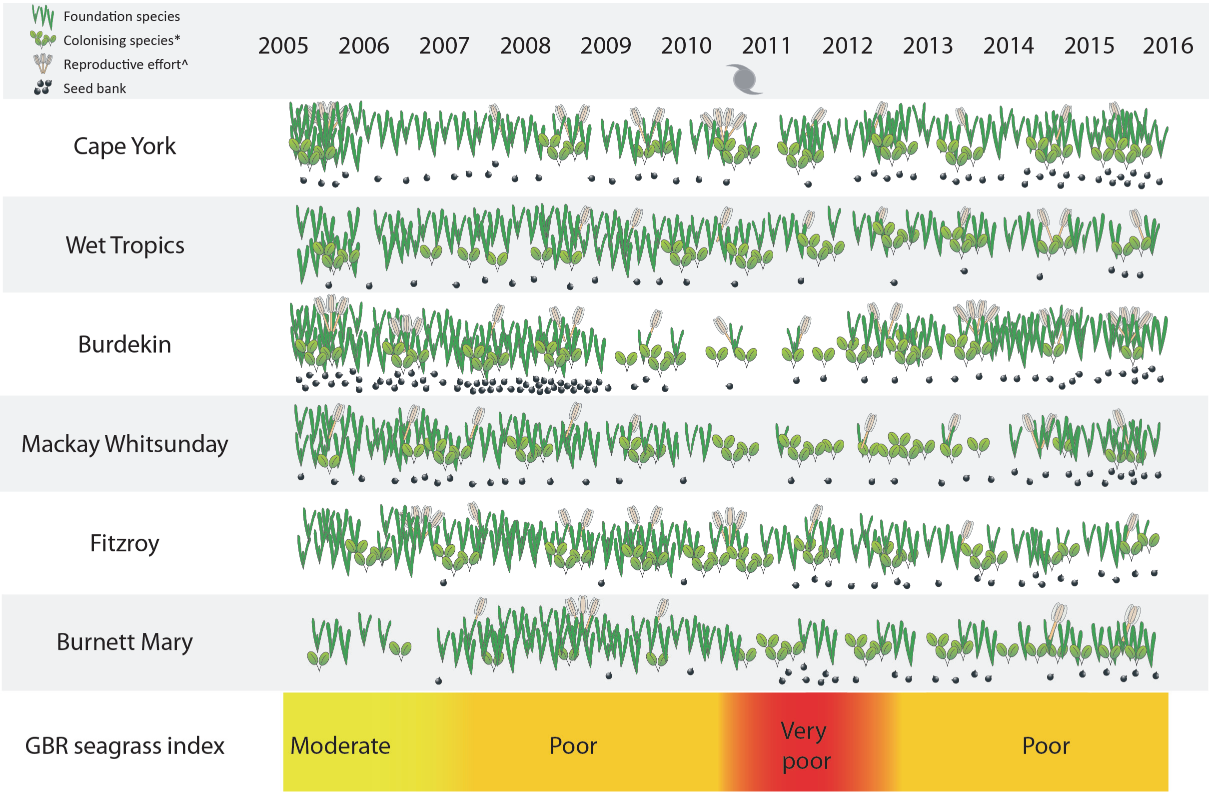

Figure 118. *Summary of GBR MMP inshore seagrass state illustrating abundance of foundation / colonising species, seed banks and reproductive effort from 2005 to 2016. * colonising species are represented by the genus Halophila, however, Zostera and Halodule can be both colonising and foundational species depending on meadow state. ^ not conducted in 2005.*

The meadows of the GBR have been in a highly fluctuating state over the past decade, and this disturbance regime is seemingly typical of the region and makes the meadows highly dynamic (e.g. Birch and Birch 1984; Preen, *et al.* 1995; Campbell and McKenzie 2004; Waycott, *et al.* 2007). By contrast, the meadows to the north in the Torres Strait, and to the south in Moreton Bay remain relatively stable over similar time frames (Roelfsema *et al.* 2009; McKenzie, *et al.* 2010c; Roelfsema *et al.* 2013; Carter *et al.* 2014b; Carter *et al.* 2014a).

There was increasing evidence that water quality degradation within the seagrass meadows of the inshore GBR prior to the episodic disturbances of 2011 may have reduced their resilience. Light availability is one of the primary driving factors in seagrass growth and persistence (Collier and Waycott 2009; Brodie, *et al.* 2013;Collier, *et al.* 2012c). Seagrasses can survive in highly turbid sites if restricted to shallow areas where light reaches the canopy around low tide (Petrou *et al.* 2013). Despite this, declines in abundance at intertidal habitats up to 2011 were also likely caused in part by low light levels (e.g. Petus *et al.* 2014c). Low light impacts in intertidal habitats may result from infrequent low tide exposure occurring in summer months when water can be very turbid coincident with high water temperatures which drives faster rates of decline (Collier, *et al.* 2016b). From 2009, reduced canopy light to low and limiting light levels was reported in seagrass meadows across the GBR, and, coincident with this, nutrients (N and P) increased relative to plant requirements.

Consequences of loss

The loss of seagrass as a consequence of reduced water quality and physical disturbance (e.g. cyclones) can have significant flow-on effects to the dugong and green turtle populations which are highly dependent on the local seagrass meadows that provide their primary food supply (Preen and Marsh 1995; Marsh*, et al.* 2011; Meager and Limpus 2012). Malnutrition can make animals prone to disease, and other pre-existing conditions, or force the animals to travel long distances to find alternative food sources. As a consequence of the widespread loss of seagrass along the east coast of Queensland in early 2011, stranding rates of sea turtles and dugong increased during that year across the GBR to some of the highest since records commenced in 1997 (Figure 119) (Wooldridge 2017). In 2015, reported dugong mortalities decreased to the lowest levels since records commenced. Although turtle mortalities have progressively decreased, they remain above the long-term median. The flow-on effects of seagrass loss to other associated fauna or fisheries are less obvious, because in subtropical and tropical systems these may manifest as community shifts rather than losses. As seagrasses are also environmental engineers, declines can have broader consequences to coastal processes, such as reduced carbon sequestration, sediment stabilisation, and habitat connectivity (Waycott*, et al.* 2007; Adams *et al.* 2016; Maxwell *et al.* 2016).

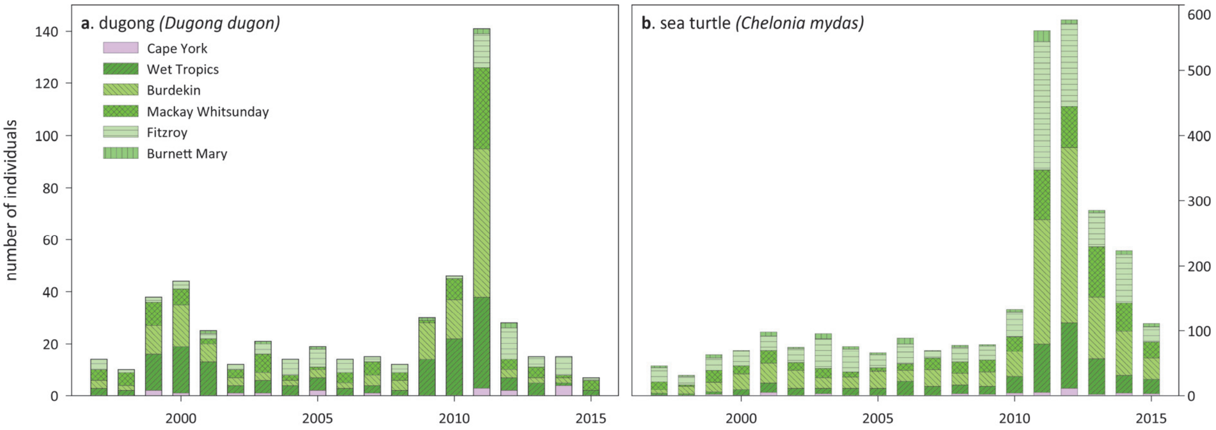

Figure 119. *Annual dugong and sea turtle mortalities attributed to natural or unidentified causes in each NRM region, 1997 to 2015. Mortalities do not include boat strikes, drownings or hunting. Data courtesy StrandNet, accessed 04 October 2016*

Outlook

Throughout the inshore GBR, the rate of seagrass recovery since 2011 appears slower than expected in some locations and habitats compared to previous reports (e.g. Birch and Birch, 1984; Campbell and McKenzie 2004b), particularly at reef locations. This appears a consequence of low seed bank densities prior to the events of 2011, and these densities continue to remain low. At most sites, this is possibly the result of low reproductive effort; the causes for which are a priority for investigation. At remaining sites there is some reproductive effort, however seed banks are not forming or persisting either because no seeds are being produced, or seeds are lost through other processes, such as predation. The presence of seeds is fundamental to building resilience at reef sites, as without them the meadows remain vulnerable to large disturbances and would need to rely on recruitment of propagules from other meadows (Grech *et al.* 2016) or assisted recovery would be required.

The capacity of seagrass meadows to naturally recover community structure following disturbance involves the maintenance of favourable environmental conditions including light availability, nutrient loads and the absence of major physical disturbances. For example, the low and variable light availability across the GBR habitats in 2014-15 and 2015-16 may have slowed recovery, which in turn may reduce capacity to produce a viable seed banks in some locations (van Katwijk *et al.* 2010). Absence of a seed bank at some sites and poor reproductive effort across the GBR, has left most of the MMP meadows vulnerable to further environmental perturbations.

There is also concern that seagrass may not fully recover to previous levels due to a globally changing climate (Stocker *et al.* 2013). Sea surface temperatures of the GBR have significantly warmed since the late 19th century (Figure 120), at a rate of 0.1°C from 1951-2012 with March, April and May in 2016 the warmest months on record since 1880 (Schaffelke *et al.* 2017). Rising sea temperatures can elevate seagrass respiratory load, increasing light requirements for photosynthesis to balance metabolic demand, and exacerbate the negative effects associated with the already low and variable light availability across GBR habitats.

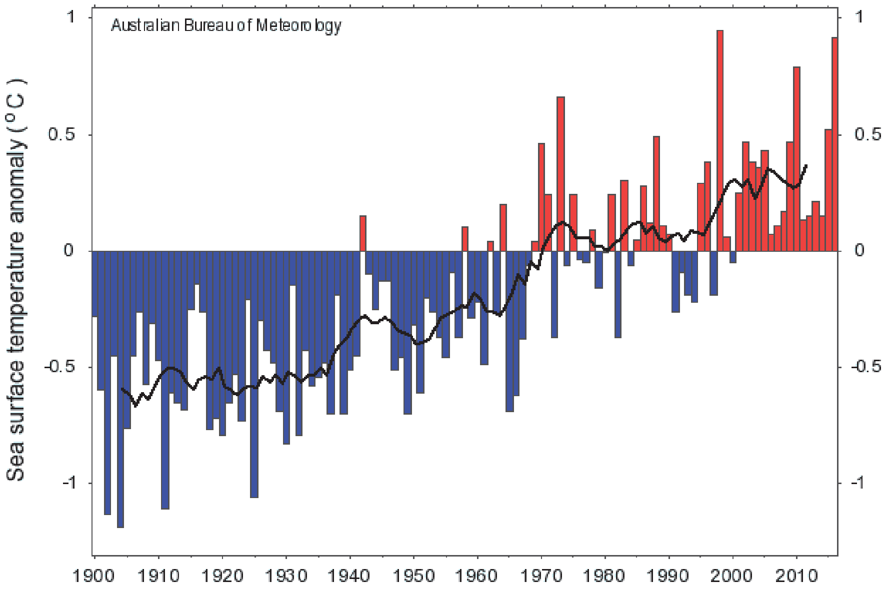

Figure 120. *Annual sea surface temperature anomalies for the Great Barrier Reef (1990 – 2016), based on a 30-year climatology (1961-1990) with a 10-year running average shown by black curve. From BOM*

Disturbance regimes have also changed. In the eleven-year period since the Marine Monitoring Program began in 2005, nine category 3 or above cyclones have affected the GBR. All of the category 5 cyclones that affected the region since 1970 have occurred in the last decade (including Tropical Cyclones Larry, Hamish, Yasi, Ita and Marcia) (Figure 121). The combined paths of all severe cyclones since 2005 have exposed more than 80 per cent of the GBR to gale force or stronger winds (Figure 121). These disturbance events in concert with rising sea water temperatures, continue to undermine seagrass resilience in some habitats.

Implementing strategies to improve recovery and ultimately resilience of seagrass ecosystems across the GBR will need to account for rising temperatures and changing disturbance regimes in attempting to avert any future losses due to reduced water quality. The GBR is not alone in this challenge, as recent findings from overseas propose that managers must increase their water quality targets at the local and regional levels to offset losses caused by global factors outside their immediate control (see Lefcheck *et al.* 2017). This is particularly important for the GBR as we embark on a series of integration exercises to define seagrass desired state targets and derive ecologically relevant targets for water quality and terrestrially sourced sediment loads (see NESP TWQ 2017).

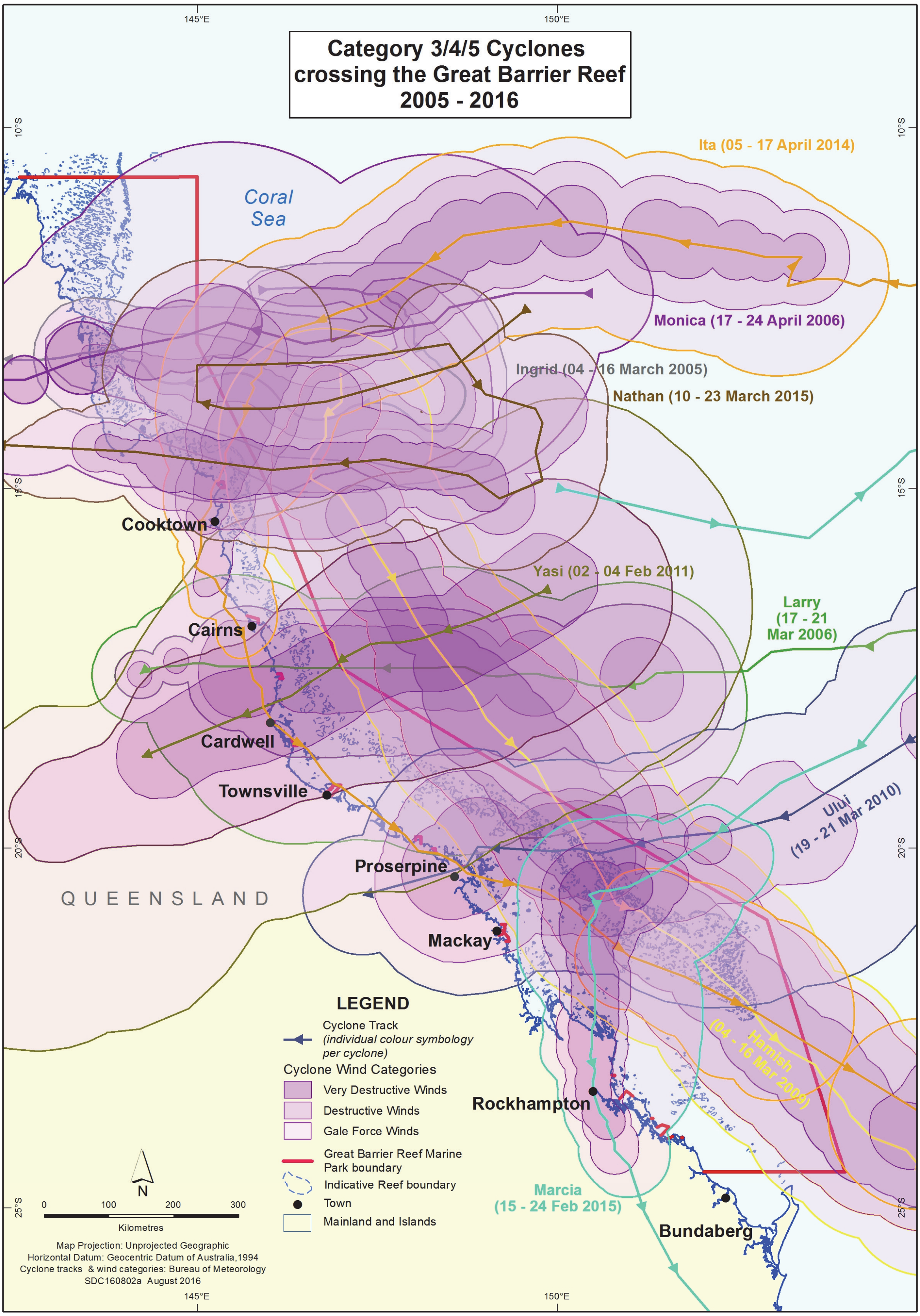

Figure 121. *Tracks and wind zones for all category 3, 4 and 5 cyclones which crossed the Great Barrier Reef 2005-2016. Courtesy GBRMPA.*

6 Case study - Response of seagrass abundance to temperature and light among habitat types.

6.1 Introduction

Light is essential for seagrass growth as it drives photosynthetic carbon uptake. At sub-saturating light levels, this relationship is approximately linear so that increasing light leads to increasing photosynthetic carbon uptake, and therefore more carbon is available for investment into biomass production and reserve formation (Fourqurean et al 1991, Zimmerman et al 1995). Light affects seagrass distribution, in particular the depth limit, which is typically constrained by the minimum light requirement for seagrass survival (Dennison 1987b). Light limitation can arise when water quality is reduced by suspended sediment, plankton blooms, and by high concentrations of coloured dissolved organic matter, or organic flocculent. Light limitation can also be caused by dense cover of epiphytes or macroalgal blooms over growing seagrass meadows. Light limitation causes seagrass growth rates to slow, and after critical light thresholds have been exceeded for a prolonged period (1-14 weeks, depending on species), leaves and shoots are senesced, causing reductions in biomass and cover (Collier*, et al.* 2012b; Chartrand *et al.* 2016a; Collier *et al.* 2016a). Complete mortality occurs after 2 weeks to 2 years, depending on the species, timing and the severity of light limitation (Collier *et al.* 2009a; Lavery *et al.* 2009; Collier*, et al.* 2016a). The physiological and morphological changes, and plant responses to minimize the consequences of light limitation have been detailed elsewhere (Ralph *et al.* 2007).

Water temperature also exerts a strong control over seagrass photosynthesis, growth and biomass production, and therefore seasonally varying temperatures affects abundance (Lee *et al.* 2007b). Temperature extremes can impair photosystems (Campbell *et al.* 2006b), reducing overall photosynthetic carbon incorporation (Adams *et al.* 2017). Respiratory rates are also increased with temperature, and prolonged exposure to temperature extremes can induce mortality through the combined effects of photosystem impairment and respiratory carbon loss (Collier and Waycott 2014). Very shallow and intertidal habitats are at the greatest risk of exposure to extreme temperature, because temperature can heat to over 40^{o}C (this report). Elevated temperature also enhances the effects of light deprivation (Collier*, et al.* 2016a) and herbicide exposure (Wilkinson *et al.* 2015), and chronic increases in temperature can drive seagrass mortality (Marbá and Duarte 2010).

Inshore seagrass abundance (per cent cover) on the GBR has been through a period of decline (2009 – 2011) caused by extreme weather conditions, poor water quality and reduced light reaching seagrass for photosynthesis (this report, Collier*, et al.* 2012b; Petus *et al.* 2014b; Rasheed*, et al.* 2014). Prior to those events, subtidal seagrass habitats were considered the most vulnerable to light reduction because they do not receive high light during low tide to the same extent as do the intertidal/very shallow seagrass habitats. However, habitat type does not appear to have affected vulnerability to the extreme climatic conditions (as seagrass cover and biomass declined in all habitats) and therefore the relative vulnerability to low light among habitats may not be as distinct as initially believed. All GBR NRM regions have shown some signs of recovery, which may have been facilitated by less extreme conditions (as detailed in this report) and by light levels that have been higher than those in 2009-2011, particularly during the wet season.

The objectives of this case study were to:

1. Identify the role that water temperature and light availability have in changing seagrass abundance within the GBR.
2. Identify whether responses to temperature and light differ among habitat types.

6.2 Methods

All temperature, light and seagrass percent cover data was collated (Table 36). Temperature and light data is limited by the start date of collection. Abundance data (per cent cover) is available from the start of the temperature and/or light series at all sites; however, abundance is recorded only 1 to 4 times per year depending on the location, whereas temperature and light is recorded continuously using deployed *in situ* loggers. Therefore, the analysis is limited by frequency of abundance sampling at each site. At a number of sites there were fewer than 5 sampling events which included all three parameters: BY1, BY2, HM1, JR1, JR2, MP2, MP3, SR1, SR2, ST1 and ST2.

The effects of mean daily temperature (°C) and mean daily light (mol m^{-2} d^{-1}) on seagrass percent cover (site mean per sampling event) were analysed using linear models. Firstly, an analysis was conducted on all data with habitat as an interaction factor (percent cover ~ light*temperature*habitat) in the statistical program R (betareg package) using a beta distribution for proportional data (i.e. percent cover). The effect of temperature and light were tested for four different history or averaging times (15d, 30d, 60d and 90d prior to per cent cover sampling) to identify the best temperature or light indicator period (sensu. Adams *et al.* 2015). The full model was run for each combination of averaging times for light and temperature. The Akaike information criterion (AIC) was used to select the best model on the basis of the combination of averaging times, and the AIC was also used to identify whether the best model included both light and temperature or only one of these parameters. Light and temperature were checked for correlation.

This analysis identified an interaction between habitat type and light (light * estuarine $p<0.001$; light * reef subtidal $p<0.01$), or habitat and light and temperature (light * temperature * reef intertidal, $p<0.05$). Therefore, a second analysis was conducted for each habitat separately. This second analysis was a Bayesian general linear model run in JAGS (4.2.0) through R. The data was again analysed using a beta distribution (betareg) with a logit link function with light, temperature and site as parameters (percent cover ~ Std.Light * Std.Temp * Site). Logitlink gives the log-odds of the parameter (or the logarithm of the odds), and therefore also produces non-linear relationships towards the edges of the data range. Temperature and light were standardized (MyStd(x) = (x - mean(x)) / sd(x)) for the analysis. The analysis was conducted on percent cover data, and a separate analysis was also conducted on site-standardized cover (z-score transformation), but the transformed variable did not improve the model (i.e. it had higher AIC) so the untransformed form for the response variable (i.e. percent cover) was retained for all subsequent analyses. Replicate sites within a location (e.g. GI1, GI2) were included as separate sites in the analysis (i.e. they were not averaged).

The analysis produces 3-dimensional distribution plots (abundance, light, temperature). For illustrative purposes, the response to temperature is shown for an upper (but not the highest) and lower light level, and the response to light is shown for an upper and lower temperature. The Bayesian analysis produces a posterior probability distribution, with credible intervals (CIs) within which 95 per cent of the predictions occur. This is analogous to (but different to) the confidence interval. If zero falls within the credible interval of a parameter estimate (i.e. 2.5 per cent = -1, 97.5 per cent = 1) then this parameter does not have a “significant” effect on the response variable as it is potentially equal to 0. If the credible interval does not include zero, then the parameter does have a “significant” effect on the response variable. Therefore, results are presented as whether zero is excluded i.e. YES, for an important variable or NO for one that is not.

It was not possible to run an analysis on habitat within region because of the imbalanced representation of habitats in the regions. For example, estuarine sites are sampled only in the southern 3 regions, and subtidal reef sites are sampled in the Wet Tropics and Burdekin regions. Therefore, the analysis for habitat and region were conducted separately. This analysis was also conducted for each NRM, however, there were few significant results and they have not been included here for brevity.

Table 36. *Data availability including start date of collection for temperature and light.* †*=subtidal.*

Region	Habitat	Site	First Date Temp	First date light	#data
CY	Reef	**AP1**	27/03/09	26/10/15	**1**
CY	Reef	**AP2**	5/05/08	27/10/15	**1**
CY	Coast	**BY1**	26/09/12	17/09/13	**2**
CY	Coast	**BY2**	26/09/12	17/09/13	**3**
CY	Reef	**FR1**	28/09/12	19/09/13	**2**
CY	Reef	**FR2**	28/09/12	19/09/13	**2**
CY	Coast	**SR1**	27/09/12	25/04/13	**2**
CY	Coast	**SR2**	27/09/12	25/04/13	**2**
CY	Reef	**ST1**	25/09/12	27/04/13	**1**
CY	Reef	**ST2**	25/09/12	27/04/13	**2**
WT	Reef	**DI1**	30/07/08	30/07/08	**15**
WT	Reef	**DI2**	30/07/08	30/07/08	**18**
WT	Reef†	**DI3**	3/03/09	3/03/09	**16**
WT	Reef	**GI1**	7/10/03	10/01/09	**26**
WT	Reef	**GI2**	16/04/07	10/01/09	**27**
WT	Reef†	**GI3**	10/01/09	10/01/09	**21**
WT	Reef	**LI1**	5/02/15	28/01/09	**3**
WT	Reef†	**LI2**	26/11/08	28/01/09	**21**
WT	Coast	**YP1**	22/01/04	29/01/10	**19**
WT	Coast	**YP2**	23/01/04	29/01/10	**16**
B	Coast	**BB1**	28/08/04	5/07/09	16
B	Coast	**JR1**	25/04/13	7/09/15	1
B	Coast	**JR2**	22/09/14	7/09/15	1
B	Reef	**MI1**	13/10/05	5/05/08	25
B	Reef	**MI2**	16/10/05	30/01/10	17
B	Reef†	**MI3**	20/03/08	20/03/08	30
B	Coast	**SB1**	20/01/04	16/05/11	17
MW	Coast	**MP2**	26/03/14	15/05/15	1
MW	Coast	**MP3**	26/03/14	15/05/15	2
MW	Coast	**PI2**	23/01/04	28/03/10	9
MW	Coast	**PI3**	22/01/04	28/03/10	5
MW	Estuary	**SI1**	22/07/06	8/10/10	3
MW	Estuary	**SI2**	5/10/06	8/10/10	4
F	Estuary	**GH1**	28/09/07	20/02/11	16
F	Estuary	**GH2**	28/09/07	20/02/11	16
F	Reef	**GK1**	15/10/08	28/04/10	4
F	Reef	**GK2**	15/10/08	28/04/10	7
F	Reef	**HM1**	28/09/08	27/03/10	2
F	Reef	**HM2**	28/09/08	27/03/10	8
F	Coast	**RC1**	1/05/07	13/04/10	6
F	Coast	**WH1**	9/10/07	14/04/10	10
BM	Estuary	**RD1**	15/10/08	18/02/11	9
BM	Estuary	**RD2**	15/10/08	4/10/09	8
BM	Estuary	**UG1**	30/10/05	4/04/11	4
BM	Estuary	UG2	25/04/06	4/04/11	8

6.3 Results & Discussion

6.3.1 GBR-wide summary

There was no overall effect of light or temperature on percent cover in the GBR-wide analysis; however, an interaction between light and habitat (reef subtidal and estuarine), and between light, temperature and habitat (reef intertidal) indicates that light is required for predicting percent cover in these habitat types and temperature is needed at reef intertidal habitat. On the basis of this, further detailed analysis was undertaken on each habitat in order to explore the effects of light and temperature.

Table 37. *Summary of a GBR-wide glm (frequentist) of temperature and light effects on percent cover, including habitat type.*

parameter	*Estimate*	*Std Error*	*z*	*P-value*	*Sig*
(Intercept)	-1.87	0.10	-18.63	<0.001	***
Light	0.15	0.08	1.83	0.07	
Temperature	0.15	0.10	1.52	0.13	
Estuarine	-0.21	0.16	-1.27	0.20	
Reef intertidal	0.00	0.13	0.02	0.98	
Reef subtidal	0.81	0.25	3.22	0.00	**
light:temp	0.04	0.09	0.46	0.65	
light:estuarine	-0.77	0.16	-4.69	0.00	***
light:reef inter	0.02	0.13	0.13	0.90	
light:reef sub	0.71	0.23	3.04	0.00	**
temp:estuarine	-0.01	0.15	-0.08	0.94	
temp:reef inter	-0.11	0.14	-0.79	0.43	
temp:reef sub	-0.09	0.27	-0.33	0.74	
light:temp:estuarine	0.11	0.15	0.71	0.48	
light:temp:reef inter	0.31	0.14	2.21	0.03	*
light:temp:reef sub	0.19	0.25	0.78	0.44	

6.3.2 Coastal habitat

For coastal habitats, the data sets that included ≥ 5 records (sampling events) for all three variables were from the sites PI2,PI3 (Mackay Whitsunday), SB1, BB1 (Burdekin), RC1,WH1 (Fitzroy) and YP1,YP2 (Wet Tropics). The results of the analysis had poor residuals when BB1 (Burdekin) was included making the model unreliable, so it was also removed for the final analysis for coastal sites.

The best model for percent cover at coastal sites was:

percent cover ~ light.std 90d * temp.std 15d * site

Water temperature significantly affected percent cover at coastal sites (Table 38), with cover increasing at higher temperatures, i.e. in summer (Figure 122). The prediction for percent cover at Shoalwater Bay (WH1 and RC1) was also different to that of the reference site in the analysis (PI2), requiring an adjustment of the estimate to predict the posterior distribution of percent cover (i.e. percent cover was higher at WH1 and RC1 than at PI2), while other sites did not (Table 36).

Light did not have a significant effect on percent cover in coastal habitat even though they have high frequency of exposure to turbid water or to green, plankton-rich water (see frequency of exposure tables in each NRM). Coastal habitats also have the most frequent exceedance of light thresholds among intertidal habitats (see Figure 9 in main document), which could place them under light stress. These habitats are exposed to a range of complex environmental conditions that influence their average cover and changes in cover, including: temperature stress, desiccation, physical disturbance (e.g. wind), and grazing by dugongs and sea turtles (Carruthers *et al.* 2002b). Furthermore, these coastal meadows have been in a period of recovery from loss in 2009 – 2011. The majority of the data points are available from after the period of loss, or after considerable loss had already occurred (i.e. some sites were set up in 2009 or 2010) and light may not be the main primary limiting factor for recovery. In addition to the other aforementioned environmental conditions that affect coastal habitat, recruitment process and ecological changes during recovery (e.g. changing species composition), may also affect changes in percent cover during recovery. This highlights our general lack of understanding about recovery processes.

Table 38. *Results of the GLM for coastal sites*

parameter	*Estimate*	*Std error*	*2.5 per cent CI*	*97.5 per cent CI*	*0 not included in CI = important*
Intercept	-2.753	0.304	-3.38	-2.18	**YES**
Light.std	-0.250	0.138	-0.52	0.016	No
Temp.std	0.423	0.098	0.24	0.615	**YES**
Site PI3	0.084	0.437	-0.82	0.887	NO
Site RC1	1.432	0.455	0.55	2.362	**YES**
Site SB1	-0.307	0.334	-0.93	0.381	NO
Site WH1	1.246	0.456	0.32	2.151	**YES**
Site YP1	0.306	0.366	-0.40	1.066	NO
Site YP2	0.469	0.360	-0.21	1.220	NO
*Light.std*temp.std*	0.037	0.092	-0.14	0.225	NO
theta	16.75	2.86	11.66	22.69	**YES**

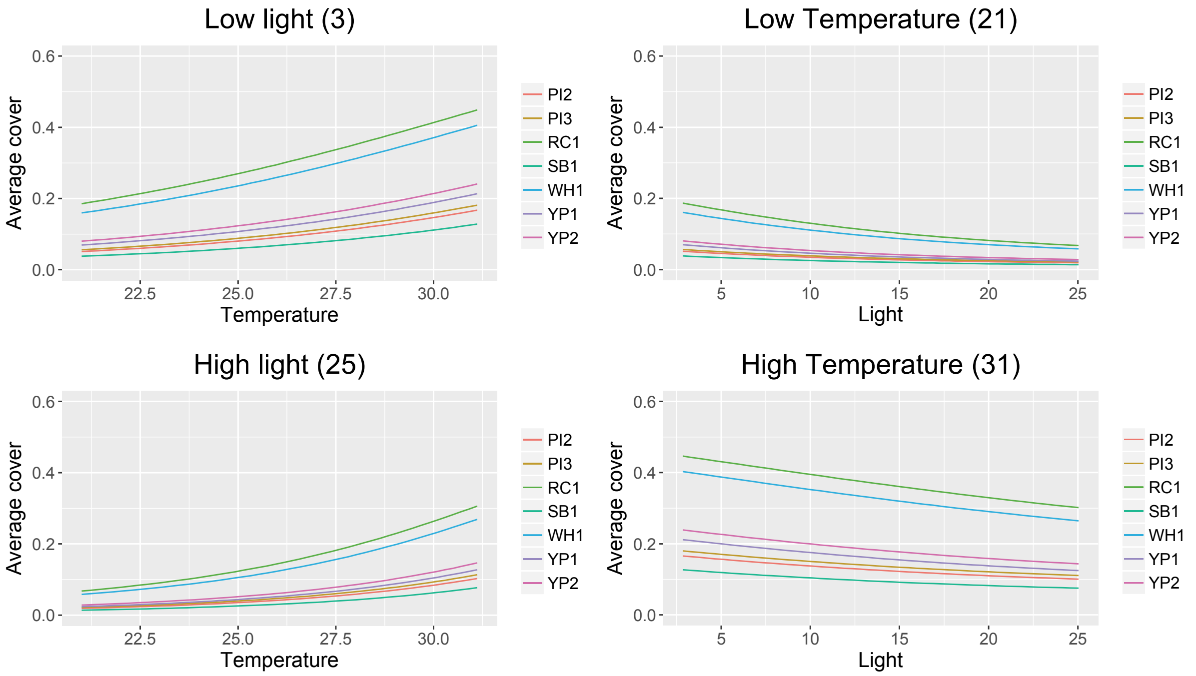

Figure 122. *Posterior distribution of percent cover in coastal habitats against temperature (left) at low light (3 mol m^{-2} d^{-1}) and high light (25 mol m^{-2} d^{-1}), and against light (right) at 21°C (top) and 31°C (bottom). The distribution is presented for each site separately.*

6.3.3 Reef intertidal

Of the intertidal reef sites, ≥5 records for all three variables occurred at DI1, DI2, GI1, GI2 (Wet Tropics), MI1, MI2 (Burdekin), GK2 (Fitzroy), and HM2 (Mackay Whitsunday). GK2 and HM2 had high variance making it very difficult to run the glm and furthermore they had only 7 and 8 records each, therefore, this analysis was conducted without GK2 and HM2. Light and temperature were correlated in data for reef intertidal sites.

The best model for percent cover at reef intertidal sites was:

percent cover ~ light.std 90d * site

Daily light had a significant effect on seagrass abundance, with per cent cover increasing at higher light intensities. Highest cover and highest daily light occurs during the late dry season, (i.e. late spring). Lowest cover occurs during the late wet (i.e. April) or during winter when daily light is also lowest. Light and temperature were uncorrelated in this data set and therefore, temperature does not explain the seasonal responses. These meadows have also undergone a period of loss due to light limitation. Because of the differences in per cent cover among locations, there was also an adjustment of the intercept (compared to DI1) for GI1, GI2, MI1, MI2.

Note, when GI1 and GI2, were investigated there was a strong temperature effect (frequentist glm temperature p <0.001, data not shown).

Table 39. *Results of the Bayesian glm on percent cover, light and temperature at reef intertidal sites. The best model excluded temperature.*

parameter	Estimate	Std error	2.5 per cent CI	97.5 per cent CI	0 not included in CI = important
Intercept	-3.437115	0.257309	-3.953897	-2.96833	**YES**
Light.std	0.187074	0.071615	0.043798	0.32715	**YES**
Site DI2	0.081335	0.329616	-0.567068	0.72593	NO
Site GI1	2.805214	0.275430	2.298831	3.38874	**YES**
Site GI2	2.294617	0.273786	1.781589	2.86206	**YES**
Site MI1	1.544228	0.284333	1.006015	2.12389	**YES**
Site MI2	2.217494	0.288319	1.685743	2.78486	**YES**
theta	14.870815	1.958851	11.342919	19.04845	**YES**

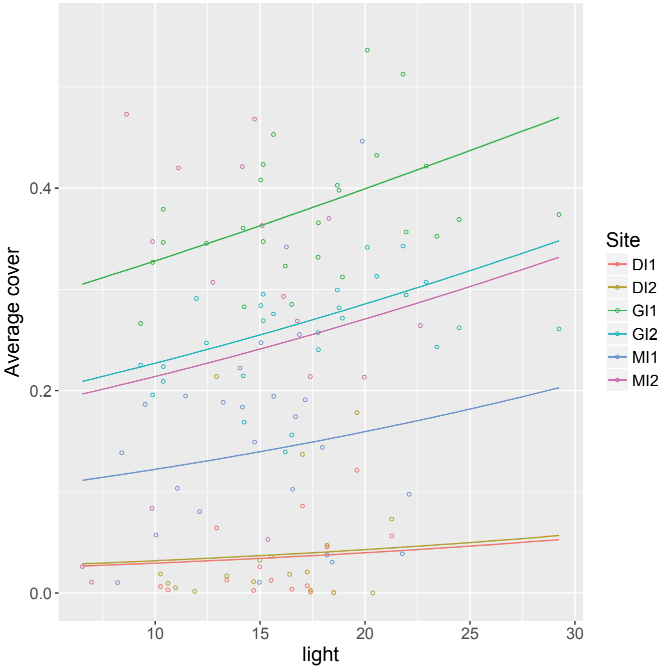

Figure 123. *Posterior distribution of percent cover in intertidal reef habitats against light. The best model (lowest AIC), did not include temperature, so response to light only is shown here. The distribution is presented for each site separately.*

6.3.4 Reef subtidal

Four reef subtidal sites are sampled in the GBR MMP. The best model (lowest AIC) for the reef subtidal sites included light only; however, MI3 was creating poor residual patterns in that model and it could not be considered reliable. Therefore, the glm was run for LI2, GI3 and DI3 only which are all in the Wet Tropics and it did not include MI3 (B).

The best model for reef subtidal sites was:

percent cover ~ light.std 60d * site

Light did not have a significant effect on seagrass per cent cover at these reef subtidal sites, however, there was only minor overlap of the CIs with zero owing to a weak trend of increasing percent cover with light (Figure 124). Light is expected to be occasionally limiting at subtidal sites due to the lower overall light availability and the high frequency with which the light thresholds are exceeded (ranging from 4.5 to 45 per cent of days each year on average (Figure 9). LI2 has had low and variable seagrass cover dominated by *H. ovalis* since monitoring began in 2008 and moderate threshold exceedance (27 per cent of days). At DI3 low cover in 2008-09 was reduced to zero cover in 2011 with slow recovery beginning only in 2014 with threshold exceedance on 31 per cent of days. At GI3 there has been no long-term change in percent cover, though percent cover has varied, and thresholds have been exceeded on 4.5 per cent of days on average. The slight trend for percent cover increasing with light at reef intertidal sites is possibly driven by a combination of long-term trends, but also caused by seasonal variation in light and percent cover.

Light thresholds have been exceeded at Magnetic Island (MI3) with the greatest frequency among the subtidal meadows indicating that it is a light-limited meadow. There have been dynamic changes at Magnetic Island, including substantial loss (zero seagrass recorded in transects in 2011) and subsequent recovery (>60 per cent cover in 2014-15). Low light likely drove losses at Magnetic Island in 2009-2011, but since then, there has been frequent exposure to secondary green water (Waterhouse*, et al.* 2017), and periods of low light particularly in early 2013 and 2014. Despite this, percent cover increased until 2014-15 when there was a slight, reversal of this trend. Therefore recovery has occurred since 2011 despite periods of low and limiting light and when the light glm was run on MI3 only, there was a weak ($p = 0.082$) negative effect of light on abundance. Thus the reef subtidal model was not a good fit when Magnetic Island was included. This trend appears to be counter to those observed at the other reef subtidal sites, and the model could not be applied across them all. Again, this highlights the need for greater understanding of recovery processes and the factors limiting, or enhancing recovery.

Table 40. *Results of the Bayesian glm on percent cover, light and temperature at reef subtidal sites. The best model excluded temperature.*

parameter	Estimate	Std error	2.5 per cent CI	97.5 per cent CI	0 not included in CI = important
Intercept	-3.188211	0.25268	-3.677859	-2.70558	**YES**
Light.std	0.267322	0.14377	-0.022168	0.54767	No but close
Site GI3	2.490029	0.24723	1.999974	2.94793	**YES**
Site LI2	-0.018377	0.25410	-0.520054	0.48433	No
theta	23.698737	4.21654	16.431318	32.68999	**YES**

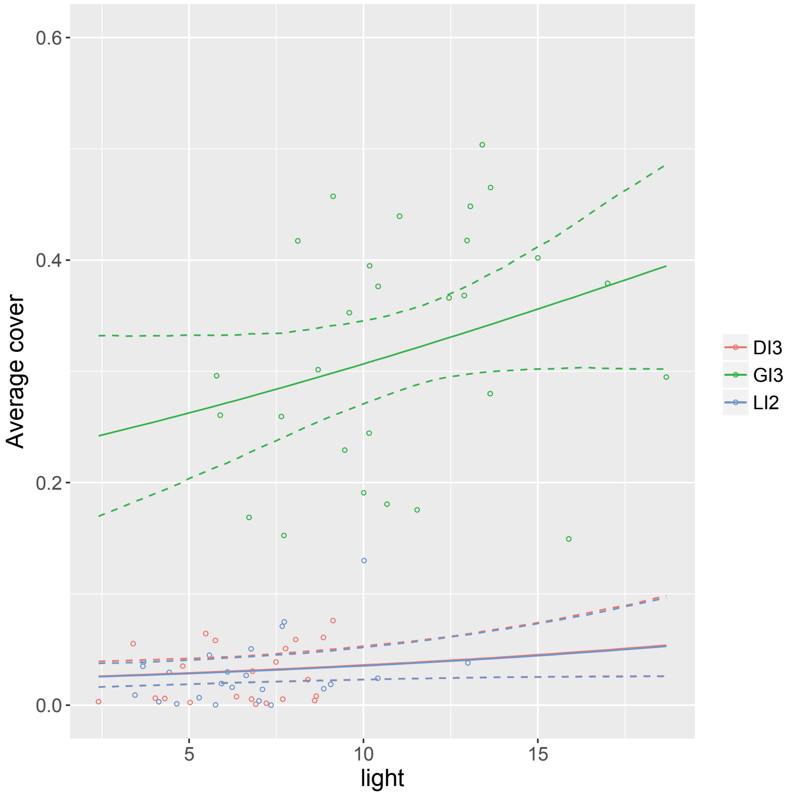

Figure 124. *Light and seagrass percent cover at reef subtidal sites (LI2, GI3, DI3).*

6.3.5 Estuarine intertidal

Estuarine intertidal sites are located in the three most southern GBR regions; however, there were insufficient data points from SI (Mackay Whitsunday) to include in the analysis. Therefore the glm was run for GH1, GH2 (Fitzroy), RD1, RD2 and UG1, UG2 (Burnett Mary). Rodds Bay (RD1, RD2) has very low cover despite having high light availability and this is probably because of physical disturbance from wave action, sediment movement, *etc*. Therefore, the analysis was run for GH1, GH2, UG1 and UG2 only.

The best model for estuarine sites was:

percent cover ~ light.std 90d * temp.std 15d * site

There was no effect of light or temperature on percent cover at these estuarine intertidal sites (Table 41).

Table 41. *Results of the Bayesian glm on percent cover, light and temperature at estuarine sites.*

parameter	Estimate	Std error	2.5 per cent CI	97.5 per cent CI	0 not included in CI = important
Intercept	-1.533419	0.21403	-1.96053	-1.111029	**YES**
Light.std	0.003484	0.15915	-0.31121	0.311207	NO
Temp.std	0.067460	0.12804	0.17522	0.324936	NO
Site GH2	0.269154	0.25682	-0.22021	0.769839	NO
Site UG1	-1.602986	0.42518	-2.49480	-0.799974	**YES**
Site UG2	-0.555981	0.34090	-1.24566	0.090675	NO
*Light.std*temp.std*	0.050885	0.14854	-0.24667	0.339350	NO
theta	10.075377	2.12916	6.38493	14.721557	**YES**

6.3.6 Possible further work

1. The GBR is a diversity hotspot, hosting 15 species of seagrass that fall across the spectrum of growth forms ranging from colonisers (fast-growing e.g. *Halophila* spp.), opportunistic (e.g. *Halodule, Zostera*) and persistent species (slow-growing foundational species, e.g. *Thalassia* and *Enhalus*) (sensu. sensu. Kilminster*, et al.* 2015). These species differ in their sensitivity to light (Collier*, et al.* 2016a; Collier *et al.* 2016c) and to temperature (Campbell*, et al.* 2006b; Collier *et al.* 2011a; Collier and Waycott 2014). This analysis has been conducted on average percent cover at the site, irrespective of species composition. Generally speaking, the four habitat types differ in the species that can be found within them (e.g. estuarine sites are dominated by *Zostera muelleri*), and therefore the differences in results by habitat are partially driven by species differences. However, the analysis could be re-run on the basis of percent cover of individual species, or of species groups, which could reveal a more distinct response to environmental conditions.
2. The effects of temperature and light could be in a broader analysis investigating how environmental conditions affect percent cover and/or species composition. This could include a greater variety of environmental variables such as river discharge, water type exposure, sediment type, tissue nutrients (as a proxy for nutrient availability). However, this would need to be undertaken at a coarser temporal level (e.g. annual changes) or a spatial level as the environmental data required for such analysis are less frequent (e.g. water type exposure is an annual wet season value and tissue nutrients are measured once per year in the dry season). Such analysis could provide further insight into the relative role of these environmental drivers in the spatial-temporal percent cover changes.
3. The effects of light and temperature can be tested using alternative indicators. For example, threshold values representing light limitation have been defined for the opportunistic species (*H. uninervis*, *Z. muelleri*, *C. serrulata*), and the frequency in which these thresholds are exceeded could be a better predictor of changing abundance than total daily light.
4. Environmental conditions could be pooled to assess risk to seagrass habitat on the basis of departure from long-term medians using a risk scoring technique. Such an analysis could include any environmental data for which we have a long-term record and could provide the basis against which to interpret and report on environmental conditions on an annual basis.
5. The effect of environmental conditions on percent cover can be predicted using physiological data (including P-I curves, temperature-response curves, herbicide dose-response curves). A departure from modelled vs actual changes in cover could indicate information gaps. This analysis is planned as future work for the 2016-17 reporting year.

6.4 Conclusions

The findings from this preliminary analysis indicate that light and temperature do not appear to exert a strong control on seagrass percent cover for the period of time included. Light had a weak effect on percent cover at reef sites (significant at intertidal, but not at subtidal). However, there was correlation between light and water temperature at reef sites, indicating that this relationship was caused by seasonal changes. There was no effect of light or temperature on percent cover at estuarine intertidal sites. At coastal sites, seasonal changes in temperature dominated the overall changes in percent cover, and daily light did not have a significant effect.

This analysis has been conducted at a time of dynamic changes in the GBR caused by extreme climatic conditions, and most of the data comes from the period of recovery (early 2011- 2016) compared to during loss (late 2008 – early 2011). The analysis has been further constrained by data availability, in particular, the date of initial deployment of loggers (many only deployed in 2010 or 2011), and due to infrequent sampling at some locations (1-2 times per year). While light limitation is thought to have been the primary cause of loss in 2009-2011, light and temperature do not appear to be the primary limiting factors for recovery. However, this should not be interpreted as light and temperature not affecting percent cover or driving recovery. Indeed, recovery would not have been possible if light levels were not sufficient, or if climatic conditions had led to extreme temperature stress. This analysis highlights that there are other environmental conditions or biological processes that are limiting the rate of recovery and these are as yet not identified. This underscores the need for greater understanding of recovery processes including environmental requirements and ecological processes.

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Appendix 1 Background to the NRMs, including conceptual models

Results and discussion of monitoring are presented firstly in a GBR general overview and then by the NRM regions identified in the GBR area. These discrete regions have been used for stratifying issues of land and catchment based resource management and used to report downstream impacts on the reef environment such as from the effect of water quality. There are 56 NRM regions identified in Australia, 15 are in Queensland and six are part of the coastal processes of the GBR. These regions are mostly based on catchments or bioregions using assessments from the National Land and Water Resources Audit. Regional plans have been developed for each of these setting out the means for identifying and achieving natural resource management targets and detailing catchment-wide activities addressing natural resource management issues including land and water management, biodiversity and agricultural practices. Seagrass habitat data forms part of these targets and activities.

A1.1 Cape York

Cape York Peninsula is the northernmost extremity of Australia. From its tip at Cape York it extends southward in Queensland for about 800 km, widening to its base, which spans 650 km from Cairns (east) to the Gilbert River (west). The largest rivers empty into the Gulf of Carpentaria on the west, however there are several significant catchments which empty into the GBR. Major catchments of the region include the Macmillian, Olive, Pascoe, Lockhart, Stewart, Normanby, Jeannie, and Annan Rivers (Figure 207).

The region has a monsoonal climate with distinct wet and dry seasons with mean annual rainfall ranging from 1715 mm (Starke region) to 2159 mm (Lockhart River airport). Most rain falls between December and April. Mean daily air temperatures in the area range between 19.2 – 32.1°C. The prevailing winds are from the south east and persist throughout the year (Earth Tech 2005).

Cape York Peninsula is an area of exceptional conservation value and has cultural value of great significance to both Indigenous and non-Indigenous communities. The majority of the land is relatively undeveloped, therefore water entering the GBR lagoon is perceived to be of a high quality. Cattle station leases occupy about 52 per cent of the total area, mostly located in central Cape York Peninsula but only around 33 per cent are active leases. Indigenous land comprises about 22 per cent, with a significant area of the West coast being held under Native title and other areas being under native title claim. The remainder is mostly declared as National Park including joint management areas with local traditional owners or under other conservations tenures e.g. nature refuges, conservation areas, wildlife reserves. Mining, agriculture, and commercial and recreational fishing are the major economic activities. All these activities have the potential to expand in this region and with this expansion the risk of increased pollutants.

Extensive seagrass meadows are present in the GBRWHA waters of the Cape York NRM region. The seagrass historical baseline for the region was established in October-November 1984 (Coles *et al.* 1987), when the nearshore seagrasses (shallower than 15m depth) were mapped as part of a multi year mapping project for the entire Queensland coast (Lee Long*, et al.* 1993). Initial mapping results from the Cape York region were first published in 1985, however in 2001, this data was entered into a relational database, validated and migrated to GIS format (Coles*, et al.* 2001c). To complement the nearshore mapping, the seagrass historical baseline for deeper water (15m and deeper) seagrass meadows was established in November 1994 (south of Cape Weymouth) and November 1998 (north of Cape Weymouth) (Coles*, et al.* 2009).

Since the historical baselines, there have been several issued focussed fine-scale mapping surveys and the establishment of monitoring sites for the MMP. Seagrass meadows have been found from intertidal regions to depths of 61m near Lizard Island (Coles*, et al.* 2009). Approximately 1,887 km^2 of seagrass meadows have been mapped in the inshore waters of the Cape York region to 15m bMSL (McKenzie*, et al.* 2010c; C. Howley, Unpublished data; Carter *et al.* 2012; Carter and Rasheed 2013; Carter and Rasheed 2014, 2015; Saunders*, et al.* 2015) and an additional 10,878 km^2 in offshore waters (>15m depth) (McKenzie*, et al.* 2010c). Approximately 60 per cent of the mapped seagrass area in the shallow waters (<15m) of the GBRWHA occurs in the Cape York NRM (McKenzie*, et al.* 2010c). Seagrass meadows in the Cape York region were characterized by high diversity and relatively small total biomass (Lee Long*, et al.* 1993). Fifteen species of seagrass have been identified in the region (Coles *et al.* 1985; Coles*, et al.* 1987; Lee Long*, et al.* 1993; Rasheed *et al.* 2005b): *Enhalus acoroides, Halodule pinifolia, Halodule uninervis, Halophila capricorni, Halophila decipiens, Halophila minor, Halophila ovalis, Halophila spinulosa, Halophila tricostata, Cymodocea rotundata, Cymodocea serrulata, Syringodium isoetifolium, Thalassia hemprichii, Thalassodendron ciliatum* and *Zostera muelleri* ssp. *capricorni*. Areas notable as species rich include Barrow Point to Murdoch Point (12 species), Flinders Island and Princess Charlotte Bay (9 species), Weymouth Bay, Cape Direction, Murdoch Point - Lookout Point and Bedford Bay - Cedar Bay (8 species) and Escape River Margaret Bay, Bathurst Bay, Ninian River and Cape Flattery (7 species).

Halodule uninervis and *Halophila ovalis* are the most common species in coastal intertidal areas. *Cymodocea serrulata* and *Syringodium isoetifolium* are found in shallow subtidal areas that are sheltered from the south-east winds in a variety of habitats including estuaries and muddy bays and reef tops (Coles*, et al.* 1987; Lee Long*, et al.* 1993). Subtidal meadows of *Halophila ovalis* and *Halophila spinulosa* are also quite extensive (Lee Long*, et al.* 1993). Species common on coral reef platforms include *Thalassia hemprichii* and *Cymodocea rotundata*, generally around islands and on vegetated cays (Coles *et al.* 2007). *Enhalus acoroides* is usually found as small isolated patches in sheltered embayments (Womersley 1981; Coles *et al.* 2003). Sites that have been revisited since the broadscale surveys in the mid 1980s show that seagrasses generally occurred in similar areas but when surveyed at a finer scale were more extensive (Coles*, et al.* 2007).

Seagrasses in the deeper waters (>15m) have been assessed twice; once between 1994 and 1999 (Coles*, et al.* 2009) and again between 2003 and 2006 (Pitcher *et al.* 2007). The modelled distribution of seagrass species for both time periods shows spatial discontinuities in deep water seagrass meadows along the north-south axis with a low probability of seagrass being present north of Princess Charlotte Bay and extensive seagrass areas in the south of the region extending out from the coast in the Lizard Island region (De'ath *et al.* 2007; Coles*, et al.* 2009). *Halophila ovalis, Halophila spinulosa, Halophila tricostata, Halophila decipiens* and *Halophila capricorni* dominated the meadows in both surveys. The distribution of deepwater seagrasses appears to be mainly influenced by water clarity and a combination of propagule dispersal, nutrient supply, and current stress. Unfortunately monitoring in the deeper waters is beyond the scope of the MMP funds and only intertidal reef and coastal seagrass habitats are currently monitored.

Reef habitats in the Cape York region support diverse seagrass assemblages. Approximately 3 per cent of all mapped seagrass meadows in the Cape York region are located on fringing-reefs (Coles*, et al.* 2007). In these environments, physical disturbance from waves and swell and associated sediment movement primarily control seagrass growth (Figure 125). Shallow unstable sediment, fluctuating temperature, and variable salinity also characterize these habitats. Sediment movement due to bioturbation and prevalent wave exposure creates an unstable environment where it is difficult for seagrass seedlings to establish or persist.

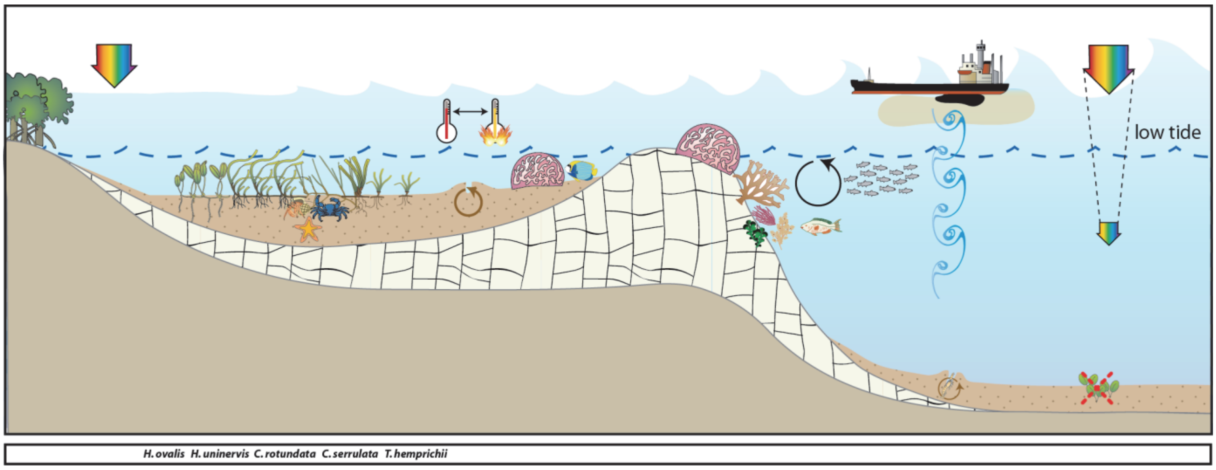

Figure 125. *Conceptual diagram of reef habitat in the Cape York region – major control is pulsed physical disturbance, salinity and temperature extremes: general habitat and seagrass meadow processes (see* Figure 139 *for icon explanation).*

Seagrass meadows on inshore reef habitats were monitored at 3 locations, from the north of the region (12.25°S), to the south (15.6°S) (Table 3). The most southern location (Archer Point) includes a legacy site which has been monitored over the longest time period for the region. The sites at

Archer Point were located in a sheltered section of bay adjacent to Archer Point, fringed by mangroves, approximately 15km south of Cooktown (Figure 207). There are two major rivers within the immediate area: the Endeavour and the Annan River. The Endeavour River is the larger of the two river systems and has a catchment area of approximately 992 km^2. The Annan River is located approximately 5 km south of Cooktown and extends inland from Walker Bay. The Annan River catchment area is approximately 850 km^2 (Hortle and Person 1990).

The other two reef habitat locations were included for monitoring from early 2012: Stanley Island and Piper Reef. Stanley Island is within the Flinders Island group north of Bathurst Bay (Figure 207). The site is a fringing reef site also fringed with mangroves. The islands are influenced by the Princess Charlotte Bay catchment which has four river systems, the Normanby, Marrett, Bizant and North Kennedy Rivers. Piper Reef is approximately 45km north west of Portland Roads, 15 km off the mainland coast (Figure 207). It is influenced by coastal waters from the Olive and Pascoe Rivers along with the Temple Bay catchment. There are minor land use activities in these catchments with some small level housing on the Pascoe River at the Wattle Hills settlement.

Most inshore seagrass meadows in the Cape York region are within coastal habitats. The majority of these meadows are in the shallow subtidal waters of large bays sheltered from the prevailing trade winds. These seagrass meadows are also highly productive and provide important nursery grounds for fisheries (Coles*, et al.* 1987). The meadows are also of important to the large dugong population within the region (Marsh and R 2002). In early 2012, coastal seagrass habitat locations paired with the new reef habitat locations, were also included for monitoring, they included: Bathurst Head (paired with Stanley Island) and Shelburne Bay (paired with Piper Reef). The coastal seagrass meadows at Bathurst Head and Shelburne Bay are located on naturally dynamic sand banks. These meadows are dominated by *Halodule uninervis* with some *Halophila ovalis* and are often exposed to regular periods of disturbance from wave action and consequent sediment movement. A dominant influence to these coastal meadows is exposure to wind/wave disturbance and terrigenous runoff from seasonal rains (Carruthers*, et al.* 2002a) (Figure 126).

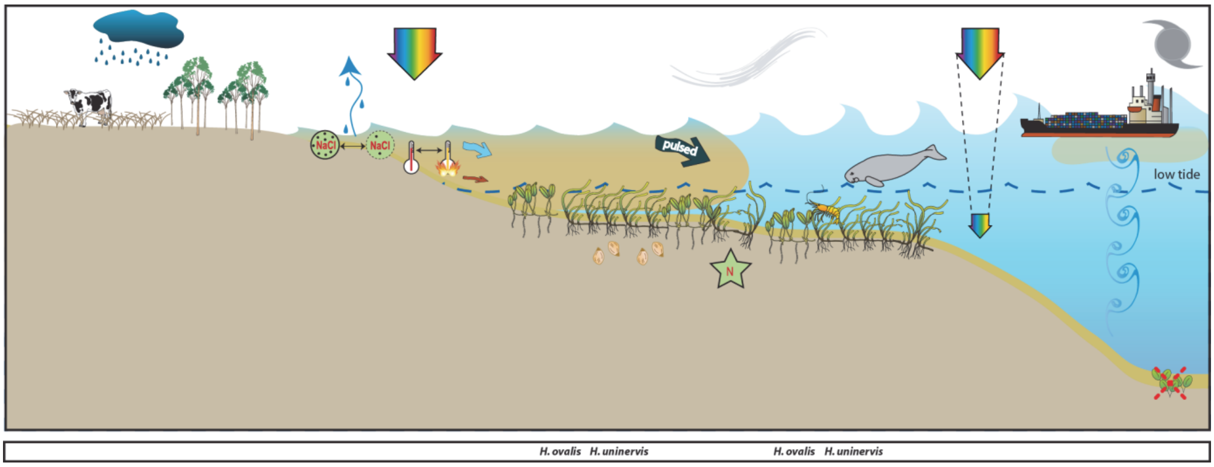

Figure 126. *Conceptual diagram of coastal habitat in the Cape York region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

Bathurst Head is located just east of Combe Point in the Bathurst Bay area to the east of Princess Charlotte Bay (Figure 207). It is a coastal location fringed by mangroves on the eastern edge of the bay. The sites are within 20km of the mouths of the Normanby and Margaret Rivers. The Normanby River is the fourth largest river system flowing into the Great Barrier Reef. The catchment area covers 24,228 km^2 and consists of one of Queensland's largest conservation areas, extensive cattle grazing country (75 per cent of the catchment), and rich agricultural land at Lakeland Downs (Reef Water

Quality Protection Plan Secretariat 2011). Less than 5 per cent of the catchment has been cleared Reef Water Quality Protection Plan Secretariat 2011). Grazing densities are generally low on Cape York Peninsula (~1 beast/40 ha), however, the productive pastures in the Normanby catchment can have densities from ~1 beast/20 ha to >1 beast/5 ha (Cotter 1995).

Shelburne Bay is located 112 km north of Lockhart River and 122 km southeast of Bamaga on the east coast of the GBR. The bay has a limited catchment with only Harmer Creek discharging directly into it, and the MacMillan River discharging into the adjacent Margaret Bay. The catchment contains one of the least disturbed parabolic sand dunes areas in the world and is made up of seasonal wetlands and sand ridges. There are no current land use activities occurring in this catchment. The area is prone to extreme weather with the cyclone database stating that 47 cyclones have tracked within 200km of Shelburne Bay between 1906 and 2007. The monitoring site at Shelburne Bay is approximately 5 km west of the mouth of Harmer Creek mouth.

A1.2 Wet Tropics

The Wet Tropics region covers 22,000 km^2 and land use practices include primary production such as cane and banana farming, dairying, beef, cropping and tropical horticulture (Commonwealth of Australia 2013e). Approximately 6.5 per cent of the seagrass area mapped in the shallow waters (<15m) of the GBR occurs in the Wet Tropics region (McKenzie*, et al.* 2010c). The most extensive areas of seagrass in this region occur around Low Isles, Cairns Harbour, Green Island, Mourilyan Harbour and the Hinchinbrook Island area (between Dunk Island and Lucinda) (Coles*, et al.* 2007). Thirteen seagrass species have been recognised for this region (Lee Long*, et al.* 1993). Nearshore seagrass meadows are situated on sand and mud banks and mostly dominated by *Halodule uninerv*is with some *Halophila* in the northern and southern areas. Intertidal meadows in Cairns Harbour and southern Hinchinbrook channel are dominated by *Zostera muelleri*. Shallow subtidal coastal meadows consist of *Halodule uninervis* and *Halophila* communities mostly along sheltered coasts and harbours (e.g. Cairns Harbour and Mourilyan Harbour). *Cymodocea* spp., *Thalassia* and a suite of *Halophila* species tend to dominate island habitats in the region (e.g. Dunk Island and northern Hinchinbrook Island). Only reef (subtidal and intertidal) and coastal seagrass habitats are currently monitored in the Wet Tropics region.

Coastal seagrass habitats were monitored at Yule Point in the north and Lugger Bay in the south of the region. The seagrass meadows at Yule Point and Lugger Bay occur on shallow sand banks, protected by fringing reefs. Coastal seagrass meadows are dominated by *Halodule uninervis* with some *Halophila ovalis* and are often exposed to regular periods of disturbance from wave action and consequent sediment movement. The sediments in these habitats are relatively unstable restricting seagrass growth and distribution. A dominant influence of these meadows is terrigenous runoff from seasonal rains (Figure 127). The Barron, Tully and Hull Rivers are a major source of pulsed sediment and nutrient input to these coastal meadows.

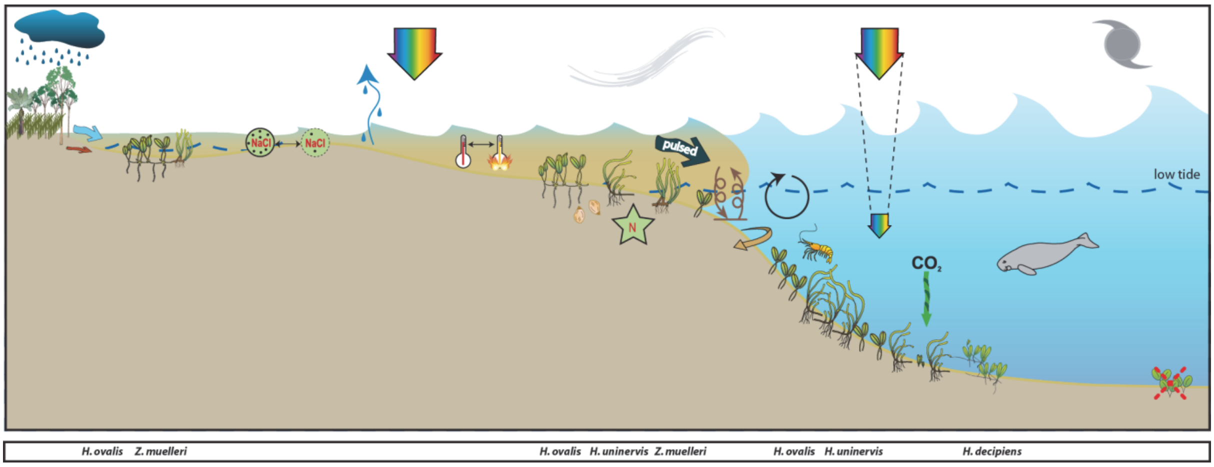

Figure 127. *Conceptual diagram of coastal habitat (<15m) in the Wet Tropics region – major control is pulsed terrigenous runoff, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

Reef seagrass habitats were monitored at Low Isles, Green Island and Dunk Island. Low Isles is located in the north of the region and the monitoring sites were paired intertidal and subtidal (not replicated) (Figure 208). Low Isles is an inshore reef located 15km south east of the Daintree River mouth. Low Isles refers to the two islets of Low Isles reef: Low Island (the cay) and Woody Island (predominantly *Rhizophora* forest). The intertidal site was located near the northern edge of the reef platform between Low Island and Woody Island. This area is dominated by *Halodule uninervis* and *Halophila ovalis*. The subtidal site was approximately 250 north of the intertidal site, in the eastern edge of the anchorage (Low Isles lagoon), and was dominated by *Halophila ovalis* and *Halodule uninervis*.

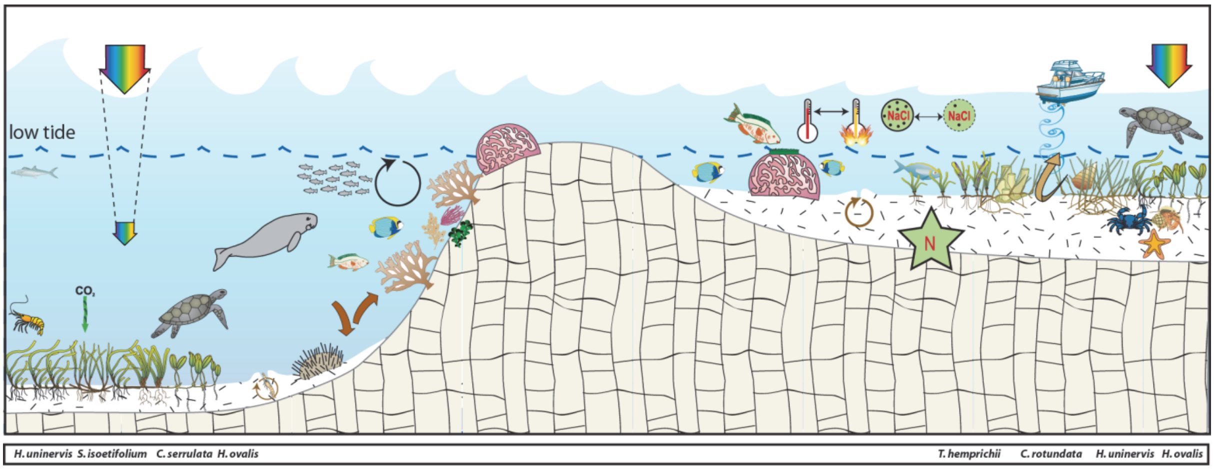

Figure 128. *Conceptual diagram of reef habitat (<15m) in the Wet Tropics region – major control is nutrient limitation, temperature extremes, light and grazing: general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

Green Island is a mid shelf reef located 26km north east of Cairns and the Barron River mouth, in approximately the centre of the Wet Tropics region (Figure 208). Monitoring at Green Island occurs on the large reef-platform and in the shallow lagoon to the south west and north west of the cay, respectively. The meadows are dominated by *Cymodocea rotundata* and *Thalassia hemprichii* with some *Halodule uninervis* and *Halophila ovalis*. The seagrass meadows at Green Island have been the focus of research since the 1980's and monitoring includes a legacy site (GI1).

Dunk Island is an inshore continental island located in the southern section of the region (Figure 208). Intertidal monitoring sites are located on the sand spit between the main island and Kumboola Island. The subtidal site is located in the lee of the island, in front of the former Dunk Island resort.

Shallow unstable sediment, fluctuating temperature, and variable salinity in shallow regions characterise reef habitats. Physical disturbance from waves and swell and associated sediment movement primary forcing factors which control seagrass growing in these habitats (Figure 128). Reef seagrass habitats in the region are often adjacent to areas of high tourism use and boating activity with propeller and anchor scarring impacts. Globally, nutrient concentrations are generally low in reef habitats due to the coarse nature of the coral sand sediments. In these carbonate sediments the primary limiting nutrient for seagrass growth is generally phosphate (Short *et al.* 1990; Fourqurean *et al.* 1992a; Erftemeijer and Middelburg 1993). This is due to the sequestering of the phosphate by the calcium carbonate. In this region seagrass meadows inhabiting the near shore inner reefs and fringing reefs of coastal islands inhabit a mixture of terrigenous and carbonate sediments, such as Green Island. Seagrasses at this location in the 1990's were shown to be nitrogen limited (Udy*, et al.* 1999).

A1.3 Burdekin

The Burdekin region, includes an aggregation of the Burdekin, Don, Haughton and Ross River catchments and several smaller coastal catchments, all of which empty into the Great Barrier Reef lagoon (Commonwealth of Australia 2013a). Rainfall is lower than other regions within tropical Queensland with an annual average of approximately 1,150 mm from on average 91 rain days. There is, however, considerable year-to-year variation due to the sporadic nature of tropical lows and storms. Approximately 75 per cent of the average annual rainfall is received during December to March (Scheltinga and Heydon 2005).

Approximately 18 per cent of the seagrass area mapped in the shallow waters (<15m) of the GBR occurs in the Burdekin NRM region (McKenzie*, et al.* 2010c). Intertidal seagrasses and shallow subtidal seagrasses dominate in this region, the majority of which are within coastal habitats (Coles*, et al.* 2007). Extensive seagrass meadows occur in Upstart, Cleveland, and Bowling Green Bays and off Magnetic Island. Twelve species have been found within this region (Lee Long*, et al.* 1993; Lee Long *et al.* 1996a). Deep water (>15m) seagrasses occur in this region but are not as common or dense as occurs in regions further north (Coles*, et al.* 2009). Most fringing reefs associated with continental islands support moderately dense mixed species meadows (especially *Cymodocea serrulata*), which are not restricted to the confines of fringing reefs, but are also found in sheltered bays at continental islands or coastal localities (Coles*, et al.* 2007).

Major threats to seagrass meadows in the region include: coastal development (reclamation); changes to hydrology; water quality declines (particularly nutrient enrichment or increased turbidity); downstream effects from agricultural (including sugarcane, horticultural, beef), industrial (including refineries) and urban centres (Scheltinga and Heydon 2005; (Haynes et al. 2001)). All four generalised seagrass habitats are present within the Burdekin region, and MMP monitoring occurs at coastal and reef seagrass habitat locations.

The coastal monitoring sites are located on naturally dynamic shallow sand banks and are subject to sand waves and erosion blowouts moving through the meadows. The Townsville (Bushland Beach and Shelley Beach) area is a sediment deposition zone, so the meadow must also cope with incursions of sediment carried by long shore drift. The Bowling Green Bay (Jerona) location is adjacent to the mouth of Barratta Creek. Sediments within this habitat are mud and sand that have been delivered to the coast during the episodic peak flows of the creeks and rivers (notably the Burdekin) in this area. While episodic riverine delivery of freshwater nutrients and sediment is a medium time scale factor in structuring these coastal seagrass meadows, it is the wind induced turbidity of the costal zone that is likely to be a major short term driver (Figure 129). In these shallow coastal areas waves generated by the prevailing SE trade winds are greater than the depth of water, maintaining elevated levels of suspended sediments, limiting the amount of light availability for photosynthesis during the trade season. Another significant feature in this region is the influence of ground water (Stieglitz 2005). The meadows are also frequented by dugongs and turtles as witnessed by abundant grazing trails and patches of cropping .

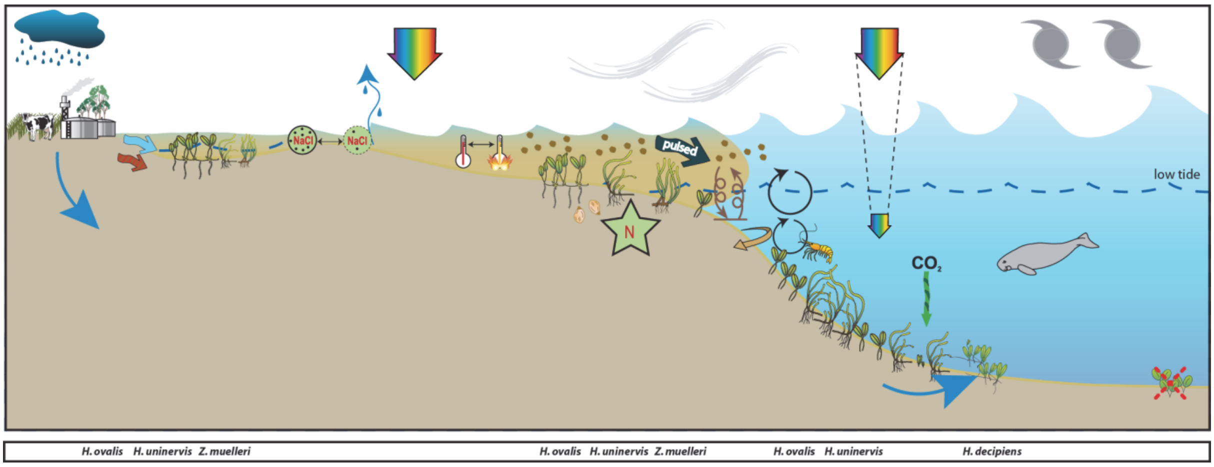

Figure 129. *Conceptual diagram of coastal habitat in the Burdekin region - major control is wind and temperature extremes, general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

The reef habitats are mainly represented by fringing reefs on the many continental islands within this area. Most fringing reefs have seagrass meadows growing on their shallow banks. Nutrient supply to these meadows is by terrestrial inputs via riverine discharge, re-suspension of sediments and groundwater supply (Figure 130). The meadows are typically composed of zones of seagrasses: *Cymodocea serrulata, Thalassia hemprichii* and *Halodule uninervis* (wide leaf) often occupy the lower littoral/subtidal area, blending with *Halodule uninervis* (narrow leaved) and *Halophila ovalis* in the upper intertidal zone. Phosphate is often the nutrient most limiting to reefal seagrasses (Short*, et al.* 1990; Fourqurean*, et al.* 1992a). Experimental studies on reef top seagrasses in this region however, have shown seagrasses to be nitrogen limited primarily with secondary phosphate limitation, once the plants have started to increase in biomass (Mellors 2003). In these fringing reef top environments fine sediments are easily resuspended by tidal and wind generated currents making light availability a driver of meadow structure.

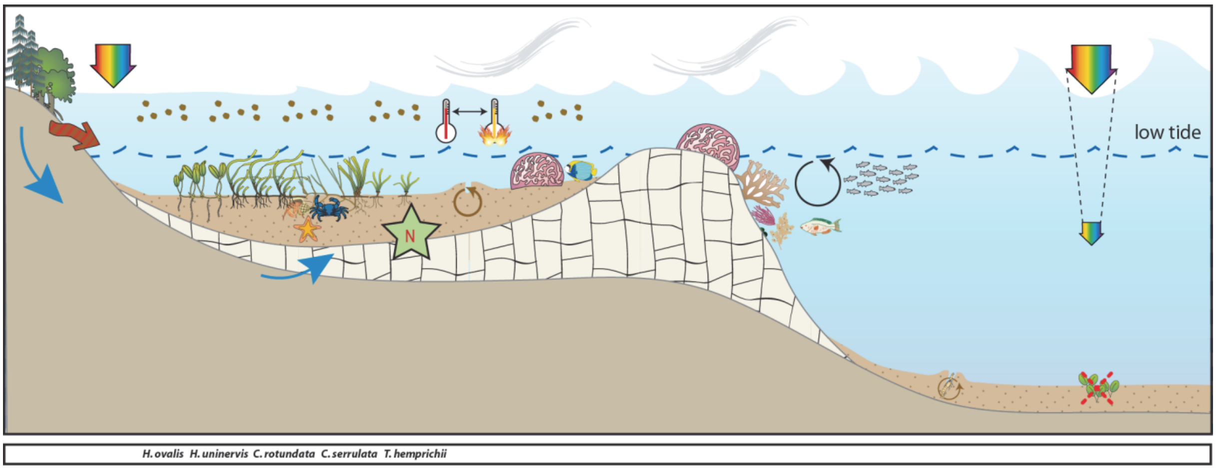

Figure 130. *Conceptual diagram of fringing reef habitat in the Burdekin region - major control is nutrient supply (groundwater), light and shelter: general habitat and seagrass meadow processes (see* Figure 139 *for icon explanation).*

A1.4 Mackay Whitsunday

The Mackay Whitsunday region comprises an area of almost 940,000 ha and extends from Bowen (Queens Beach) in the north to Clairview (Clairview Bluff) in the south and includes several large continental islands. The region includes the major population centres of Mackay, Proserpine, Airlie Beach and Sarina; encompassing the Proserpine, O'Connell, Pioneer and Plane Creek river systems (Commonwealth of Australia 2013d).

The Great Barrier Reef protects the coastline from predominantly south-easterly winds which often accompany a light south-easterly ocean swell (Mackay Whitsunday Natural Resource Management Group Inc 2005). Coastal waters adjacent to the large rivers and mangrove-lined inlets are generally very turbid and shallow, with predominantly mud sediments. Tidal range in the south of the region is large, and in some places has the effect of creating extensive tidal banks. The region receive rainfall between 500-3000 mm annually, which falls mostly (~70 per cent) from December to March. Average daily temperatures for Mackay range between 23 31°C in January and 11-22°C in July. The major land use of each catchment is livestock grazing, and crops such as sugar cane.

Extensive seagrass meadows occur both on shallow banks and in nearshore subtidal areas in the region. Approximately 448 km^2 of seagrass habitat has been mapped in the Mackay Whitsunday region over the past 3 decades, with 154 km^2 in shallow waters and 293 km^2 in deeper (>15m) waters (McKenzie*, et al.* 2010c). In 1999/2000, 5553 ±1182 hectares of seagrass was mapped from Midge Point in the south to Hydeaway Bay in the north (Campbell*, et al.* 2002). This represented a 40 per cent increase in overall seagrass habitat compared to the 1987 baseline, however losses had occurred at some localities. For a detailed description of seagrass meadows and habitats across the region (see McKenzie and Yoshida 2012).

Twelve species of seagrass have been recorded in the Mackay Whitsundays, representing 80 per cent of the known species found in Queensland waters (McKenzie and Yoshida 2012). The wide range of physical habitats where seagrasses were found undoubtedly contributes to the high species diversity. Habitats include intertidal and subtidal areas of estuary, coastal fringing reef environments and deepwater environments. MMP sites are located on three of the generalised seagrass habitats represented in the region, including estuarine, coastal and reef.

Estuarine seagrass habitats in the Mackay Whitsunday region tend to be intertidal on the large sand/mud banks of sheltered estuaries. Run-off through the catchments connected to these estuaries is variable, though the degrees of variability is moderate compared to the high variability of the Burdekin and the low variability of the Tully (Brodie 2004). Seagrass in this habitat must cope with extremes of flow, associated sediment and freshwater loads from December to April when 80 per cent of the annual discharge occurs (Figure 131).

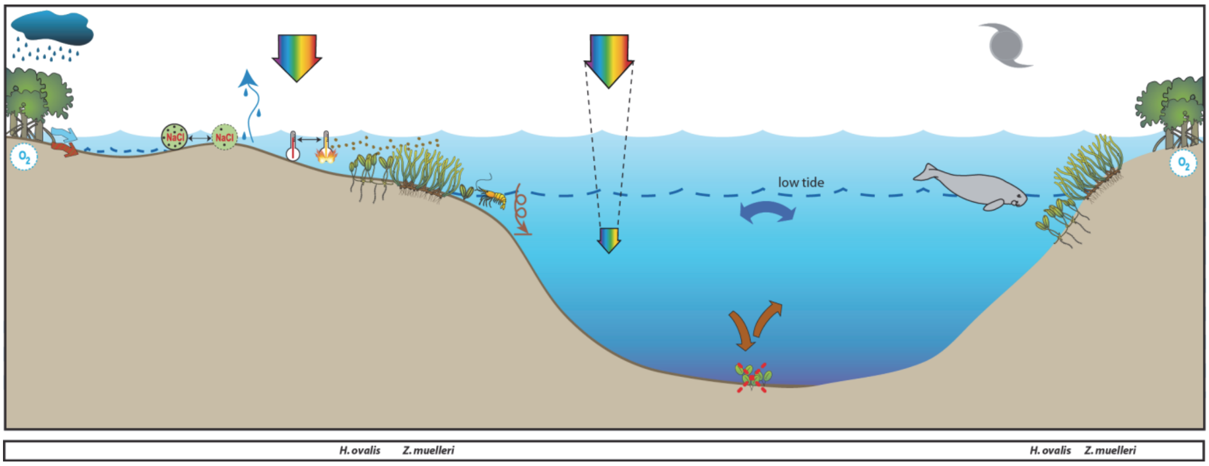

Figure 131. *Conceptual diagram of estuary habitat in the Mackay Whitsunday region: general habitat and seagrass meadow processes (see* Figure 139 *for icon explanation).*

Coastal seagrass habitats are found in areas such as the leeward side of inshore continental islands and in north opening bays. These areas offer protection from the south-easterly trade winds. Potential impacts to these habitats are issues of water quality associated with urban, marina development and agricultural land use (Figure 132). Monitoring sites of coastal seagrass habitat were located on the sand/mud flats adjacent to Cannonvale in southern Pioneer Bay.

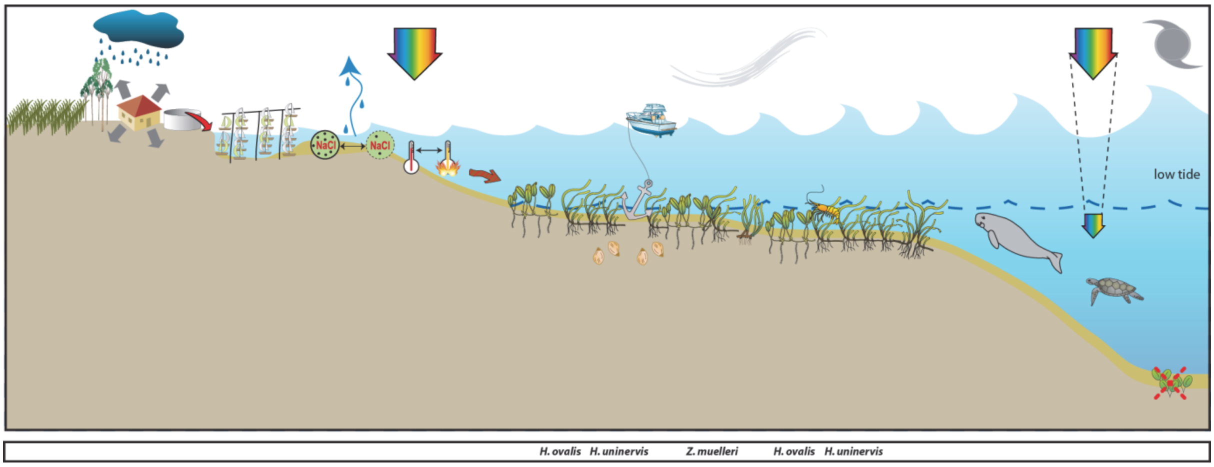

Figure 132. *Conceptual diagram of coastal habitat in the Mackay Whitsunday region – major control is shelter and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

Reef habitat seagrass meadows are found on the shallow fringing reefs adjacent to the mainlands or associated with the many islands in this region. The drivers of these habitats is exposure to waves and temperature extremes (Figure 133). Major threats would be increased tourism activities including marina and coastal developments.

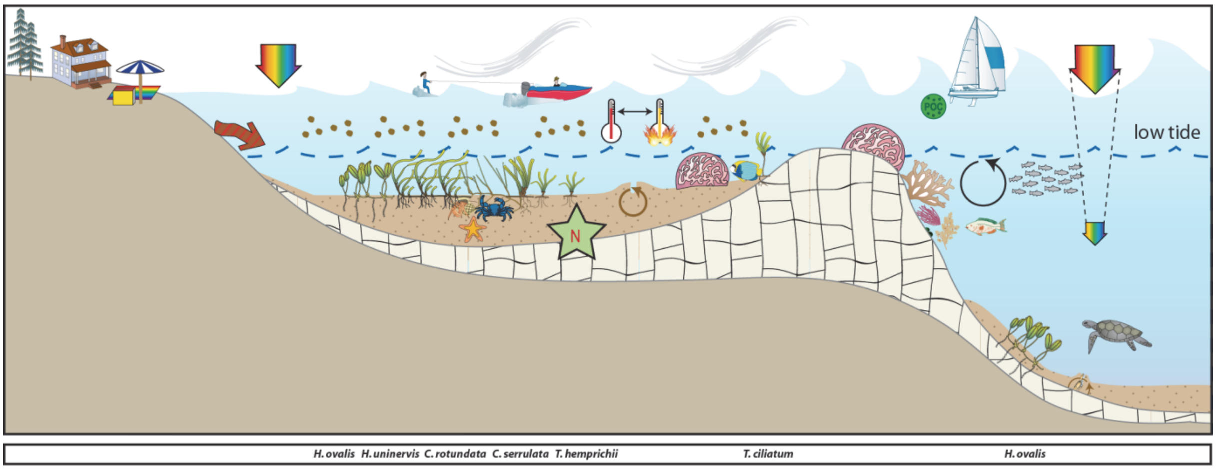

Figure 133. *Conceptual diagram of reef habitat in the Mackay Whitsunday region - major control is light and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

A1.5 Fitzroy

The Fitzroy region covers an area of nearly 300,000 km^2. It extends from Nebo in the north to Wandoan in the south, and encompasses the major systems of the Fitzroy, Boyne, and Calliope rivers as well as the catchments of the smaller coastal streams of the Capricorn and Curtis Coasts (Commonwealth of Australia 2013c). The Fitzroy River is the largest river system running to the east coast of Australia. The Boyne and Calliope Rivers drain the southern part of the region, entering the GBR lagoon at Gladstone. The region covers ten percent of Queensland's land area and is home to approximately 200,000 people. It is one of the richest areas in the state in terms of land, mineral and water resources and supports grazing, irrigated and dryland agriculture, mining, forestry and tourism land uses (Christensen *et al.* 2006). Agricultural production constitutes the largest land use in Central Queensland, with nearly 90 per cent of the land under agricultural production. Concomitant with this land use is concern of the quality of the water that is entering the GBR lagoon.

The Fitzroy region experiences a tropical to subtropical humid to semi arid climate. Annual median rainfall throughout the region is highly variable, ranging from about 800 mm to over 1000mm. Most rain falls in the summer, with many winters experiencing no rain at all. Because of the tropical influence on rainfall patterns, heavy storms can trigger flash flooding, and occasional cyclones wreak havoc.

The first broad scale survey of seagrass habitat in this region occurred in 1987, followed by more fine scale surveys of Shoalwater Bay (Lee Long *et al.* 1996b), the Dugong Protection Areas of Llewellyn Bay, Ince Bay and the Clairview Region (Coles *et al.* 2002) and Port Curtis to Rodds Bay (Rasheed*, et al.* 2003). Ten species of seagrass have been recorded from this region ranging from the intertidal to a depth of 48m (Coles*, et al.* 2007; McKenzie*, et al.* 2010c). The majority of seagrass in this region exist on large shallow banks flats. Expansive meadows exist on the coastal intertidal flats of Ince Bay, Clairview, Shoalwater Bay and Rodds Bay. The area of shallow subtidal coastal seagrass habitat in this region is small, as most of the coastline is exposed to south-east winds (Coles*, et al.* 2007). A significant factor contributing to the lack of suitable coastal habitat is the scouring tidal currents and associated high water turbidity in this region which limits light penetration and therefore the depth to which seagrasses can grow. Deepwater seagrasses were generally not found in the central and northern parts of this region, apart from occasional sites in the lee of islands or reefs (Coles*, et al.* 2009).

MMP sites within this region are located in coastal, estuarine or fringing-reef seagrass habitats. Coastal sites are monitored in Shoalwater Bay and are located on the large shallow banks of the north western shores of Shoalwater Bay. The remoteness of this area (due to its zoning as a military exclusion zone) represents a near pristine environment, removed form anthropogenic influence. In contrast, the estuarine sites are located within Gladstone Harbour: a heavily industrialized port. Offshore reef sites are located at Monkey Beach, Great Keppel Island.

The Shoalwater Bay monitoring sites are located in a bay which is a continuation of a coastal meadow that is protected by headlands. A feature of the region is the large tidal amplitudes and consequent strong tidal currents (Figure 134). As part of this tidal regime, large intertidal banks are formed which are left exposed for many hours. Pooling of water in the high intertidal, results in small isolated seagrass patches 1-2m above Mean Sea Level (MSL).

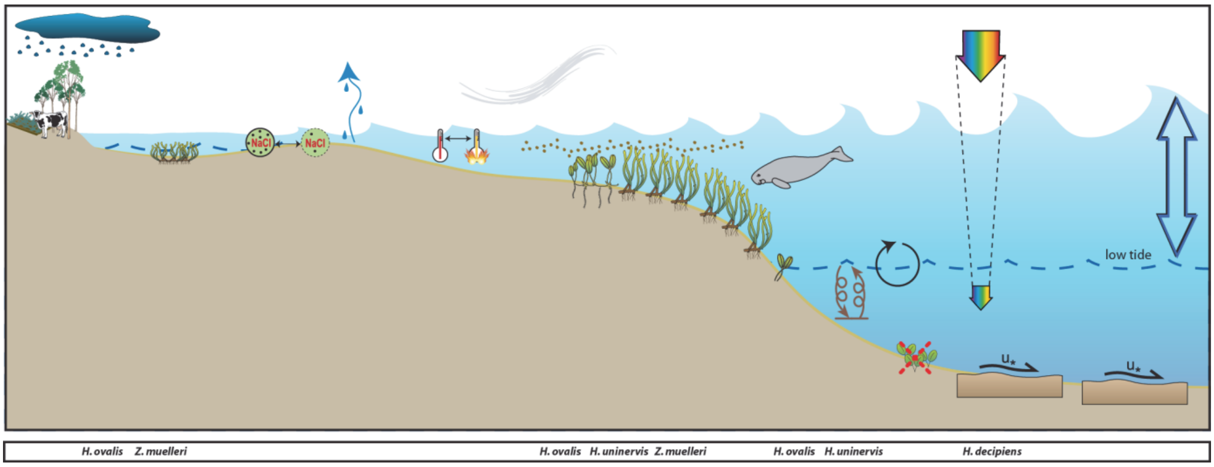

Figure 134. *Conceptual diagram of coastal habitat in the Fitzroy region – major control is pulsed light, salinity and temperature extremes: general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

Reef habitat seagrass meadows are found intertidally on the top of the fringing reefs associated with the Keppel Isles and Cannibal Island groups, however many of the reefs in the north of the region have not been surveyed. The drivers of these habitats are exposure and desiccation (intertidal meadows) and light limitation associated with wind driven resuspension (Figure 135).

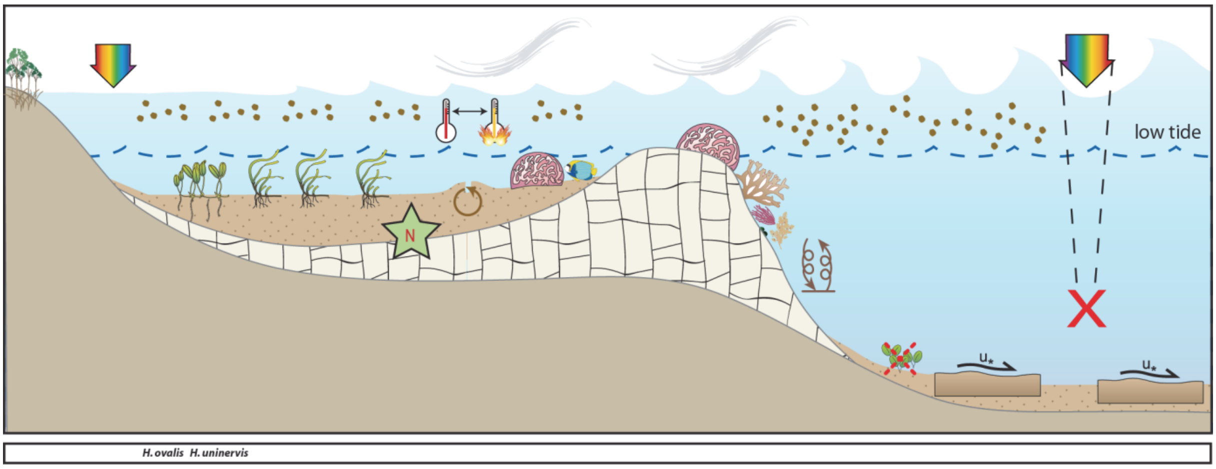

Figure 135. *Conceptual diagram of reef habitat in the Fitzroy region - major control is light and temperature extremes and benthic shear from tidal currents: general habitat, seagrass meadow processes and threats/impacts (see* Figure 139 *for icon explanation).*

Estuarine seagrass habitats in the southern Fitzroy region tend to be intertidal, on the large sand/mud banks in sheltered areas of the estuaries. Tidal amplitude is not as great as in the north and estuaries that are protected by coastal islands and headlands support meadows of seagrass. These habitats feature scouring, high turbidity and desiccation (linked to this large tide regime), and are the main drivers of distribution and composition of seagrass meadows in this area (Figure 136). These southern estuary seagrasses (Gladstone, Port Curtis) are highly susceptible to impacts from local industry and inputs from the Calliope River. Port Curtis is highly industrial with the world's largest alumina refinery, Australia's largest aluminium smelter and Queensland's biggest power station. In addition, Port Curtis contains Queensland's largest multi-cargo port (Port of Gladstone) with 50 million tonnes of coal passing through the port annually.

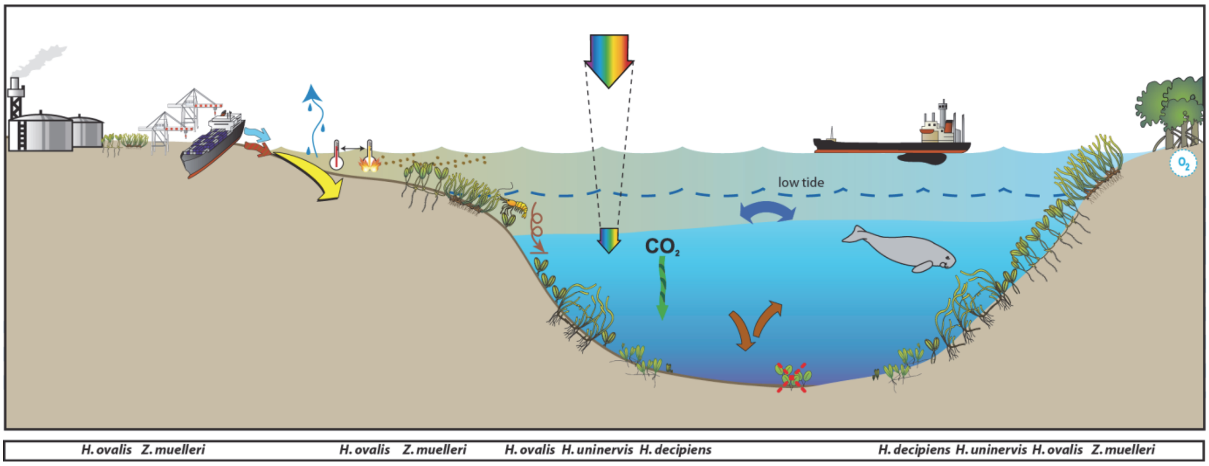

Figure 136. *Conceptual diagram of estuary habitat in the Fitzroy region – major control variable rainfall and tidal regime: general habitat, seagrass meadow processes and threats/impacts (see Figure 2 for icon explanation).*

A1.6 Burnett-Mary

The Burnett Mary Region encompasses a land area of more than 56,000 km^2, a marine area of almost 10,000 km^2 and supports a population of over 200,000 people. The region is comprised of a number of catchments including the Baffle Creek, Kolan, Burnett, Burrum and Mary Rivers (Commonwealth of Australia 2013b). Only the northern most catchment of the Burnett Mary region, the Baffle Basin, is within the GBR and includes the tidal mudflats and mangroves in Rodds Peninsula/Turkey Beach considered 'near pristine' (Burnett Mary Regional Group 2005).

Principal land uses in the Burnett-Baffle area are beef cattle grazing (the largest though currently declining), small crop growers, forestry (including plantations), tourism and fishing (Burnett Mary Regional Group 2010). Other significant land uses include conservation, rural and urban residential development (Prange and Duke 2004). Located in the northern section of the region is Rodds Bay, where freshwater input is minor from seasonal flows in small catchments, and water quality generally good - little organic/inorganic pollution even though Rodds Harbour has elevated natural turbidity and minor increases in sediment loads from grazing and development (Ford 2004). The southern region includes the Mary River catchment (9181km^2) and although outside the GBR Marine Park, is highly connected through oceanographic processes and plays a major driver of southern GBR ecosystems (Burnett Mary Regional Group 2013). Grazing predominates and utilises 42 per cent of the land area of the Mary catchment. High rainfall areas to the south and east host the majority of residential development, horticulture, and intensive livestock. Forestry and nature conservation, each of which occupies 18 per cent of the catchment, are the second largest land uses, with intensive anthropogenic uses (residential, manufacturing, services, waste treatment, transport, and services) occupying 13 per cent of the catchment area (Walker and Esslemont 2008). Sediment, total nitrogen and total phosphorus exports from the Mary catchment to the coastal receiving waters are estimated to be 455 kt.yr^{-1}, 1.541 kt.yr^{-1} and 0.344 kt.yr^{-1}, respectively (DeRose *et al.* 2002). Since European settlement, relative erosion rates in some sections of the Western Mary have increased 2 to 7 fold, and 4 to more than 14 fold in the Upper Mary (Esslemont *et al.* 2006).

Seagrass in the region were first broadly surveyed in 1988 (Lee Long *et al.* 1992) with the section north of Rodds Peninsula resurveyed at a finescale in 2002 (Rasheed*, et al.* 2003). Seven seagrass species have been reported in the Burnett Mary NRM region (McKenzie and Yoshida 2008), five within the marine park boundary (Coles*, et al.* 2007). Meadows have been reported throughout the inlets protected from the south easterly winds and oceanic swell, and throughout Hervey Bay and the Great Sandy Strait. Very little seagrass has been mapped on the exposed coastline between Bustard Head to just north of Hervey Bay. Within the GBRWHA boundaries, the majority of seagrass meadows are within coastal and estuary habitats. South of the GBRWHA boundary in one of the largest single areas of seagrass resources on the eastern Australian seaboard (McKenzie and Yoshida 2008). The southern marine area of the Burnett Mary NRM region includes large meadows in deepwater, coastal (including intertidal and shallow subtidal) and estuarine habitats (McKenzie and Yoshida 2008).

Meadows in the north of the Burnett Mary region generally face low levels of anthropogenic threat, and monitoring sites are located within Rodd's Bay. The only other location that is monitored within this region is in the south, at Urangan (Hervey Bay). This location is adjacent to the Urangan marina and in close proximity to the mouth of the Mary River.

Estuarine habitats occur in bays that are protected from the south easterly-winds and consequent wave action. The seagrasses in this area must survive pulsed events of terrestrial run-off, sediment turbidity and drops in salinity. Estuary seagrasses in the region are susceptible to temperature related threats and desiccation due to the majority being intertidal (Figure 137).

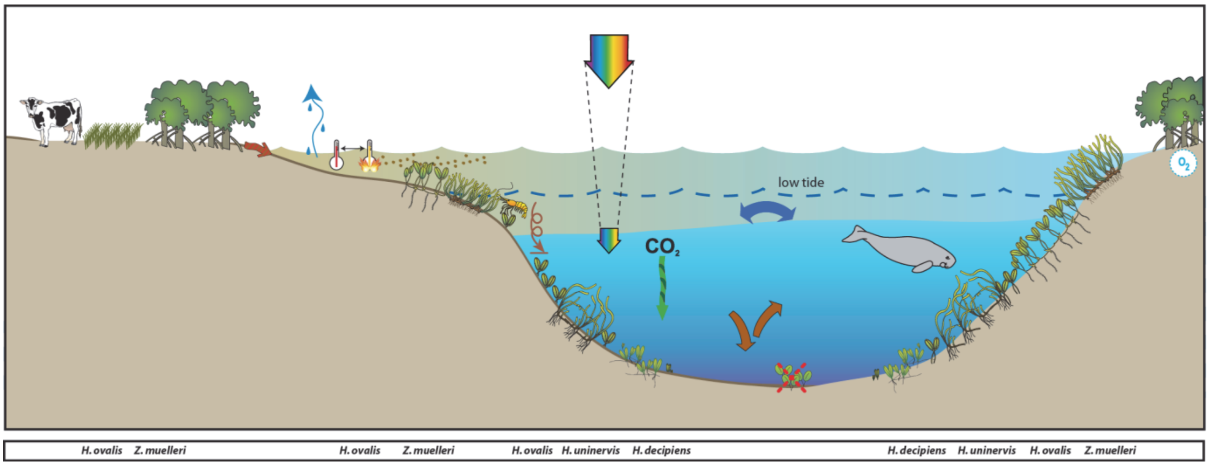

Figure 137. *Conceptual diagram of Estuary habitat in the GBR section of the Burnett Mary region – major control is shelter from winds and physical disturbance: general habitat and seagrass meadow processes (see* Figure 139 *for icon explanation).*

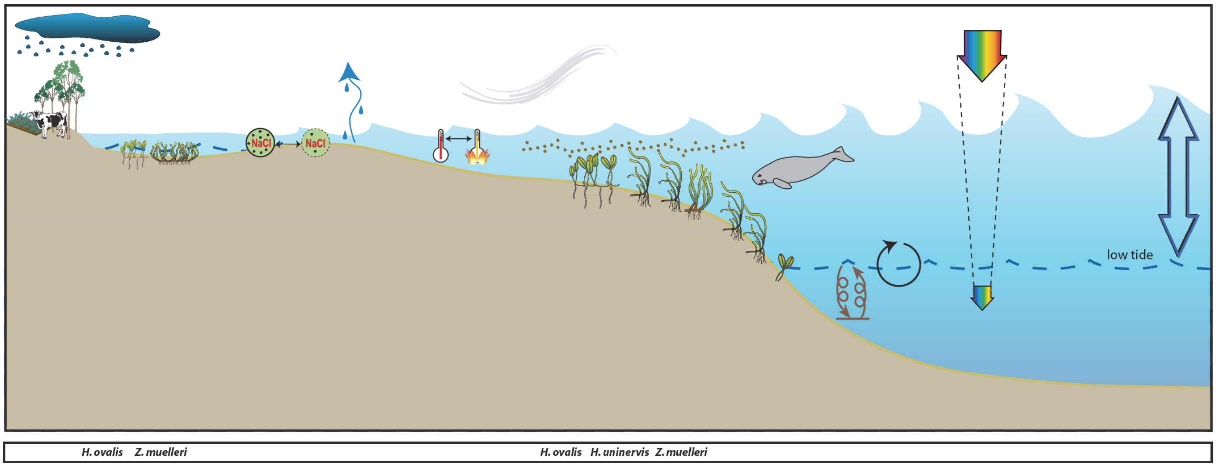

Figure 138. *Conceptual diagram of Coastal habitat in the Burnett Mary region – major control is shelter from winds / physical disturbance, and temperature extremes: general habitat and seagrass meadow processes (see* Figure 139 *for icon explanation).*

BIOLOGICAL ENVIRONMENT

- *Cymodocea serrulata*
- *Cymodocea rotundata*
- *Halodule uninervis*
- *Halophila decipiens*
- *Halophila ovalis*
- *Syringodium isoetifolium*
- *Thalassia hemprichii*
- *Thalassodendron ciliatum*
- *Zostera muelleri*
- seagrass seedbank
- epiphytes
- encrusting epiphytes
- mangrove
- Macro-algae
- Commercial prawns
- forest & grassland
- macro-invertebrates
- boulder corals
- branching corals
- reef fish

BIOLOGICAL PROCESS

- seagrass germination & growth
- seagrass loss & recovery
- high and low seagrass production
- parrotfish and urchin herbivory regulates distribution of seagrass species near patch reefs (38, 39, 40)
- grazing epifauna reduce epiphyte biomass and promote seagrass growth, productivity and depth distribution (41)
- Bioturbation can excavate or bury seagrass plants and seeds (36, 37, 42)
- Grazing by dugongs and green sea turtles can impact seagrass community structure by favoring rapidly growing, opportunistic seagrass species (43,44,45)

PHYSICAL ENVIRONMENT & PROCESS

- sediment resuspension & deposition
- Nutrient input
- nitrogen limitation
- Phosphorus limitation
- flushing
- bank erosion
- Suspended sediments
- wind
- Wave energy creates an unstable sediment environment where it is difficult for seagrass seedlings to establish or persist (51)
- Dessiccation results in photosynthesis inhibition & tissue death in some seagrass species (59)
- Pulsed turbidity events from river discharges of summer rainfall restrict light availability, limiting seagrass growth (49, 48, 50)
- Reduced light quality & quantity with depth results in reduction of maximum depth distribution of seagrass (54)
- High light reduces effective photochemical efficiency in seagrass (58)
- No light. Seagrass require ~11% of surface irradiance for growth, but ranges from 5-25% depending on species (58)
- Herbicides in water column inhibit photosynthesis in seagrass (1, 2, 3, 4)
- Elevated seawater temperatures >40°C inhibit photosynthesis causing seagrass leaf death (53)
- Anoxia from fine sediments & high organic loading stresses seagrasses (57)
- Floods, cyclones and long term weather patterns modify seagrass abundance (47, 48)
- Low & high salinities decrease chlorophyll content in seagrass leaves, uptake of nutrients and soluble sugar content in rhizomes (55, 56)
- Ground water & submarine springs can be a source of phosphorus and/or iron to seagrasses (60, 63, 64)
- Low salinity, turbidity and siltation associated with rainfall events depresses seagrass abundance and neatively impacts macro-invertebrates (57)
- High tidal velocities scour and resuspend sediments inhibiting seagrass colonisation (34)
- Particulate organic matter from sewage promotes excessive algae/epiphyte growth which reduces light available to seagrass (61, 62)

ANTHROPOGENIC IMPACTS

water quality related

- Herbicides in runoff from intensive coastal agriculture (sugarcane, banana and dairying) can reduce or inhibit local seagrass (1, 2, 3, 4)
- Land clearing/deforestation cause sediment plumes which reduce subsurface light intensity, resulting in plant loss (21)
- Treated effluent, nutrient enrichment & heavy metals can degrade seagrasses (1, 22, 23, 35)
- Groundwater nutrients from housing developments can cause eutrophication and seagrass loss (24, 26)
- Non-nutrient chemicals from industry can poison seagrass (18, 20, 26)
- Port dredging and sand mining physically remove and/or bury seagrass and increase turbidity & sedimentation (15, 16, 17)
- Oil spills cause intertidal seagrass leaf death (28), decrease invertebrate abundances (28, 29, 30, 31) and associated algae blooms reduce available light (28, 30, 32). Dispersants use in oil spill cleanup are toxic to many tropical seagrass species (33)
- Shipping antifouling chemicals reduce seagrass photosynthetic efficiency and growth (13, 14)
- Deep-draft vessel movements in shallow waters resuspend sediments inhibiting light to seagrass & induce erosion (51, 52)

other

- Marinas decrease penetration of light resulting in lower chlorophyll and seagrass density (10, 11, 12, 25)
- Recreational boat wash depresses abundances of macroinvertebrates due to displacement by flapping seagrass blades (5). Propeller scars, anchoring and mooring of boats can physically damage seagrass (6, 7, 8, 9)
- Artificial beach nourishment can bury or physically remove seagrass (19)

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Figure 139. *Key to symbols used for conceptual diagrams detailing drivers and pressures to seagrasses.*

Appendix 2 Materials and Methods

The following section includes excerpts from McKenzie *et al.* (2014b).

A2.1 Sampling design

In late 2004 all data collected within the GBR region as part of existing monitoring programs were supplied to a Senior Statistician at AIMS for independent review (De'ath 2005) examined the available datasets to estimate expected performance with regard to detecting long-term changes (including estimates of precision for annual mean, differences in means and linear trends) of the monitoring program. Seagrass data included in the analyses was collected from 2000–2004 and across 63 sites in 29 locations from Cooktown to Hervey Bay. Results concluded that the existing spatial and temporal coverage of monitoring was providing valuable information about long-term trends and spatial differences, with changes in seagrass cover occurring at various spatial and temporal scales. The report recommended that the value of the monitoring would be greatly enhanced by adding more widely spread locations. Therefore additional meadows were added according to criteria listed in materials and methods.

The sampling design was selected to detect change in inshore seagrass community status to compare with seagrass environmental status (water quality) in relation to specific catchments or groups of catchments (NRM region). Within each region, a relatively homogenous section of a representative seagrass meadow is selected to represent each of the seagrass habitats present (estuarine, coastal, reef) (Habitat(Region)). To account for spatial heterogeneity, two sites were selected within each location (Site[Habitat(Region)]). Subtidal sites were not replicated within locations. Within each site, finer scale variability is accounted for by using three 50 m transects nested in each site. An intertidal site is defined as a 50mx50m area. The sampling strategy for subtidal sites was modified to sample along 50m transects 2-3 m apart (aligned along the depth contour) due to logistical purposes of SCUBA diving in often poor visibility. At each site, monitoring is conducted during the late-wet (April) and late-dry (October) periods each year; additional sampling is conducted at more accessible locations in the dry (July) and wet (January).

Table 42. *Samples collected at each MMP inshore monitoring site per parameter for each season. Activities include: SG = seagrass cover & composition, SM=seed monitoring, TN=tissue nutrients, EM=edge mapping, RH=reproductive health, TL=temperature loggers, LL=light loggers, SH=sediment herbicides. ^=subtidal.*

GBR region	NRM region	Basin	Monitoring location		late dry Season (2015)							late wet Season (2016)					
					SG	SM	TN	EM	RH	TL	LL	SG	SM	EM	RH	TL	LL
Far Northern	Cape York	Jacky Jacky / Olive Pascoe	Shelburne Bay	**SR1**	33	30	3	✓	15	✓						✓	
				SR2	33	30	3	✓	15	✓	✓					✓	✓
			Piper Reef	**FR1**	33	30	3	✓	15	✓						✓	
				FR2						✓	✓					✓	✓
		Lockhart	Lloyd Bay	**LR1^**	33												
				LR2^	33												
		Normanby / Jeanie	Stanley Island	**ST1**	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				ST2	33	30	3	✓	15	✓		33	30	✓	15	✓	
			Bathurst Bay	**BY1**	33	30	3	✓	15	✓		33	30	✓	15	✓	
				BY2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
		Endeavour	Archer Point	**AP1**	33	30	3	✓	15	✓						✓	
				AP2	33	30	3	✓	15	✓	✓					✓	✓
Northern	Wet Tropics	Daintree	Low Isles	**LI1**	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				LI2^	33	30	3	✓		✓	✓	33	30	✓	15	✓	✓
		Mossman / Barron / Mulgrave - Russell / Johnstone	Yule Point	**YP1**	33	30	3	✓	15	✓		33	30	✓	15	✓	
				YP2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
			Green Island	**GI1**	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				GI2	33	30	3	✓	15	✓		33	30	✓	15	✓	
				GI3^	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
		Tully / Murray / Herbert	Mission Beach	**LB1**	33	30	3	✓		✓		33	30	✓		✓	
				LB2	33	30		✓		✓		33	30	✓		✓	
			Dunk Island	**DI1**	33	30	3	✓	15	✓		33	30	✓	15	✓	
				DI2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				DI3^	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
			Rockingham Bay	**GO1**	33												
			Missionary Bay	**MS1^**	10												
				MS2^	10												
Central	Burdekin	Ross / Burdekin	Magnetic Island	**MI1**	33	30	3	✓	15	✓		33	30	✓	15	✓	
				MI2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				MI3^	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
			Townsville	**SB1**	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				SB2	33	30				✓		33	30			✓	
				BB1	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
			Bowling Green Bay	**JR1**	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				JR2	33	30	3	✓	15	✓		33	30	✓	15	✓	
	Mackay Whitsunday	Don	Shoal Bay	**HB1**	33	30				✓						✓	
				HB2	33	30				✓						✓	
		Proserpine	Pioneer Bay	**PI2**	33	30				✓		33	30			✓	
				PI3	33	30				✓		33	30			✓	
		Proserpine / O'Connell	Repulse Bay	**MP2**	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				MP3	33	30	3	✓	15	✓		33	30	✓	15	✓	
			Hamilton Is.	**HM1**	33	30	3	✓	15	✓		33	30	✓	15	✓	
				HM2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
			Tongue Bay	**TO1^**	20												
				TO2^	20												
		O'Connell	Newry Islands	**NB1^**	22												

GBR region	NRM region	Basin	Monitoring location		late dry Season (2015)							late wet Season (2016)					
					SG	SM	TN	EM	RH	TL	LL	SG	SM	EM	RH	TL	LL
				NB2^	21												
		Plane	Mackay	**SI1**	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓
				SI2	33	30	3	✓	15	✓		33	30	✓	15	✓	
Southern	Fitzroy	Fitzroy	Shoalwater Bay	**RC1**	33	30	3	✓	15	✓						✓	
				WH1	33	30	3	✓	15	✓	✓					✓	✓
			Great Keppel Island	**GK1**	33	30	3	✓	15	✓	✓					✓	✓
				GK2	33	30		✓	15	✓						✓	
		Boyne	Gladstone	**GH1**	33	30	3	✓	15	✓	✓					✓	✓
				GH2	33	30	3	✓	15	✓						✓	
	Burnett Mary	Burnett	Rodds Bay	**RD1**	33	30		✓	15	✓	✓					✓	✓
				RD2	33	30		✓	15	✓						✓	
		Burrum	Hervey Bay	**BH1**	33	30				✓		33	30			✓	
				BH3	33	30				✓		33	30			✓	
		Mary	Hervey Bay	**UG1**	33	30	3	✓	15	✓		33	30	✓	15	✓	
				UG2	33	30	3	✓	15	✓	✓	33	30	✓	15	✓	✓

A2.2 Climate and environmental pressures

A2.2.1 Tidal exposure

The majority of meadows monitored within the MMP are located in shallow turbid waters where the duration of emersion and exposure has been shown to be important environmental drivers of seagrass change (Unsworth *et al.* 2012b). In the inshore waters of the GBR, where turbidity is naturally high, seagrasses are often restricted exclusively to the intertidal zone, as the periods around and even during exposure may provide critical windows of sufficient light for positive net photosynthesis (Pollard and Greenway 1993). However, during tidal exposure, these intertidal seagrasses are susceptible to high irradiance, potentially high UV-A and UV-B, thermal stress and desiccation (Erftemeijer and Herman 1994; Stapel *et al.* 1997; Björk *et al.* 1999; Campbell*, et al.* 2006a). Research on upper intertidal Enhalus acoroides meadows in the northern Gulf of Carpentaria (Weipa), reported strong correlative evidence that long-term tidal cycles coinciding with daylight and high solar radiation are linked to this long-term variability and seagrass decline (Unsworth*, et al.* 2012b). Actual tidal data was provided by Maritime Safety Queensland and exposure times calculated for each site based on measured height relative to the Lowest Astronomical Tide.

A2.2.2 Light loggers

Submersible Odyssey™ photosynthetic irradiance autonomous loggers were attached to permanent station markers at 20 intertidal and 4 subtidal seagrass locations from the Cape York region to the Burnett Mary region (Table 42). Measurements were recorded by the logger every 15 - 30 minutes and are reported as total daily light (mol m^{-2} d^{-1}). Automatic wiper brushes cleaned the optical surface of the sensor every 15 minutes to prevent marine organisms fouling.

The deployment durations were variable, with some deployed since 2008 under a different program (e.g. MTSRF); however the light monitoring was expanded and incorporated into the MMP in late 2009. Data were patchy for a number of intertidal sites because visitation frequency was low (3- 6 months), which increases the risk of light logger or wiper unit failure and increases the gap in data if loggers do fail. Furthermore, there are some sites that are frequently accessed by the public and tampering is suspected in the disappearance of some loggers. For subtidal sites, and their associated intertidal sites (Picnic Bay, Dunk Island, Green Island and Low Isles, 8 sites in total), the logger replacement time was every 6 weeks so data gaps were reduced.

Odyssey™ data loggers (Odyssey, Christchurch, New Zealand) record Photosynthetically Active Radiation (400-1100nm) and store data in an inbuilt memory which is retrieved every three to six months, depending on the site. Each logger has the following technical specifications:

- Cosine corrected photosynthetic irradiance sensor 400-700 nm
- Cosine corrected solar irradiance sensor 400-1100 nm
- Integrated count output recorded by Odyssey data recorder
- User defined integration period
- Submersible to 20m water depth
- 64k memory.

The logger is self-contained in a pressure-housing with batteries providing sufficient power for deployments of longer than six months. For field deployment, loggers are attached to a permanent station marker using cable ties; this is above the sediment-water interface at the bottom of the seagrass canopy. This location ensures that the sensors are not exposed to air unless the seagrass meadow is almost completely drained and places them out of sight of curious people. At subtidal sites, the loggers are deployed on the sediment surface (attached to a permanent marker) with the sensor at seagrass canopy height. Two loggers are deployed at subtidal sites as there is an increased chance of logger fouling, and the dual logger set-up offers a redundant data set in the instance that one logger fouls completely. Where possible, additional light loggers are deployed at subtidal sites 80 cm from the sediment surface. Data from this logger, together with data from the logger at canopy height, is used for calculation of the light attenuation co-efficient. Furthermore, another logger is deployed above the water surface at each of the subtidal monitoring stations. These additional loggers (surface and subtidal higher in the water column) allow comparison of water quality indices for some of the time.

Each light logger has a unique serial number which is recorded within a central secure database. The logger number is recorded on the monitoring site datasheet with the time of deployment and collection. At each monitoring event (every three to six months) the light loggers are removed and replaced with a ‘fresh’ logger. At subtidal monitoring sites, the loggers are checked by SCUBA (and replaced if fouled) every six weeks due to the increased fouling rates at permanently submerged sites. After collection, details of the logger number, field datasheet (with date and time) and logger are returned to JCU for downloading.

Photographs of the light sensor and/or notes on the condition of the sensor are recorded at logger collection. If fouling is major (e.g. wiper failure), the data are truncated to included only that data before fouling began – usually one to two weeks. If fouling was minor (up to ~25 per cent of the senor covered), back corrections to the data are made to allow for a linear rate of fouling (linear because with minor fouling it is assumed that the wiper was retarding algal growth rates, but not fully inhibiting them).

Loggers were calibrated against a certified reference Photosynthetically Active Radiation (PAR) sensor (LI-COR™ LI-192SB Underwater Quantum Sensor) using a stable light source (LiCor) enclosed in a casing that holds both the sensor and light source at a constant distance. Calibration is repeated after each deployment period of 6 weeks to 6 months. When the loggers are immersed in water (i.e. most fo the deployment time), a multiplication of 1.33 is used to adjust for in-water changes in absorption by the sensor. This is not applied when the loggers emerge from the water (i.e. at low tide).

Autonomous iBTag™ submersible temperature loggers and submersible Odyssey™ photosynthetic irradiance autonomous logger deployed at Green Island.

Light data measured as instantaneous irradiance ($\mu mol\ m^{-2}\ s^{-1}$) was converted to daily irradiance (I_d, mol $m^{-2}\ d^{-1}$). I_d is highly variable in shallow coastal systems, being affected by incoming irradiance, the tidal cycle as well as water quality (Anthony*, et al.* 2004). This high variability makes it difficult to ascertain trends in data. To aid with the visual interpretation of trends, I_d was averaged over a 28-day period (complete tidal cycle). 28 days is also biologically meaningful, as it corresponds to the approximate duration over which leaves on a shoot are fully replaced by new leaves and it is the approximate time over which shoot density and biomass starts to decline following reductions in light (Collier *et al.* 2012a). 28-day averaged I_d are presented graphically against draft thresholds with different values for northern and southern communities as the dominant species and habitat types vary from north to south. Thresholds applied in the northern GBR (5 mol m^{-2} s^{-1}) were developed for *Halodule uninervis*-dominated communities during episodic seagrass loss (Collier*, et al.* 2012b). The threshold applied to southern GBR communities (6 mol m^{-2} s^{-1}) were developed for *Zostera muelleri* dominated communities over a 2-week rolling average using a range of experimental and monitoring approaches (Chartrand *et al.* 2012). These working thresholds describe light levels associated with short-term changes in seagrass abundance.

Also discussed, I_d is relative to estimated minimum light requirements (MLR). MLR describes the light required for the long-term survival of seagrass meadows (Dennison 1987a). It is frequently calculated from measurement of annual light availability at the deepest edge of seagrass meadow, beyond which seagrasses cannot survive. MLR is difficult to determine in the dynamic seagrass meadows of the GBR, which often have poorly defined meadow boundaries, and these boundaries vary over intra-annual cycles. Therefore, MLR were estimated based on the average range in MLR for other 'blady' tropical species from the same genera (e.g. *Halodule, Thalassia*). MLR are usually reported as percent of surface irradiance (SI), even though this not the most meaningful representation of light requirements. The average MLR of 15-25 per cent SI for tropical blady species (summarized in Lee *et al.* 2007a) was converted to I_d using surface light data from Magnetic Island, Dunk Island, Green Island and Low Isles, which has been recorded at these sites since 2008. From this we estimate that the MLR equivalent to 15-25 per cent SI is 4.7 to 7.9 mol photons m^{-2} d^{-1}. *Halophila* species typically have a much lower MLR, around 5-10 per cent SI (Lee*, et al.* 2007a), which is equivalent to 1.5 to 2.9 mol m^{-2} d^{-1} at the monitoring sites for which we have surface light data. There are other species that possibly have higher MLR than the range given here; for example, *Zostera muelleri* is thought to have an MLR greater than 30 per cent (Carruthers*, et al.* 2002a). There is similarity between the working light thresholds and the MLR, reflecting the sensitivity of the dominant coastal seagrasses, to perturbations in their light environment.

Table 43. *Minimum light requirements (MLR) derived from the literature (15-25 per cent) were converted to daily irradiance from surface light at sites where surface light is also monitored.*

Site	**Average daily irradiance (mol m^{-2} d^{-1})**	
	15 per cent SI	**25 per cent SI**
Low Isles	4.5	7.4
Green Island	4.9	8.2
Dunk Island	4.9	8.1
Magnetic Island	4.6	7.7
AVERAGE	**4.7**	**7.9**

A2.2.3 Within seagrass canopy temperature loggers

Autonomous iBTag™ submersible temperature loggers are deployed at all sites identified in Table 42. The loggers record temperature (degrees Celsius) within the seagrass canopy every 30 to 90 minutes (depending on duration of deployment and logger storage capacity) and store data in an inbuilt memory which is downloaded every three to six months, depending on the site.

iBCod 22L model of iBTag™ loggers are used as they can withstand prolonged immersion in salt water to a depth of 600 metres. It is reinforced with solid titanium plates and over molded in a tough polyurethane casing that can take a lot of rough handling.

Main features of the iBCod 22L include:

- Operating temperature range: -40 to +85°C

- Resolution of readings: 0.5°C or 0.0625°C
- Accuracy: ±0.5°C from -10°C to +65°C
- Sampling Rate: 1 second to 273 hours
- Number of readings: 4,096 or 8,192 depending on configuration
- Password protection, with separate passwords for read only and full access.

The large capacity of this logger allows the collection of 171 days of readings at 30 minute intervals.

iBCod 22L submersible temperature loggers are placed at the permanent marker at each site for three to six months (depending on monitoring frequency). Loggers are attached to the permanent station marker using cable ties, above the sediment-water interface. This location ensures that the sensors are not exposed to air unless the seagrass meadow is completely drained and places them out of sight of curious people.

Each logger has a unique serial number which is recorded within a central secure database. The logger number is recorded on the monitoring site datasheet with the time of deployment and collection. At each monitoring event (every three to six months) the iBTag™ temperature loggers are removed and replaced with a fresh logger (these are dispatched close to the monitoring visit). After collection, details of the logger number, field datasheet (with date and time) and logger are returned for downloading.

Logger deployment and data retrieval is carried out by JCU professional and technical personnel who have been trained in the applied methods. Methods and procedures documents are available to relevant staff and are collectively kept up-to-date. Changes to procedures are developed and discussed and recorded in metadata records.

A2.3 Seagrass status

A2.3.1 Field survey methods

Inshore seagrass meadow abundance, community structure and reproductive health

Site marking

Each selected inshore seagrass site is permanently marked with plastic star pickets at the 0 m and 50 m points of the centre transect. Labels identifying the sites and contact details for the program are attached to these pickets. Positions of 0 m and 50 m points for all three transects at a site are also noted using GPS (accuracy ±3 m). This ensures that the same site is monitored each event.

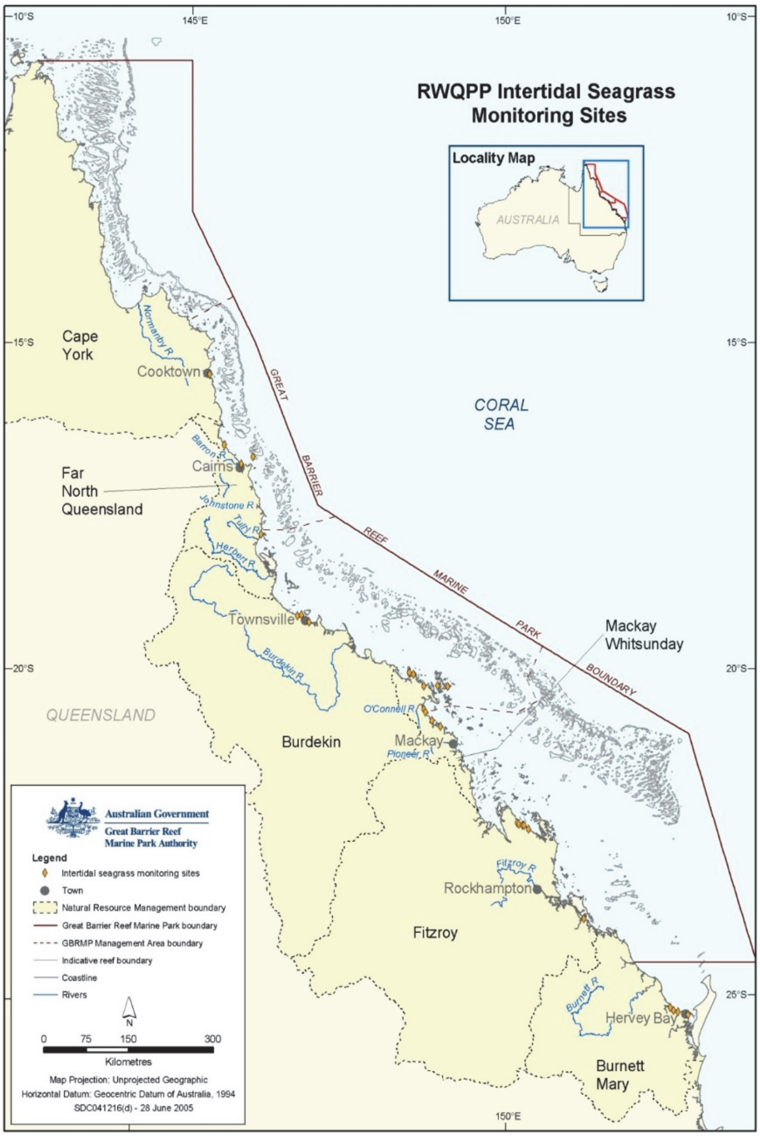

Figure 140. *Inshore seagrass monitoring sites for the Reef Rescue Marine Monitoring Program.*

Seagrass cover and species composition

Survey methodology follows globally standard methodologies, originally developed for the Seagrass-Watch program (McKenzie*, et al.* 2003). A site is defined as an area within a relatively homogenous section of a representative seagrass community/meadow (McKenzie *et al.* 2000a).

Monitoring at the 45 sites identified for the MMP long-term inshore monitoring in late-wet (April) and late dry season (October) of each year is conducted by qualified and trained scientists who have demonstrated competency in the methods. Monitoring conducted outside these periods is conducted by a trained scientist assisted by volunteers.

At each site, during each survey, observers record the percent seagrass cover within a total of 33 quadrats (50 cm × 50 cm quadrat placed every 5 m along three 50m transects, 25m apart). Seagrass abundance (per cent cover) was visually estimated as the fraction of the seabed (substrate) obscured by the seagrass species when submerged and viewed from above. This method was used because the technique has wider application and is very quick, requiring only minutes at each quadrat; yet it is robust and highly repeatable, thereby minimising among-observer differences. Quadrat percent cover measurements have also been found to be far more efficient in detecting differences in seagrass abundance than seagrass blade counts or measures of above- or below-ground biomass (Heidelbaugh and Nelson 1996). To improve resolution and allow greater differentiation at very low percentage covers (e.g. <3 per cent), shoot counts based on global species density maxima were used. For example: 1 pair of *Halophila ovalis* leaves in a quadrat = 0.1 per cent; 1 shoot/ramet of *Zostera* in a quadrat = 0.2 per cent. Additional information was collected at the quadrat level, although only included as narrative in this report, including: seagrass canopy height of the dominant strap leaved species; macrofaunal abundance; abundance of burrows, as an measure of bioturbation; presence of herbivory (e.g. dugong and sea turtle); a visual/tactile assessment of sediment composition (see McKenzie 2007); and observations on the presence of superficial sediment structures such as ripples and sand waves to provide evidence of physical processes in the area (see Koch 2001).

Seagrass species were identified as per Waycott *et al.* (2004). Species were further classified into colonising, opportunistic or persistent as broadly defined by Kilminister (2015). For species which display characteristics across the range of strategies (e.g. *Zostera* can be colonising or opportunistic) as a consequence of community type, meadow status (e.g. expansion/recovery phase after loss), or the environment within which they persist (Harrison 1979), classification was assisted by expert elucidation until such time as a rigorous traits-based method can be developed. Opportunistic species were classified as colonising during the period of time when meadows underwent major decline i.e. >80 per cent loss of cover (or below abundance 20th percentile).

The proportion of colonising species contributing to the total seagrass abundance is then calculated for each site for each monitoring event. To aid with the visual interpretation of trends, the proportion of colonising species are presented graphically against the long-term average proportion of colonist species contributing to the total seagrass abundance for each GBR habitat.

Table 44. *Long-term average proportion (±SE) of colonising species in each GBR seagrass habitat type.*

Seagrass habitat	average proportion colonist species
estuary	0.47 ±0.047
coast	0.34 ±0.045
reef - intertidal	0.30 ±0.05
reef - subtidal	0.32 ±0.049

Seagrass reproductive health

An assessment of seagrass reproductive health at locations identified in Table 3 via flower and fruit production is conducted in late-dry season (October) of each year at each site. Additional collections are also conducted in late-wet (April) where possible.

In the field, 15 haphazardly placed cores (100mm diameter x 100mm depth) of seagrass are collected from an area adjacent, of similar cover and species composition, to each monitoring site. All samples collected are given a unique sample code/identifier providing a custodial trail from the field sample to the analytical outcome.

Seeds banks and abundance of germinated seeds were sampled according to standard methods (McKenzie*, et al.* 2003) by sieving (2mm mesh) 30 cores (50mm diameter, 100mm depth) of sediment collected across each site and counting the seeds retained in each. This mesh size will retain seeds of *Halodule uninervis* and *Cymodocea* spp. For *Zostera muelleri* subsp*. capricorni*, where the seeds are <1mm diameter, intact cores (18) were collected and returned to the laboratory where they were washed through a 710µm sieve and seeds identified using a hand lens/microscope.

Seagrass leaf tissue nutrients

In late dry season (October) 2013, foundational seagrass (opportunistic and persistent species that are dominant at the site) species leaf tissue nutrient samples were collected from each monitoring site (Table 3). For nutrient status comparisons, collections were recommended during the growth season (e.g. late dry when nutrient contents are at a minimum) (Mellors*, et al.* 2005) and at the same time of the year and at the same depth at the different localities (Borum*, et al.* 2004). Shoots from three haphazardly placed 0.25m^2 quadrats were collected from an area adjacent (of similar cover and species composition) to each monitoring site. Leaves were separated from the below ground material in the laboratory and epiphytic algae removed by gently scraping. Dried (60°C) and milled samples were analysed according to (McKenzie*, et al.* 2014b). Elemental ratios (C:N:P) were calculated on a mole:mole basis using atomic weights (i.e., C=12, N=14, P=31).

Analysis of tissue nutrient data was based upon the calculation of the atomic ratios of C:N:P. The ratios of the most common macronutrients required for plant growth has been used widely as an indicator of growth status, in phytoplankton cultures this known as the familiar "*Redfield*" ratio of 106C:16N:P (Redfield*, et al.* 1963). Seagrass and other benthic marine plants possess large quantities of structural carbon, resulting in ''seagrass Redfield ratios'' estimated to be between 550:30:1 (Atkinson and Smith 1983) and 474:24:1 (Duarte 1990). The magnitude of these ratios and their temporal changes allow for a broad level understanding of the physical environment of seagrass meadows. Like phytoplankton, seagrasses growing in eutrophic waters have C:N:P ratios that reflect elevated nitrogen and phosphorus levels (Duarte 1990). Plants residing in nutrient poor waters show significantly lower N:P ratios than those from nutrient rich conditions (Atkinson and Smith 1983). Comparing deviations in the ratios of carbon, nitrogen and phosphorous (C:N:P) retained within plant tissue has been used extensively as an alternative means of evaluating the nutrient status of coastal waters (Duarte 1990).

Changing C:N ratios have been found in a number of experiments and field surveys to be related to light levels, as leaves with an atomic C:N ratio of less than 20, may suggest reduced light availability when N is not in surplus (Abal*, et al.* 1994; Grice*, et al.* 1996; Cabaço and Santos 2007; Collier*, et al.* 2009b). The ratio of N:P is also a useful indicator as it is a reflection of the "*Redfield*" ratios (Redfield*, et al.* 1963), and seagrass with an atomic N:P ratio of 25 to 30 can be determined to be 'replete' (well supplied and balanced macronutrients for growth) (Atkinson and Smith 1983; Fourqurean*, et al.* 1997a; Fourqurean and Cai 2001). When N:P values are in excess of 30, this may indicate P-limitation and a ratio of less than 25 is considered to show N limitation (Atkinson and Smith 1983; Duarte 1990; Fourqurean*, et al.* 1992b; Fourqurean and Cai 2001). The median seagrass tissue ratios of C:P is approximately 500 (Atkinson and Smith 1983), therefore deviation from this value is also likely to be indicative of some level of nutrient enriched or nutrient limited conditions. A combination of these ratios can indicate seagrass environments which are impacted by nutrient enrichment. Plant tissue which has a high N:P and low C:P indicates an environment of elevated (saturated) nitrogen.

Investigations of the differences in each individual tissue ratio within each of the species revealed that although tissue nutrient concentrations were extremely variable between locations and between years, by pooling species within habitat types trends were apparent (McKenzie and Unsworth 2009). As seagrass tissue nutrient ratios of the foundation species were generally not significantly different from each other at a site within each sampling period (McKenzie and Unsworth 2009), the tissue nutrient ratios were pooled at the request of the GBRMPA to assist with interpretation of the findings.

To identify the sources of the nitrogen and provide insight into the occurrence of carbon limitation associated with light limitation, leaf tissue were also analysed for nitrogen and carbon stable isotope ratios (δ^{15}N and δ^{13}C). There are two naturally occurring atomic forms of nitrogen (N). The common form that contains seven protons and seven neutrons is referred to as ^{14}N, and a heavier form that contains an extra neutron is called ^{15}N: with 0.3663 per cent of atmospheric N in the heavy form.

Plants and animals assimilate both forms of nitrogen, and the ratio of ^{14}N to ^{15}N compared to an atmospheric standard ($\delta^{15}N$) can be determined by analysis of tissue on a stable isotope mass spectrometer using the following equation:

$$\delta^{15}\mathrm{N}\ (‰) = \left(\frac{\left(atomic^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{sample}}\right) - \left(atomic^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{standard}}\right)}{\left(atomic^{15}\mathrm{N}/^{14}\mathrm{N}_{\mathrm{standard}}\right)} \right) \times 1{,}000$$

Seagrasses are passive indicators of $\delta^{15}N$ enrichment, as they integrated the signature of their environment over time throughout their growth cycle. The various sources of nitrogen pollution to coastal ecosystems often have distinguishable $^{15}N/^{14}N$ ratios (Heaton 1986), and in regions subject to anthropogenic inputs of nitrogen, changes in the $\delta^{15}N$ signature can be used to identify the source and distribution of the nitrogen (Costanzo 2001). Nitrogen fertilizer, produced by industrial fixation of atmospheric nitrogen results in low to negative $\delta^{15}N$ signatures (i.e. $\delta^{15}N$ ~0 - 1‰) (Udy and Dennison 1997a). In animal or sewage waste, nitrogen is excreted mainly in the form of urea, which favours conversion to ammonia and enables volatilization to the atmosphere. Resultant fractionation during this process leaves the remaining ammonium enriched in ^{15}N. Further biological fractionation results in sewage nitrogen having a $\delta^{15}N$ signature greater than 9 or ~10‰ ((Lajtha and Marshall 1994; Udy and Dennison 1997b; Dennison and Abal 1999; Abal *et al.* 2001; Costanzo*, et al.* 2001). Septic and aquaculture discharge undergo less biological treatment and are likely to have a signature closer to that of raw waste ($\delta^{15}N$ ~5‰) (Jones *et al.* 2001).

Similar to N, there are two naturally occurring atomic forms of carbon (C), ^{13}C and ^{12}C, which are taken up during photosynthesis where ^{12}C is the more abundant of the two, accounting for 98.89 per cent of carbon. The ratio that ^{13}C is taken up relative to ^{12}C varies in time as a function of productivity, organic carbon burial and vegetation type. A measure of the ratio of stable isotopes ^{13}C:^{12}C (i.e. $\delta^{13}C$) is known as the isotopic signature, and reported in parts per thousand (per mil, ‰):

$$\delta^{13}\mathrm{C} = \left[\left(\frac{\left(^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{sample}}\right)}{\left(^{13}\mathrm{C}/^{12}\mathrm{C}_{\mathrm{standard}}\right)} \right) - 1 \right] \times 1{,}000$$

where the standard is an established reference material.

Experimental work has confirmed that seagrasses from high light, high productivity environments demonstrate (less negative) isotopic enrichment: i.e. low per centC, low C:N, in contrast, more negative $\delta^{13}C$, may indicate that light is limited (Grice*, et al.* 1996; Fourqurean *et al.* 2005).

Epiphyte and macroalgae abundance

Epiphyte and macroalgae cover were measured according to standard methods (McKenzie*, et al.* 2010a). The total percentage of leaf surface area (both sides, all species pooled) covered by epiphytes and percentage of quadrat area covered by macroalgae, were measured each monitoring event. Values were compared against the GBR long-term average (1999-2010) calculated for each habitat type.

Increased epiphyte (the plants growing on the surfaces of slower-growing seagrass leaves (Borowitzka *et al.* 2006) loads may result in shading of seagrass leaves by up to 65 per cent, reducing photosynthetic rate and leaf densities of the seagrasses (Sand-Jensen 1977; Tomasko and Lapointe 1991; Walker and McComb 1992; Tomasko *et al.* 1996; Frankovich and Fourqurean 1997; Ralph and Gademann 1999; Touchette 2000). In seagrass meadows, increases in the abundance of epiphytes are stimulated by nutrient loading (e.g. Borum 1985; Silberstein *et al.* 1986; Neckles *et al.* 1994; Balata *et al.* 2008) and these increases in abundance have been implicated as the cause for declines of seagrasses during eutrophication, because of the associated decrease in light reaching the seagrass blade (e.g. Orth and Moore 1983; Cambridge *et al.* 1986).

Given the observed relationships between nutrient loading and the abundance of epiphytes observed in seagrass ecosystems from around the world, and the perceived threat to water quality owing to human population, the abundance of epiphytes in seagrass meadows may prove to be a valuable indicator for assessing both the current status and trends of the GBR seagrass meadows. However, preliminary analysis of the relationship between seagrass abundance and epiphyte cover collected by the RRMMP and MTSRF did not identify threshold levels beyond which loss of abundance occurred (McKenzie 2008) suggesting further research and analysis.

Inshore seagrass meadow boundary mapping

Mapping the edge of the seagrass meadow within 100 metres of each monitoring site is conducted in both the late dry (October) and late wet (April) monitoring periods at all sites identified in Table 3. Training and equipment (GPS) are provided to personnel involved in the edge mapping.

Mapping methodology follows standard methodology (McKenzie*, et al.* 2001). Edges are recorded as tracks (1 second polling) or a series of waypoints in the field using a portable Global Positioning System receiver (i.e. Garmin GPSmap® 60CSx or 62s). Accuracy in the field is dependent on the portable GPS receiver (Garmin GPSmap® 60CSx is <15m RMS95 per cent (DGPS (USCG) accuracy: 3-5m, 95 per cent typical) and how well the edge of the meadow is defined. Generally accuracy is within that of the GPS (i.e. 3 to 5 metres) and datum used is WGS84. Tracks and waypoints are downloaded from the GPS to portable computer using MapSource or BaseCamp software as soon as practicable (preferably on returning from the day's activity) and exported as *.dxf files to ESRI® ArcGIS™. Subtidal edge mapping data has yet to be plotted.

Mapping is conducted by trained and experienced scientists using ESRI® ArcMap™ 10.3 (Environmental Systems Research Institute, ArcGIS™ Desktop 10.3). Boundaries of meadows are determined based on the positions of survey Tracks and/or Waypoints and the presence of seagrass. Edges are mapped using the polyline feature to create a polyline (i.e. 'join the dots') which is then smoothed using the B-spline algorithm. The smoothed polyline is then converted to a polygon and saved as a shapefile. Coordinate system (map datum) used for projecting shapefile is AGD94.

In certain cases seagrass meadows form very distinct edges that remain consistent over many growing seasons. However, in other cases the seagrass landscape tends to grade from dense continuous cover to no cover over a continuum that includes small patches and shoots of decreasing density. Boundary edges in patchy meadows are vulnerable to interpreter variation, but the general rule is that a boundary edge is determined where there is a gap with the distance of more than 3 metres (i.e. accuracy of the GPS). Final shapefiles are then overlayed with aerial photographs and base maps (AusLig™) to assist with illustration/presentation.

The expected accuracy of the map product gives some level of confidence in using the data. Using the GIS, meadow boundaries are assigned a quality value based on the type and range of mapping information available for each site and determined by the distance between waypoints and GPS position fixing error. These meadow boundary errors are used to estimate the likely range of area for each meadow mapped (see McKenzie *et al.* 1996; Lee Long*, et al.* 1997; McKenzie*, et al.* 1998).

Mapping at subtidal sites has been altered to suit the low visibility conditions and the requirement to map by SCUBA. From the central picket (deployment location of light and turbidity loggers) straight lines of 50m length are swum at an angle of 45 degrees from each other. The locations where the edges of the seagrass meadows/patches intercept the line are recorded. A GPS is attached to a flotation device at the surface of the water and fastened to the SCUBA diver to record travelling distance and transect orientation. Eight lines at 45 degrees are performed, with the first following the orientation of the monitoring transects; the others are undertaken at 45 degree angles from the first.

A2.3.2 Observer training

The JCU personnel collecting data in association with this project are without exception highly experienced in the collection of seagrass monitoring data. The majority of observers have been involved in seagrass monitoring for at least a decade and were employed specifically for their skills associated with the tasks required.

All observers have successfully completed at Level 1 Seagrass-Watch training course (seagrasswatch.org/training.html) and have demonstrated competency across 7 core units: achieved 80 per cent of formal assessment (classroom and laboratory) (5 units); and demonstrated competency in the field both during the workshop (1 unit) and post workshop (1 unit = successful completion of 3 monitoring events/periods within 12 months). Volunteers who assist JCU scientists have also successfully completed a Level 1 training course.

Technical issues concerning quality control of data are important and are resolved by: using standard methods which ensure completeness in the field (the comparison between the amounts of valid or useable data originally planned to collect, versus how much was collected); using standard seagrass cover calibration sheets to ensure precision (the degree of agreement among repeated measurements of the same characteristic at the same place and the same time) and consistency between observers and across sites at monitoring times. Ongoing standardisation of observers is achieved through routine comparisons during sampling events. Any discrepancy is used to identify and subsequently mitigate bias. For the most part however uncertainties in percentage cover or species identification are mitigated in the field via direct communication, or the collection of voucher specimens (to be checked under microscope and pressed in herbarium) and the use of a digital camera to record images (every quadrat is photographed) for later identification and validation. Evidence of competency is securely filed on a secure server in Cairns at James Cook University.

A2.3.3 Laboratory analysis

Inshore seagrass meadow abundance, community structure and reproductive health

Seagrass reproductive health

In the laboratory, reproductive structures (spathes, fruit, female flower or male flowers; Figure 141) of plants from each core are identified and counted for each sample and species. If *Halodule uninervis* seeds (brown green colour) are still attached to the rhizome, they are counted as fruits. Seed estimates are not recorded for *Halophila ovalis* due to time constraints (if time is available post this first pass of the samples, fruits will be dissected and seeds counted). For *Zostera muelleri* subsp. *capricorni*, the number of spathes is recorded, male and female flowers and seeds counted during dissection, if there is time after the initial pass of the samples. Apical meristems are counted if possible, however, most are not recorded as they were too damaged by the collection process to be able to be identified correctly. The number of nodes for each species is counted, and for each species present in the sample, 10 random internode lengths and 10 random leaf widths are measured. Approximately 5 per cent of samples are cross-calibrated between technicians (preferable from another centre). All samples, including flowers and spathes and fruits/fruiting bodies are kept and re-frozen in the site bags for approximately 2 years for revalidation if required. Reproductive effort is calculated as the number of reproductive structures per core.

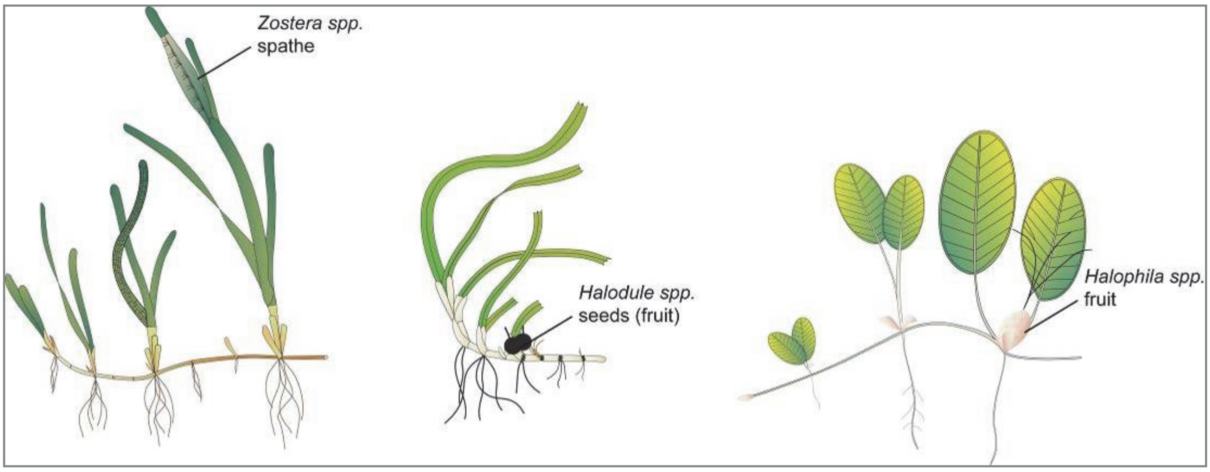

Figure 141. Form and size of reproductive structure of the seagrasses collected: *Halophila ovalis*, *Halodule uninervis* and *Zostera muelleri* subsp. *capricorni*

Seagrass leaf tissue nutrients

Leaves are separated in the laboratory into seagrass species and epiphytic algae removed by gently scraping the leaf surface. Samples are oven dried at 60°C to weight constancy. Dried biomass samples of leaves are then homogenised by milling to fine powders prior to nutrient analyses and stored in sealed vials.

The ground tissue samples are sent to Chemcentre (Western Australia) for analysis. The Chemcentre holds NATA accreditation for constituents of the environment including soil, sediments, waters and wastewaters. (Note that details of Chemcentre accreditation can be found at the NATA website: www.nata.asn.au). The NATA accreditation held by the ChemCentre includes a wide variety of QA/QC procedures covering the registration and identification of samples with unique codes and the regular calibration of all quantitative laboratory equipment required for the analysis. The ChemCentre has developed appropriate analytical techniques including QA/QC procedures and detection of nutrients. These procedures include blanks, duplicates where practical, and internal use of standards. In 2010, QA/QC also included an inter-lab comparison (using Queensland Health and Scientific Services – an additional NATA accredited laboratory) and an additional blind internal comparison.

Nitrogen and phosphorus are extracted using a standardized selenium Kjeldahl digest and the concentrations determined with an automatic analyser using standard techniques at Chemcentre in Western Australia (a NATA certified laboratory). Percent C was determined using atomic absorption, also at Chemcentre. Elemental ratios (C:N:P) are then calculated on a mole:mole basis using atomic weights (i.e., C=12, N=14, P=31). Analysis of all seagrass tissue nutrient data is based upon the calculation of the atomic ratios of C:N:P.

To determine percent carbon, dried and milled seagrass leaf tissue material is combusted at 1400°C in a controlled atmosphere (e.g. Leco). This converts all carbon containing compounds to carbon dioxide. Water and oxygen is then removed from the system and the gaseous product is determined spectrophotometrically.

Total nitrogen and phosphorus content of dried and milled homogenous seagrass tissue material is determined by Chemcentre using a standardized selenium Kjeldahl digest. Samples are digested in a mixture of sulphuric acid, potassium sulphate and a copper sulphate catalyst (cf. Kjeldahl). This converts all forms of nitrogen to the ammonium form and all forms of phosphorus to the orthophosphate form. The digest is diluted and any potentially interfering metals present are complexed with citrate and tartrate. For the nitrogen determination an aliquot is taken and the ammonium ions are determined colorimetrically following reduction with hydrazine to the nitrate ion, followed by diazotisation of 1-naphthylenediamine and subsequent coupling with sulphanilamide. For total phosphorus an aliquot of the digest solution is diluted and the P determined as the phosphomolybdenum blue complex (modified Murphy and Riley[117] procedure).

Seagrass leaf isotopes

A subset of each ground tissue sample was sent to Natural Isotopes (Western Australia) for $\delta^{15}N$ and $\delta^{13}C$ analysis. The samples were weighed into tin capsules and combusted by elemental analyser (ANCA-SL, SerCon Limited, Crewe, United Kingdom) to N_2 and CO_2. The N_2 and CO_2 was purified by gas chromatography and the nitrogen and carbon elemental composition and isotope ratios were determined by continuous flow isotope ratio mass spectrometry (20-22 IRMS, SerCon Limited, Crewe, United Kingdom). Reference materials of known elemental composition and isotopic ratios were interspaced with the samples for calibration.

Raw nitrogen and carbon elemental composition and isotope ratio data were corrected for instrument drift and blank contribution using Callisto software SerCon Limited, Crewe, United Kingdom). A standard analysed at variable weights corrects for instrument linearity, IAEA-N-2 and IAEA-N-1 used to normalise the nitrogen isotope ratio, IAEA-CH-6 and IAEA-CH-7 to normalise the carbon isotope ratio, such that IAEA-N-2 ($\delta^{15}N$ = 20.32‰), IAEA-N-1 ($\delta^{15}N$ = 0.43‰), IAEA-CH-6 ($\delta^{13}C$ = -10.45‰) and IAEA-CH-7 $\delta^{13}C$ = -32.15‰).

Nitrogen isotope ratios were reported in parts per thousand (per mil) relative to N_2 in air. The nitrogen bearing internationally distributed isotope reference material N_2 in air had a given value of 0‰ (exactly). Carbon isotope ratios were reported in parts per thousand (per millilitre) relative to V-PDB. The carbon bearing internationally distributed isotope reference materials NBS19 and L-SVEC, had a given value of +1.95‰ (exactly) and -46.6‰ (exactly). Compositional values were reported as percent nitrogen and percent carbon present in the sample analysed.

Appendix 3 Report card methods and calculations

A3.1 Report card approach

Three indicators (presented as unitless scores) were selected by the GBRMPA, using advice from expert working groups and the Paddock to Reef Integration Team, for the seagrass report card:

1. seagrass abundance (cover)
2. reproductive effort
3. nutrient status (seagrass tissue C:N ratio)

The methods for calculation of scores was chosen by the Paddock to Reef Integration Team (i.e. not the authors of this report) and all report card scores are transformed to a five point scale from 0 to 100 as directed to allow integration with other components of the Paddock to Reef report card (Department of the Premier and Cabinet 2014). *Please note that the scale from 0 to 100 is unitless and should not be interpreted as a proportion or ratio.*

A3.2 Seagrass abundance

Seagrass abundance (per cent cover) is used to indicate the state of the seagrass to resist stressors, reproductive effort to indicate the potential for the seagrass to recover from loss, and the nutrient status to indicate the condition of the environment in which the seagrass are growing in recognition of seagrass' role as a bioindicator of environmental (including water quality) health.

The status of seagrass abundance (per cent cover) was determined using the seagrass abundance guidelines developed by McKenzie (2009). The seagrass abundance measure in the MMP is the average per cent cover of seagrass per monitoring site. Individual site and subregional (habitat type within each NRM region) seagrass abundance guidelines were developed based on per cent cover data collected from individual sites and/or reference sites (McKenzie 2009). Guidelines for individual sites were only applied if the conditions of the site aligned with reference site conditions.

A reference site is a site whose condition is considered to be a suitable baseline or benchmark for assessment and management of sites in similar habitats. Ideally, seagrass meadows in near pristine condition with a long-term abundance database would have priority as reference sites. However, as near-pristine meadows are not available, sites which have received less intense impacts can justifiably be used. In such situations, reference sites are those where the condition of the site has been subject to minimal/limited disturbance for 3-5 years. The duration of 3-5 years is based on recovery from impact times (Campbell and McKenzie 2004).

There is no set/established protocol for the selection of reference sites and the process is ultimately iterative. The criteria for defining a minimally/least disturbed seagrass reference site is based on Monitoring River Health Initiative 1994) and includes some or all of the following:

- beyond 10km of a major river: as most suspended solids and particulate nutrients are deposited within a few kilometres of river mouths (McCulloch *et al.* 2003; Webster and Ford 2010; Bainbridge *et al.* 2012; Brodie *et al.* 2012).
- no major urban area/development (>5000 population) within 10km upstream (prevailing current)
- no significant point source wastewater discharge within the estuary
- has not been impacted by an event (anthropogenic or extreme climate) in the last 3-5 years
- where the species composition is dominated by the foundation species expected for the habitats (Carruthers*, et al.* 2002a), and
- does not suggest the meadow is in recovery (i.e. dominated by early colonising).

The 80th, 50th and 20th percentiles were used to define the guideline values as these are recommended for water quality guidelines (Department of Environment and Resource Management 2009), and there is no evidence that this approach would not be appropriate for seagrass meadows in the GBR. At the request of the Paddock to Reef Integration Team, the 80th percentile was changed to 75th to align with other Paddock to Reef report card components. By plotting the percentile estimates with increasing sample size, the reduction in error becomes apparent as it moves towards the true value (e.g. Figure 142).

Across the majority of reference sites, variance for the 50th and 20th percentiles was found to level off at around 15–20 samples (i.e. sampling events), suggesting this number of samples was sufficient to provide a reasonable estimate of the true percentile value. This sample size is reasonably close to the ANZECC 2000 Guidelines recommendation of 24 data values.

Nonlinear regressions (exponential rise to maximum, two parameter) were then fitted to percent cover percentile values at each number of sampling events using the following model:

$$y = a\left(1 - e^{-bx}\right)$$

where *y* is the seagrass cover percentile at each number of sampling events (*x*), *a* is the asymptotic average of the seagrass cover percentile, and *b* is the rate coefficient that determines how quickly (or slowly) the maximum is attained (i.e., the slope). The asymptotic average was then used as the guideline value for each percentile (Table 45).

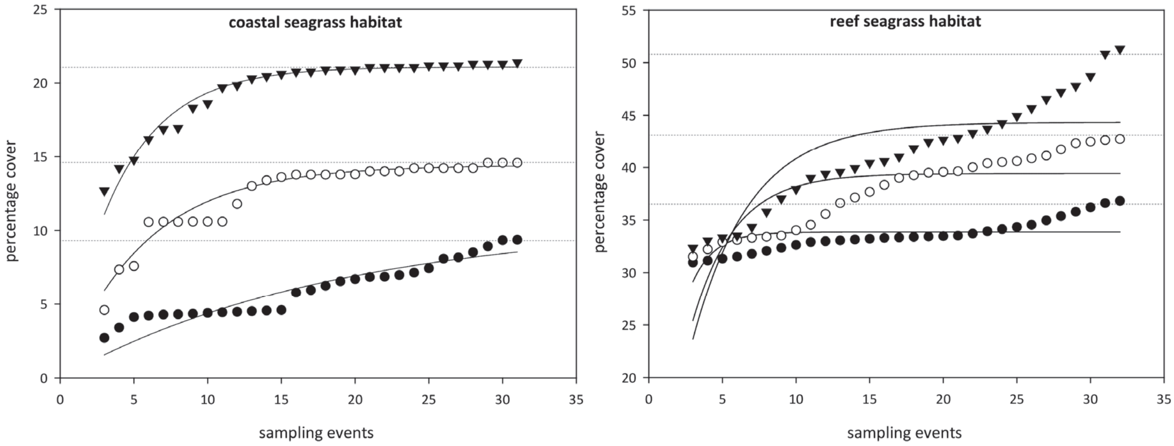

Figure 142. *Relationship between sample size and the error in estimation of percentile values for seagrass abundance (per cent cover) in coastal and reef seagrass habitats in the Wet Tropics NRM.* ▼ *= 75th percentile,* ○ *= 50th percentile,*● *= 20th percentile. Dashed lines are asymptotic averages for each percentile plot.*

As sampling events occur every 3-6 months depending on the site, this is equivalent to 3-10 years of monitoring to establish percentile values. Based on the analyses, it was recommended that estimates of the 20th percentile at a reference site should be based on a minimum of 18 samples collected over at least three years. For the 50th percentile a smaller minimum number of samples (approximately 10–12) would be adequate but in most situations it would be necessary to collect sufficient data for the 20th percentile anyway. For seagrass habitats with low variability, a more appropriate guideline was the 10th percentile primarily the result of seasonal fluctuations (as nearly every seasonal low would fall below the 20th percentile). Percentile variability was further reduced within a habitat type of each region by pooling at least two (preferably more) reference sites to derive guidelines. The subregional guideline is calculated from the mean of all reference sites within a habitat type within a region.

Using the seagrass guidelines, seagrass state can be determined for each monitoring event at each site and allocated as good (median abundance at or above 50th percentile), moderate (median abundance below 50th percentile and at or above 20th percentile), poor (median abundance below 20th or 10th percentile). For example, when the median seagrass abundance for Yule Point is plotted against the 20th and 50th percentiles for coastal habitats in the Wet Tropics (Figure 143), it indicates that the meadows were in a poor condition in mid 2000, mid 2001 and mid 2006 (based on abundance).

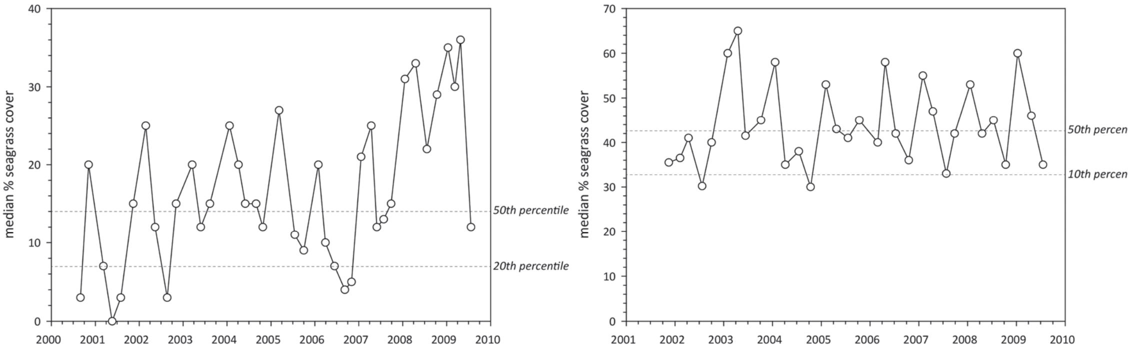

Figure 143. *Median seagrass abundance (per cent cover) at Yule Point (left) and Green Island (right) plotted against the 50th and 20th percentiles for coastal and intertidal reef seagrass habitat in the Wet Tropics.*

Similarly, when the median seagrass abundance for Green Island is plotted against the 20th and 50th percentiles for intertidal reef habitats in the Wet Tropics, it indicates that the meadows were in a poor condition in the middle of most years (based on abundance). However, the poor rating is most likely a consequence of seasonal lows in abundance. Therefore, in this instance, it was more appropriate to set the guideline at the 10th rather than the 20th percentile.

Using this approach, subregional seagrass abundance guidelines (hereafter known as “the seagrass guidelines”) were developed for each seagrass habitat types where possible (Table 45). If an individual site had 18 or more sampling events and no identified impacts (e.g., major loss from cyclone), an abundance guideline was determined at the site or location level rather than using the subregional guideline from the reference sites (i.e. as more guidelines are developed at the site level, they contribute to the subregional guideline).

After discussions with GBRMPA scientists and the Paddock to Reef integration team, the seagrass guidelines were further refined by allocating the additional categories of very good (median abundance at or above 75th percentile), and very poor (median abundance below 20th or 10th percentile and declined by >20 per cent since previous sampling event). Seagrass state was then rescaled to a five point scale from 0 to 100 to allow integration with other components of the Paddock to Reef report card (Department of the Premier and Cabinet 2014). Please note that the scale from 0 to 100 is unitless and should not be interpreted as a proportion or ratio.

Table 45. *Seagrass percentage cover guidelines ("the seagrass guidelines") for each site/location and the subregional guidelines (bold) for each NRM habitat. Values in light grey not used. ^ denotes regional reference site, * from nearest adjacent region. For site details, see Tables 3 & 4.*

NRM region	site/ location	Habitat	percentile guideline			
			10th	20th	50th	75th
Cape York	AP1^	reef intertidal	11	16.8	18.9	23.7
	AP2	reef intertidal	11		18.9	23.7
	FR	reef intertidal		16.8	18.9	23.7
	ST	reef intertidal		16.8	18.9	23.7
	YY	reef intertidal		16.8	18.9	23.7
	NRM	***reef intertidal***	***11***	***16.8***	***18.9***	***23.7***
	SR*	coastal intertidal		6.6	12.9	14.8
	BY*	coastal intertidal		6.6	12.9	14.8
	NRM	***coastal intertidal****	***5***	***6.6***	***12.9***	***14.8***
	LR	coastal subtidal		6.6	12.9	14.8
	NRM	***coastal subtidal***		***6.6***	***12.9***	***14.8***
Wet Tropics	LB	coastal intertidal		6.6	12.9	14.8
	YP1^	coastal intertidal	4.3	7	14	15.4
	YP2^	coastal intertidal	5.7	6.2	11.8	14.2
	NRM	***coastal intertidal***	***5***	***6.6***	***12.9***	***14.8***
	MS	coastal subtidal		6.6	12.9	14.8
	NRM	***coastal subtidal***		***6.6***	***12.9***	***14.8***
	DI	reef intertidal	27.5		37.7	41
	GI1^	reef intertidal	32.5	38.2	42.7	45.5
	GI2^	reef intertidal	22.5	25.6	32.7	36.7
	LI1	reef intertidal	27.5		37.7	41
	GO1	reef intertidal	27.5		37.7	41
	NRM	***reef intertidal***	***27.5***	***31.9***	***37.7***	***41***
	DI3	reef subtidal	22	26	33	39.2
	GI3^	reef subtidal	22	26	33	39.2
	LI2	reef subtidal	22	26	33	39.2
	NRM	***reef subtidal***	***22***	***26***	***33***	***39.2***
Burdekin	BB1^	coastal intertidal	16.3	21.4	25.4	35.2
	SB1^	coastal intertidal	7.5	10	16.8	22
	SB2	coastal intertidal		10	16.8	22
	JR	coastal intertidal		*15.7*	*21.1*	*28.6*
	NRM	***coastal intertidal***	***11.9***	***15.7***	***21.1***	***28.6***
	MI1^	reef intertidal	23	26	33.4	37
	MI2^	reef intertidal	21.3	26.5	35.6	41
	NRM	***reef intertidal***	***22.2***	***26.3***	***34.5***	***39***
	MI3^	reef subtidal	18	22.5	32.7	36.7
	NRM	***reef subtidal***	***18***	***22.5***	***32.7***	***36.7***
Mackay Whitsunday	SI	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	***10.8****	***18****	***34.1****	***54****
	PI2^	coastal intertidal	18.1	18.7	25.1	27.6
	PI3^	coastal intertidal	6.1	7.6	13.1	16.8
	MP2	coastal intertidal		18.9	22.8	25.4
	MP3	coastal intertidal		17.9	20	22.3
	NRM	***coastal intertidal***	***12.1***	***13.2***	***19.1***	***22.2***
	NB	coastal subtidal		13.2	19.1	22.2
	NRM	***coastal subtidal***	***12.1***	***13.2***	***19.1***	***22.2***
	HB1^	reef intertidal		10.53	12.9	14.2
	HB2^	reef intertidal		7.95	11.59	13.4
	HM	reef intertidal		9.2	12.2	13.8
	NRM	***reef intertidal***		***9.2***	***12.2***	***13.8***
	TO	reef subtidal		22.5	32.7	36.7
	NRM	***reef subtidal****	***18****	***22.5****	***32.7****	***36.7****
Fitzroy	GH	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	***10.8****	***18****	***34.1****	***54****
	RC1^	coastal intertidal	18.6	20.6	24.4	34.5
	WH1^	coastal intertidal	13.1	14.4	18.8	22.3

	NRM	***coastal intertidal***	***15.85***	***17.5***	***21.6***	***28.4***
	GK	reef intertidal		9.2	12.2	13.8
	NRM	***reef intertidal***		***9.2****	***12.2****	***13.8****
Burnett Mary	RD	estuarine intertidal		18	34.1	54
	UG1^	estuarine intertidal	10.8	18	34.1	54
	UG2	estuarine intertidal		18	34.1	54
	NRM	***estuarine intertidal***	***10.8***	***18***	***34.1***	***54***
	BH1^	coastal intertidal		7.8	11.9	21.6
	BH3	coastal intertidal		7.8	11.9	21.6
	NRM	***coastal intertidal***		***7.8***	***11.9***	***21.6***

Table 46. *Scoring threshold table to determine seagrass abundance status. low = 10th or 20th percentile guideline (Table 45). NB: scores are unitless.*

description	**category**	**score**	**status**
very good	75-100	100	81 - 100
good	50-75	75	61 - 80
moderate	low-50	50	41 - 60
poor	<low	25	21 - 40
very poor	<low by >20 per cent	0	0 - 20

Table 47. *Mean and median seagrass per cent cover and report score for each long-term monitoring site within each Cape York NRM region habitat over the 2015-16 period.Scores calculated as per* Table 45. *^denotes QPWS drop-camera site. NB: scores do not have units.*

Habitat	**Location**	**Site**	**Seasonal date**	**mean per cent cover**	**median per cent cover**	**Low percentile**	**50th percentile**	**75th percentile**	**score**
coastal intertidal	Bathurst Bay	BY1	01-Oct-15	24.8	25	6.6	12.9	14.8	100
		BY1	01-Apr-16	23.9	24	6.6	12.9	14.8	100
		BY2	01-Oct-15	18.8	18	6.6	12.9	14.8	100
		BY2	01-Apr-16	22.1	23	6.6	12.9	14.8	100
	Shelburne Bay	SR1	01-Oct-15	9.7	10	6.6	12.9	14.8	50
		SR2	01-Oct-15	10.2	10	6.6	12.9	14.8	50
coastal subtidal	Lockhart River	LR1^	01-Oct-15	10.4	9.5	6.6	12.9	14.8	50
		LR2^	01-Oct-15	33.3	31.5	6.6	12.9	14.8	100
reef intertidal	Archer Point	AP1	01-Oct-15	11.5	4	11	18.9	23.7	25
		AP2	01-Oct-15	26.7	28	11	18.9	23.7	100
	Piper Reef	FR1	01-Oct-15	10.2	10	16.8	18.9	23.7	25
	Stanley Island	ST1	01-Oct-15	11.0	10	16.8	18.9	23.7	25
		ST1	01-Apr-16	14.4	14	16.8	18.9	23.7	25
		ST2	01-Oct-15	8.2	8	16.8	18.9	23.7	25
		ST2	01-Apr-16	13.0	12	16.8	18.9	23.7	25
NRM region									59

Table 48. *Mean and median seagrass per cent cover and report score for each long-term monitoring site within each Wet Tropics NRM region habitat over the 2015-16 period. Scores calculated as per Table 45. ^denotes Seagrass-Watch or QPWS drop-camera site. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean per cent cover	Median per cent cover	Low percentile	50th percentile	75th percentile	score
coastal intertidal	Lugger Bay	LB1	01-Jul-15	0.0	0	6.6	12.9	14.8	0
		LB1	01-Oct-15	0.0	0	6.6	12.9	14.8	0
		LB1	01-Apr-16	0.0	0	6.6	12.9	14.8	0
		LB2	01-Jul-15	0.0	0	6.6	12.9	14.8	0
		LB2	01-Oct-15	0.0	0	6.6	12.9	14.8	0
		LB2	01-Apr-16	0.0	0	6.6	12.9	14.8	0
	Yule Point	YP1	01-Jul-15	11.5	12	7	14	15.4	50
		YP1	01-Oct-15	12.2	12	7	14	15.4	50
		YP1	01-Jan-16	23.1	26	7	14	15.4	100
		YP1	01-Apr-16	26.8	31	7	14	15.4	100
		YP2	01-Jul-15	7.8	9	6.2	11.8	14.2	50
		YP2	01-Oct-15	8.7	11	6.2	11.8	14.2	50
		YP2	01-Jan-16	21.4	23	6.2	11.8	14.2	100
		YP2	01-Apr-16	27.9	31	6.2	11.8	14.2	100
coastal subtidal	Missionary Bay	MS1^	01-Oct-15	0	0	6.6	12.9	14.8	25
		MS2^	01-Oct-15	11.25	12.25	6.6	12.9	14.8	50
reef intertidal	Dunk Island	DI1	01-Oct-15	0.2	0	27.5	37.7	41	0
		DI1	01-Apr-16	1.3	0	27.5	37.7	41	0
		DI2	01-Oct-15	1.1	0	27.5	37.7	41	0
		DI2	01-Apr-16	1.7	0	27.5	37.7	41	0
	Green Island	GI1	01-Jul-15	26.6	28	32.5	42.7	45.5	25
		GI1	01-Oct-15	37.9	38.5	32.5	42.7	45.5	50
		GI1	01-Jan-16	43.2	41	32.5	42.7	45.5	50
		GI1	01-Apr-16	39.8	40	32.5	42.7	45.5	50
		GI2	01-Jul-15	22.5	25	22.5	32.7	36.7	50
		GI2	01-Oct-15	22.4	21	22.5	32.7	36.7	25
		GI2	01-Jan-16	31.3	30	22.5	32.7	36.7	50
		GI2	01-Apr-16	28.2	30	22.5	32.7	36.7	50
	Low Isles	LI1	01-Jul-15	1.9	0.8	27.5	37.7	41	25
		LI1	01-Oct-15	0.7	0	27.5	37.7	41	0
		LI1	01-Jan-16	0.6	0	27.5	37.7	41	0
		LI1	01-Apr-16	2.7	1.5	27.5	37.7	41	25
	Goold Is	GO1^	01-Oct-15	2.0	1	27.5	37.7	41	25
reef subtidal	Dunk Island	DI3	01-Jul-15	5.5.	3	26	33	39.2	25
		DI3	01-Oct-15	5.9	2	26	33	39.2	0
		DI3	01-Jan-16	3.8	2.25	26	33	39.2	25
		DI3	01-Apr-16	3.9	3	26	33	39.2	25
	Green Island	GI3	01-Jul-15	15.3	15	26	33	39.2	25
		GI3	01-Oct-15	19.1	16	26	33	39.2	25
		GI3	01-Jan-16	17.6	18	26	33	39.2	25
		GI3	01-Apr-16	14.9	12	26	33	39.2	0
	Low Isles	LI2	01-Jul-15	3.5	1.8	22.5	32.7	36.7	25
		LI2	01-Oct-15	3.9	1.5	22.5	32.7	36.7	25
		LI2	01-Jan-16	0	0	22.5	32.7	36.7	0
		LI2	01-Apr-16	0.4	0	22.5	32.7	36.7	0
NRM region									**27**

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Table 49. *Mean and median seagrass per cent cover and report score for each long-term monitoring site within each Burdekin NRM region habitat over the 2015-16 period. Scores calculated as per Table 45. ^denotes Seagrass-Watch site. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean per cent cover	Median per cent cover	Low percentile	50th percentile	75th percentile	score
coastal intertidal	Townsville	BB1	01-Jul-15	20.1	18	21.4	25.4	35.2	0
		BB1	01-Oct-15	25.4	28	21.4	25.4	35.2	75
		BB1	01-Jan-16	26.7	30	21.4	25.4	35.2	75
		BB1	01-Apr-16	29.3	30	21.4	25.4	35.2	75
		SB1	01-Jul-15	3.5	2	10	16.8	22	0
		SB1	01-Oct-15	8.6	5	10	16.8	22	25
		SB1	01-Jan-16	8.4	3	10	16.8	22	0
		SB1	01-Apr-16	8.8	3	10	16.8	22	25
		SB2^	01-Jul-15	10.7	8	10	16.8	22	25
		SB2^	01-Oct-15	11.8	10	10	16.8	22	50
		SB2^	01-Apr-16	28.3	32	10	16.8	22	100
	Bowling Green Bay	JR1	01-Oct-15	29.9	30	15.7	21.1	28.6	100
		JR1	01-Apr-16	18.2	18	15.7	21.1	28.6	50
		JR2	01-Oct-15	28.5	28	15.7	21.1	28.6	75
		JR2	01-Apr-16	16.5	18	15.7	21.1	28.6	50
reef intertidal	Magnetic Island	MI1	01-Jul-15	24.7	28	26	33.4	37	50
		MI1	01-Oct-15	18.8	20	26	33.4	37	0
		MI1	01-Jan-16	17.4	18	26	33.4	37	25
		MI1	01-Apr-16	22.2	25	26	33.4	37	25
		MI2	01-Jul-15	30.7	32	21.3	35.6	41	50
		MI2	01-Oct-15	27.2	28	21.3	35.6	41	50
		MI2	01-Apr-16	35.5	35	21.3	35.6	41	50
reef subtidal	Magnetic Island	MI3	01-Jul-15	32.3	35	22.5	32.7	36.7	75
		MI3	01-Oct-15	60.8	65	22.5	32.7	36.7	100
		MI3	01-Jan-16	36	35	22.5	32.7	36.7	75
		MI3	01-Apr-16	42.2	45	22.5	32.7	36.7	100
NRM region									**50**

Table 50. *Mean and median seagrass per cent cover and report score for each long-term monitoring site within each Mackay Whitsunday NRM region habitat over the 2015-16 period. Scores calculated as per Table 45. ^denotes Seagrass-Watch or QPWS drop-camera site. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean per cent cover	Median per cent cover	Low percentile	50th percentile	75th percentile	score
estuarine intertidal	Sarina Inlet	SI1	01-Oct-15	12.6	12	18	34.1	54	25
		SI1	01-Apr-16	13.6	6	18	34.1	54	0
		SI2	01-Oct-15	11.8	7	18	34.1	54	25
		SI2	01-Apr-16	8.9	1.5	18	34.1	54	0
coastal intertidal	Midge Point	MP2	01-Oct-15	31.1	32	18.9	22.8	25.4	100
		MP2	01-Apr-16	33.3	35	18.9	22.8	25.4	100
		MP3	01-Oct-15	28.8	31	17.9	20	22.3	100
		MP3	01-Apr-16	29.5	32	17.9	20	22.3	100
	Pioneer Bay	PI2^	01-Jul-15	20.2	20	18.7	25.1	27.6	50
		PI2^	01-Oct-15	30.3	30	18.7	25.1	27.6	100
		PI2^	01-Apr-16	17.8	20	18.7	25.1	27.6	50
		PI3^	01-Jul-15	8.9	8	7.6	13.1	16.8	50
		PI3^	01-Oct-15	14.4	13.5	7.6	13.1	16.8	75
		PI3^	01-Apr-16	15.2	15	18.7	25.1	27.6	75
coastal subtidal	Newry Bay	NB1^	01-Oct-15	35.6	35.75	13.2	19.1	22.2	100
		NB2^	01-Oct-15	1.4	0	13.2	19.1	22.2	25
reef intertidal	Hydeaway Bay	HB1^	01-Oct-15	12.3	13	10.53	12.9	14.2	75
		HB2^	01-Oct-15	10.2	12	7.95	11.59	13.4	75
	Hamilton Island	HM1	01-Oct-15	0.8	0	9.2	12.2	13.8	0
		HM1	01-Apr-16	3.4	0	9.2	12.2	13.8	0
		HM2	01-Oct-15	2.0	0	9.2	12.2	13.8	0
		HM2	01-Apr-16	1.0	0	9.2	12.2	13.8	0
reef subtidal	Tongue Bay	TO1^	01-Oct-15	15.4	15.5	22.5	32.7	36.7	25
		TO2^	01-Oct-15	15.2	15.75	22.5	32.7	36.7	25

NRM region	**49s**

Table 51. *Mean and median seagrass per cent cover and report score for each long-term monitoring site within each Fitzroy NRM region habitat over the 2015-16 period. Scores calculated as per Table 45. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean per cent cover	Median per cent cover	Low percentile	50th percentile	75th percentile	score
estuarine intertidal	Gladstone Harbour	GH1	01-Oct-15	2.5	0	18	34.1	54	0
		GH2	01-Oct-15	26.7	25	18	34.1	54	50
coastal intertidal	Shoalwater Bay	RC1	01-Oct-15	14.2	15	17.3	21.8	34.5	25
		WH1	01-Oct-15	15	15	14.4	18.8	22.3	50
reef intertidal	Great Keppel Island	GK1	01-Oct-15	1.2	0	9.2	12.2	13.8	0
		GK2	01-Oct-15	2.3	1	9.2	12.2	13.8	25
NRM region									**25**

Table 52. *Mean and median seagrass per cent cover and report score for each long-term monitoring site within each Burnett Mary NRM region habitat over the 2015-16 period. Scores calculated as per Table 45. ^denotes Seagrass-Watch site. NB: scores do not have units.*

Habitat	Location	Site	Seasonal date	Mean per cent cover	Median per cent cover	Low percentile	50th percentile	75th percentile	score
estuarine intertidal	Rodds Bay	RD1	01-Oct-15	4.9	2	18	34.1	54	25
		RD2	01-Oct-15	0.1	0	18	34.1	54	0
	Urangan	UG1	01-Oct-15	37.5	38	18	34.1	54	75
		UG1	01-Apr-16	13.3	14	18	34.1	54	0
		UG2	01-Oct-15	47.7	55	18	34.1	54	100
		UG2	01-Apr-16	13.6	15	18	34.1	54	0
coastal intertidal	Burrum Heads	BH1^	01-Oct-15	9.1	10	7.8	11.9	21.6	50
		BH1^	01-Apr-16	13.1	15	7.8	11.9	21.6	75
		BH3^	01-Oct-15	13.0	13	7.8	11.9	21.6	75
		BH3^	01-Apr-16	13.2	12	7.8	11.9	21.6	75
NRM region									**42**

A3.3 Seagrass reproductive effort

The reproductive effort of seagrasses provides an indication of the capacity of seagrasses to recover from the loss of an area of seagrass through the recruitment of new plants, i.e. the resilience of the population (Collier and Waycott 2009). Given the high diversity of seagrass species that occur in the GBR coastal zone (Waycott*, et al.* 2007), their variability in production of reproductive structures (e.g. Orth *et al.* 2006), a metric that incorporates all available information on the production of flowers and fruits per unit area is the most useful.

The production of seeds also reflects a simple measure of the capacity of a seagrass meadow to recover following large scale impacts (Collier and Waycott 2009). As it is well recognized that coastal seagrasses are prone to small scale disturbances that cause local losses (Collier and Waycott 2009) and then recover in relatively short periods of time, the need for a local seed source is considerable. In the GBR, the production of seeds comes in numerous forms and seed banks examined at MMP sites are limited to foundational seagrass species (seeds >0.5mm diameter). At this time, seed banks have not been included in the metric for reproductive effort, but methods for future incorporation are currently being explored.

Using the annual mean of all species pooled in the late dry and comparing with the long-term (2005-2010) average for GBR habitat (coastal intertidal = 8.22±0.71, estuarine intertidal = 5.07±0.41, reef intertidal = 1.32±0.14), the reproductive effort was scored as the number of reproductive structures per core and the overall status determined (Table 6) as the ratio of the average number observed divided by the long term average.

Table 53. *Scores for late dry monitoring period reproductive effort average against long-term (2005-2010) GBR habitat average. NB: scores are unitless.*

description	***Reproductive Effort monitoring period / long-term***	***ratio***	***score***	***0-100 score***	***status***
very good	≥4	4.0	4	100	81 - 100
good	2 to <4	2.0	3	75	61 - 80
moderate	1 to <2	1.0	2	50	41 - 60
poor	0.5 to <1	0.5	1	25	21 - 40
very poor	<0.5	0.0	0	0	0 - 20

Table 54. *Average seagrass reproductive effort (RE ±Standard Error) and report card scores for each monitoring site (species pooled) within each NRM region habitat. Scores calculated as per* ***Table 6****. NB: scores do not have units.*

NRM region	habitat	site	RE ±SE	GBR RE (2005-10)	ratio	score
Cape York	coastal intertidal	BY1	5.47 ±1.90	8.22	0.67	25
		BY2	3.47 ±1.59	8.22	0.42	0
		SR1	0.07 ±0.07	8.22	0.01	0
		SR2	0.07 ±0.07	8.22	0.01	0
						6
	reef intertidal	AP1	0.00	1.32	0	0
		AP2	1.20 ±0.62	1.32	0.91	25
		FR1	0	1.32	0	0
		ST1	0.47 ±0.47	1.32	0.35	0
		ST2	0.13 ±0.13	1.32	0.10	0
						5
	region					**6**
Wet Tropics	coastal intertidal	LB1	0	8.22	0	0
		LB2	0	8.22	0	0
		YP1	7.73 ±2.63	8.22	0.94	25
		YP2	9.20 ±1.84	8.22	1.12	50
						19
	reef intertidal	DI1	0	1.32	0	0
		DI2	0	1.32	0	0
		GI1	0.40 ±0.34	1.32	0.30	0
		GI2	1.60 ±0.84	1.32	1.21	50
		LI1	0	1.32	0	0
						10
	reef subtidal	DI3	0.07 ±0.07	0.24	0.28	0
		GI3	0.13 ±0.13	0.24	0.56	25
		LI2	0.20 ±0.20	0.24	0.83	25
						17
	region					**15**
Burdekin	coastal intertidal	BB1	14.07 ±2.82	8.22	1.71	50
		SB1	16.73 ±3.13	8.22	2.04	75
		JR1	1.20 ±0.57	8.22	0.15	0
		JR2	4.13 ±1.42	8.22	0.50	25
						38
	reef intertidal	MI1	0.13 ±0.09	1.32	0.10	0
		MI2	0.07 ±0.07	1.32	0.05	0
						0
	reef subtidal	MI3	1.47 ±0.49	0.24	6.11	100
						100
	region					**46**
Mackay Whitsunday	estuarine intertidal	SI1	4.93 ±1.21	5.07	0.97	25
		SI2	4.20 ±1.83	5.07	0.83	25
						25
	coastal intertidal	MP2	5.27 ±1.16	8.22	0.64	25
		MP3	13.27 ±1.70	8.22	1.61	50
						38
	reef intertidal	HM1	0	1.32	0	0
		HM2	0.20 ±0.15	1.32	0.15	0
						0
	region					**21**
Fitzroy	estuarine intertidal	GH1	0.07 ±0.07	5.07	0.01	0
		GH2	4.80 ±1.25	5.07	0.95	25
						13
	coastal intertidal	RC1	0	8.22	0	0
		WH1	0.07 ±0.07	8.22	0.01	0
						0
	reef intertidal	GK1	0	1.32	0	0
		GK2	0	1.32	0	0
						0
	region					**4**
Burnett Mary	estuarine intertidal	RD1	0	5.07	0	0
		RD2	0	5.07	0	0
		UG1	4.67 ±1.52	5.07	0.92	25
		UG2	15.13 ±4.60	5.07	2.98	75
						25
	region					**25**

A3.4 Seagrass nutrient status.

The molar ratios of seagrass tissue carbon relative to nitrogen (C:N) were chosen as the indicator for seagrass nutrient status as an atomic C:N ratio of less than 20, may suggest either reduced light availability or nitrogen enrichment. Both of these deviations may indicate reduced water quality. Examination of the molar ratios of seagrass tissue carbon relative to nitrogen (C:N) between 2005 and 2008 explained 58 per cent of the variance of the inter-site seagrass cover/abundance (McKenzie and Unsworth 2009).

As changing leaf C:N ratios have been found in a number of experiments and field surveys to be related to available nutrient and light levels (Abal*, et al.* 1994; Grice*, et al.* 1996; Cabaço and Santos 2007; Collier*, et al.* 2009b) they can be used as an indicator of the light that the plant is receiving relative to nitrogen availability or N surplus to light. With light limitation, seagrass plants are unable to build structure, hence the proportion of carbon in the leaves decreases relative to nitrogen. Experiments on seagrasses in Queensland have reported that at an atomic C:N ratio of less than 20, may suggest reduced light availability relative to nitrogen availability (Abal*, et al.* 1994; AM Grice*, et al.*, 1996;). The light availability to seagrass is not necessarily an indicator of light in the water column, but an indicator of the light that the plant is receiving as available light can be highly impacted by epiphytic growth or sediment smothering photosynthetic leaf tissue. However, C:N must be interpreted with caution as the level of N can also influence the ratio in oligotrophic environments (Atkinson and Smith 1983; Fourqurean*, et al.* 1992b). Support for choosing the elemental C:N ratio as the indicator also comes from preliminary analysis of MMP data in 2009 which found that the C:N ratio was the only nutrient ratio that showed a significant relationship (positive) with seagrass cover at coastal and estuarine sites. Seagrass tissue C:N ratios explained 58 per cent of the variance of the inter-site seagrass cover data (McKenzie and Unsworth 2009). Using the guideline ratio of 20:1 for the foundation seagrass species, C:N ratios were categorised on their departure from the guideline and transformed to a 0 to 100 score using:

Equation 1 $$\overline{R} = (\mathrm{C:N} \times 5) - 50$$

NB: C:N ratios >35 scored as 100, C:N ratios <10 scored as 0

The score was then used to represent the status to allow integration with other components of the report card (Table 7).

Table 55. *Scores for leaf tissue C:N against guideline to determine light and nutrient availability. NB: scores are unitless.*

description	C:N ratio range	Score ($\overline{R}$) status
very good	C:N ratio >30*	81 - 100
good	C:N ratio 25-30	61 - 80
moderate	C:N ratio 20-25	41 - 60
poor	C:N ratio 15-20	21 - 40
very poor	C:N ratio <15*	0 - 20

Table 56. *Average seagrass leaf tissue C:N ratios and report scores for each monitoring site (species pooled) within each NRM region habitat. C:N ratios transformed to a 0 to 100 score using* Equation 1. *NB: scores do not have units. *insufficient sample*

NRM region	habitat	site	C:N ±SE	score
Cape York	coastal intertidal	BY1	17.92 ±0.37	39.6
		BY2	19.90 ±0.41	49.49
		SR1	15.73 ±0.27	28.64
		SR2	14.74 ±0.28	23.7
				35
	reef intertidal	AP1	13.11 ±0.39	15.57
		AP2	22.42 ±0.33	62.12
		FR1	16.63 ±0.18	33.16
		ST1	16.76 ±1.47	33.78
		ST2	17.91 ±0.31	39.54
				37
	region			**36**
Wet Tropics	coastal intertidal	LB1	*	
		LB2	*	
		YP1	12.30 ±0.31	11.5
		YP2	11.22 ±0.18	6.12
				9
	reef intertidal	DI1	19.85 ±0.69	49.26
		DI2	16.46 ±0.56	32.3
		GI1	19.31 ±0.52	46.57
		GI2	17.84 ±0.37	39.19
		LI1	16.55 ±0.37	32.74
				40
	reef subtidal	DI3	18.41 ±0.26	42.06
		GI3	20.39 ±0.30	51.93
		LI2	*	
				47
	region			**32**
Burdekin	coastal intertidal	BB1	13.18 ±0.75	15.88
		SB1	15.04 ±0.21	25.18
		JR1	18.91 ±0.29	44.53
		JR2	18.51 ±0.11	42.53
				32
	reef intertidal	MI1	17.41 ±0.67	37.07
		MI2	19.84 ±0.70	49.18
				43
	reef subtidal	MI3	20.43 ±0.31	100
				100
	region			**58**
Mackay Whitsunday	estuarine intertidal	SI1	16.74 ±1.40	33.69
		SI2	18.04 ±0.64	40.22
				37
	coastal intertidal	MP2	20.36 ±0.86	51.82
		MP3	19.50 ±0.90	47.51
				50
	reef intertidal	HM1	10.57 ±0.13	2.83
		HM2	12.74 ±0.25	13.69
				8
	region			**32**
Fitzroy	estuarine intertidal	GH1	16.21 ±0.67	31.03
		GH2	22.71 ±0.26	63.56
				47
	coastal intertidal	RC1	16.17 ±0.46	30.83
		WH1	15.99 ±0.29	29.94
				30
	reef intertidal	GK1	15.78 ±0.33	28.9
		GK2	16.75 ±0.76	33.76
				31
	region			**36**
Burnett Mary	estuarine intertidal	RD1	13.81 ±0.39	19.05
		RD2	*	
		UG1	22.86 ±0.66	64.28
		UG2	23.40 ±0.13	66.99
				50
	region			**50**

A3.5 Seagrass index

The seagrass index is average score (0-100) of the three seagrass status indicators chosen for the MMP. Each indicator is equally weighted as we have no preconception that it should be otherwise. To calculate the overall score for seagrass of the Great Barrier Reef (GBR), the regional scores were weighted on the percentage of GBRWHA seagrass (shallower than 15m) within that region (Table 57). *Please note: Cape York omitted from the GBR score in P2R reporting prior to 2012 due to poor representation of inshore monitoring sites throughout region*.

Table 57. *Area of seagrass shallower than 15m in each NRM region (fromMcKenzie et al. 2014c; McKenzie, et al. 2014d; Carter, et al. 2016; Waterhouse et al. 2016) within the boundaries of the Great Barrier Reef World Heritage Area.*

NRM	**Area of seagrass** (km^2)	**per cent of GBRWHA**
Cape York	2,078	0.60
Wet Tropics	207	0.06
Burdekin	587	0.17
Mackay Whitsunday	215	0.06
Fitzroy	257	0.07
Burnett Mary	120	0.03
GBRWHA	**3,464**	**1.00**

Appendix 4 Detailed data

A4.1 Climate and environmental pressures

A4.1.1 River discharge

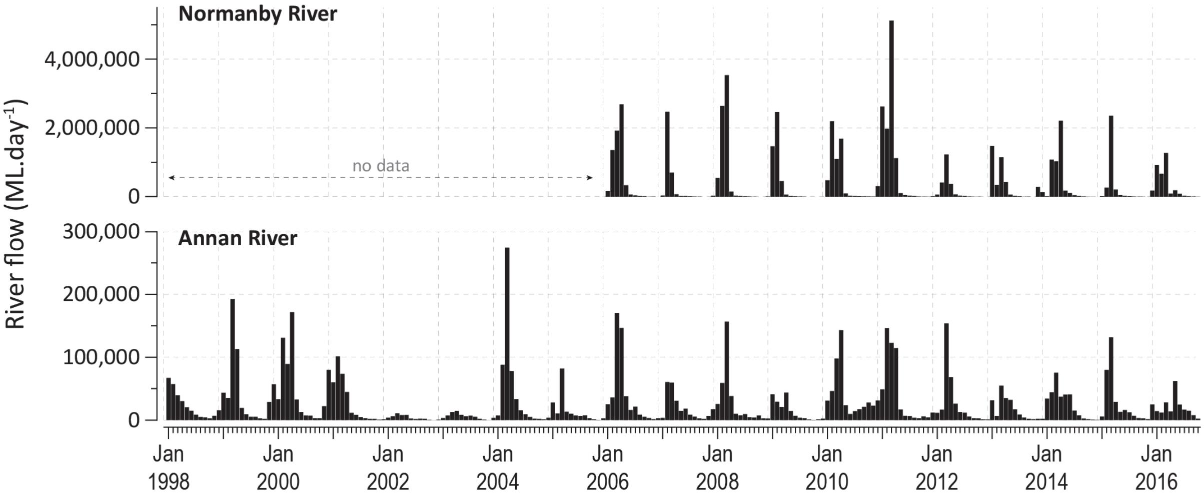

Figure 144. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact the seagrass monitoring sites in the Cape York (stations 105107A - Normanby River at Kalpowar Crossing 14.91683°S 144.211279°E, Elev:21.3m and 107003A - Annan River at Beesbike 15.68773°S, 145.2085°E, Elev: 115m) (source ©The State of Queensland (DNRM) 2016).*

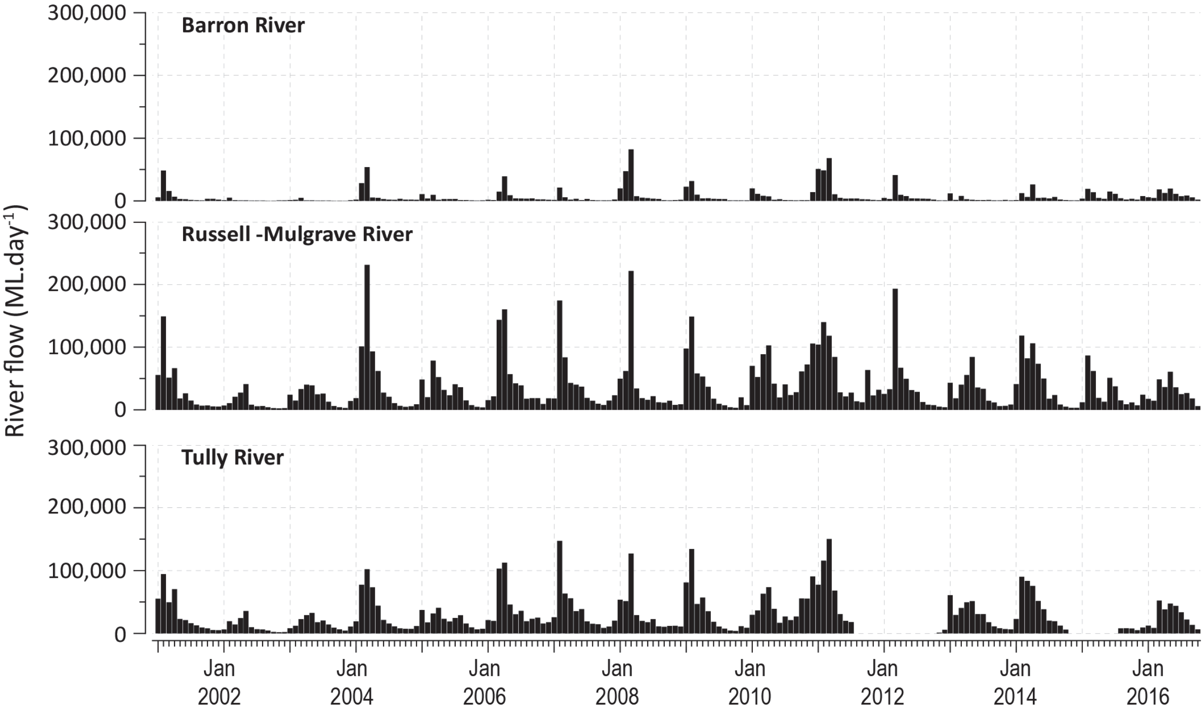

Figure 145. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact the seagrass monitoring sites in the Wet Tropics (stations 110001D - Barron River at Myola, 16.79983333°S 145.61211111°E, Elev 345m; 111007A - Mulgrave River at Peets Bridge, 17.13336111°S 145.76455556°E, Elev 27.1m; 111101D - Russell River at Bucklands 17.38595°S 145.96726667°E, Elev10m; 113006A - Tully River at Euramo, 17.99213889°S 145.94247222°E, Elev 8.76m) (source ©The State of Queensland (DNRM) 2016).*

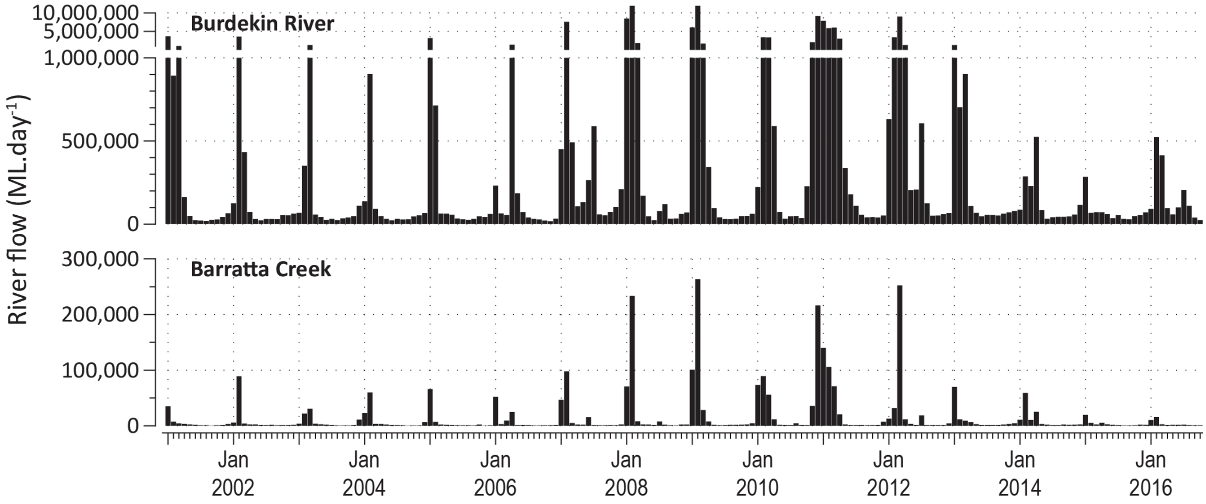

Figure 146. *Average daily flow (ML day^{-1}) per month from the Burdekin River which would impact the seagrass monitoring sites in the Burdekin region (stations 120006B - Burdekin River at Clare, 19.75856°S 147.24362°E, Elev 29m; 119101A - Barratta Creek at Northcote Lat:-19.69072778 Long:147.169825 Elev: 17.3m) (source ©The State of Queensland (DNRM) 2016).*

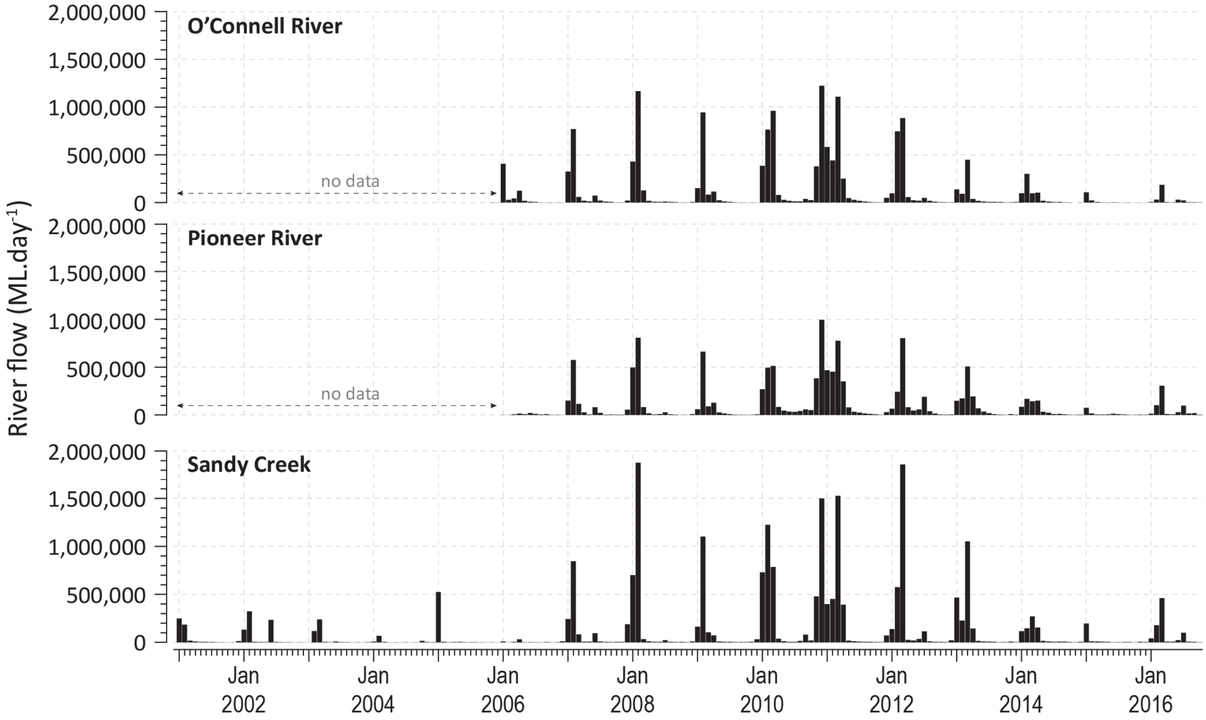

Figure 147. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact inshore seagrass monitoring sites in the Mackay Whitsunday region (stations 124001B - O'Connell River at Stafford's Crossing 20.65255556°S 148.573°E, Elev:0m; 125016A - Pioneer River at Dumbleton Weir T/W 21.14236111°S 149.07625°E, Elev 10m; 126001A - Sandy Creek at Homebush Lat:-21.2832888 Long:149.0225055, Elev 62m) (source ©The State of Queensland (DNRM) 2016).*

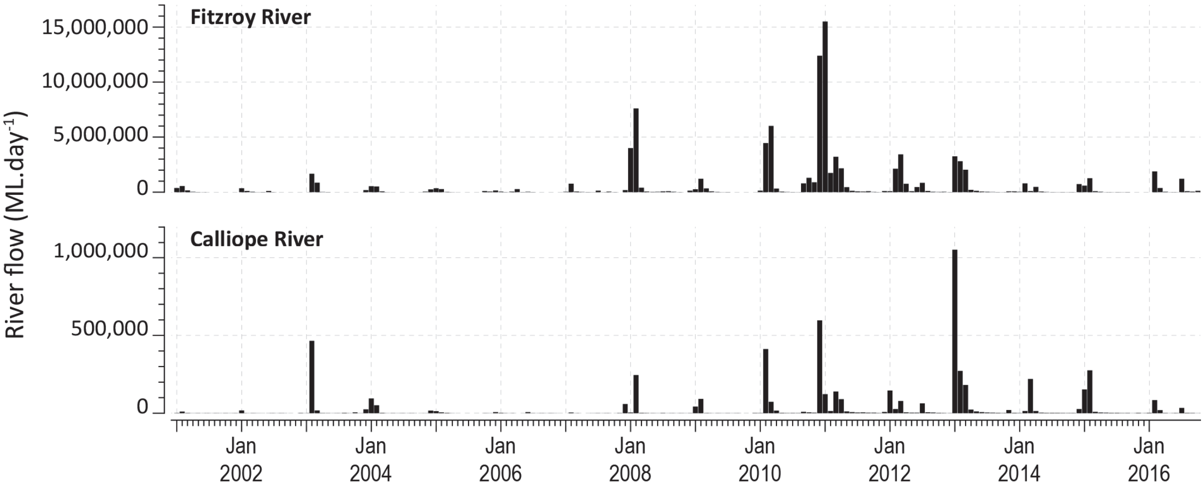

Figure 148. *Average daily flow (ML day^{-1}) per month from the main rivers which would impact seagrass monitoring sites in the Fitzroy region (stations 130005A - Fitzroy River at The Gap, 23.08897222°S 150.10713889°E, Elev 0m; 132001A - Calliope River at Castlehope 23.98498333°S 151.09756389°E, Elev:21m)(source ©The State of Queensland (DNRM) 2016).*

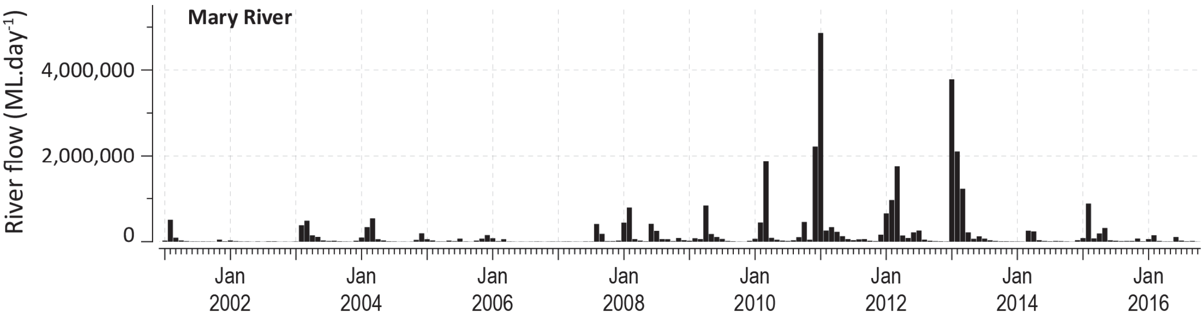

Figure 149. *Average daily flow (ML day^{-1}) per month from the Mary River which would impact estuarine seagrass monitoring sites at Urangan, southern Burnett Mary region (station 138001A - Mary River at Miva Lat:25.95332924°S:152.4956601 °E, Elev 0m) (source ©The State of Queensland (DNRM) 2016).*

A4.1.2 Climate

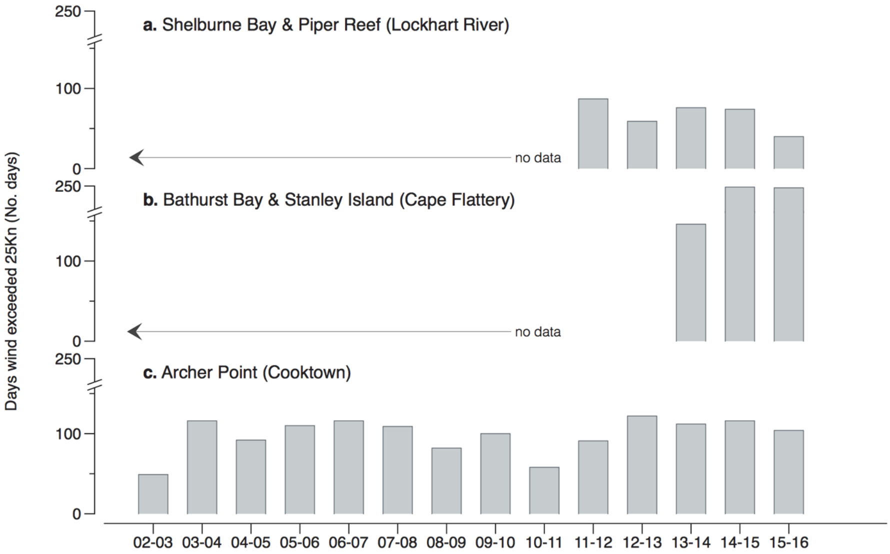

Figure 150. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Cape York NRM region. Daily 3pm wind speed from: a) from Lockhart River Airport (BOM station 028008, source www.bom.gov.au), located 108km from Shelburne Bay and 61km from Piper Reef monitoring sites; b) Cape Flattery (BOM station 031213), located approximately 139km and 144km from Bathurst Bay and Stanley Island monitoring sites, respectively and; c) Cooktown airport (BOM station 031209), located 16km from Archer Point monitoring sites.*

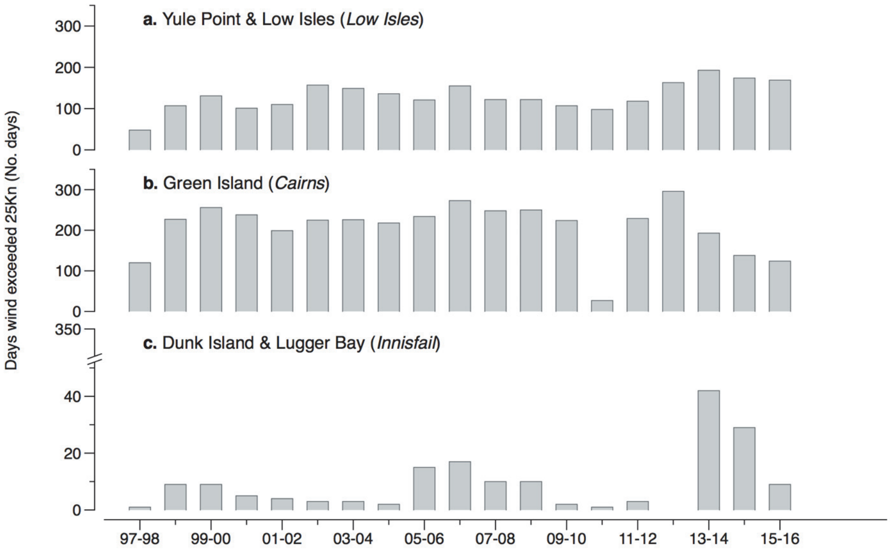

Figure 151. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Wet Tropics NRM region. Daily 3pm wind speed from: a) Low Isles (BOM station 31037), located approximately 21km from Yule Point monitoring sites; b) Green Island (BOM station 31192); and C) Innisfail (BOM station 032025), located approximately 48km from monitoring sites at Lugger Bay and Dunk Island.*

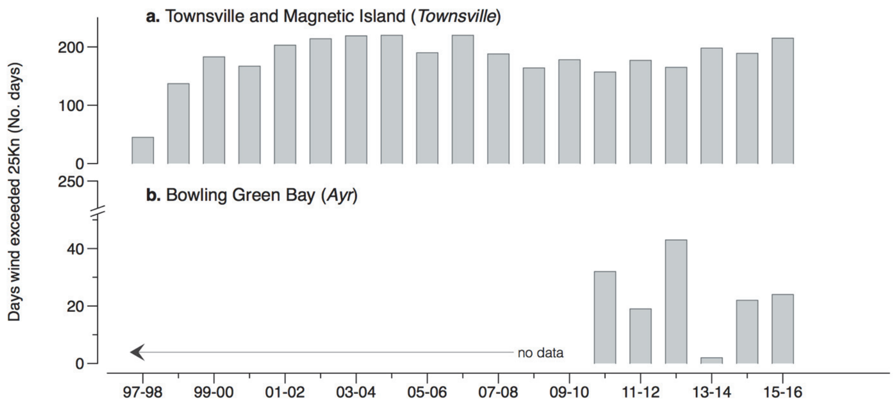

Figure 152. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Burdekin NRM region. Daily 3pm wind speed from: a) Townsville Airport (BOM station 032040) located approximately 11km from coastal (Townsville) and reef (Magnetic Island) monitoring sites, and 53km from Jerona (Bowling Green Bay) monitoring sites; and b) Ayr (BOM station 033002), located approximately 26km from from Jerona (Bowling Green Bay) monitoring sites.*

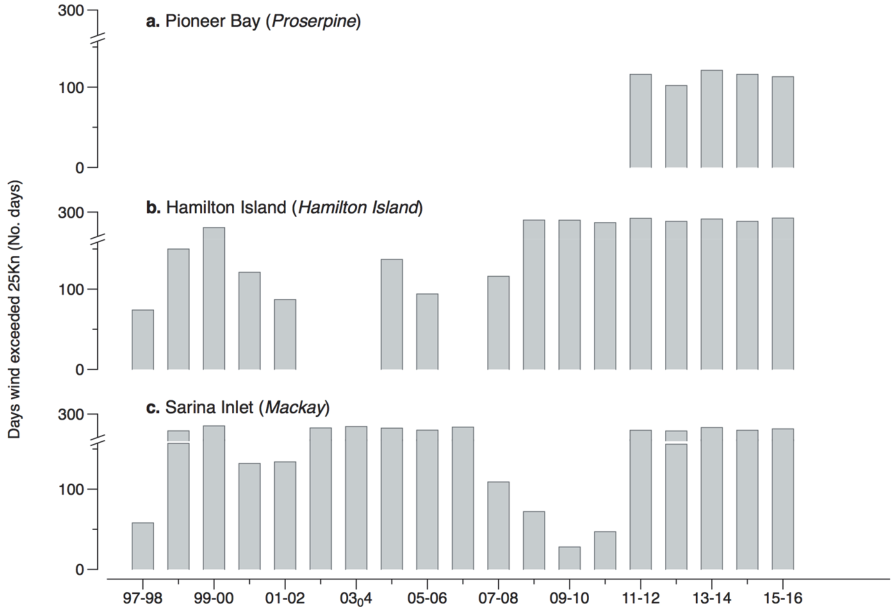

Figure 153. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Mackay Whitsunday NRM region. Daily 3pm wind speed from: a) Proserpine Post Office (BOM station 33316) (post June 2011), located 18km from Midge Point monitoring sites; b) Hamilton Island (BOM station 033106), located 1.5km from Hamilton Island monitoring sites; and c) Mackay Airport (BOM station 033045, source www.bom.gov.au), approximately 28km from Sarina Inlet monitoring sites.*

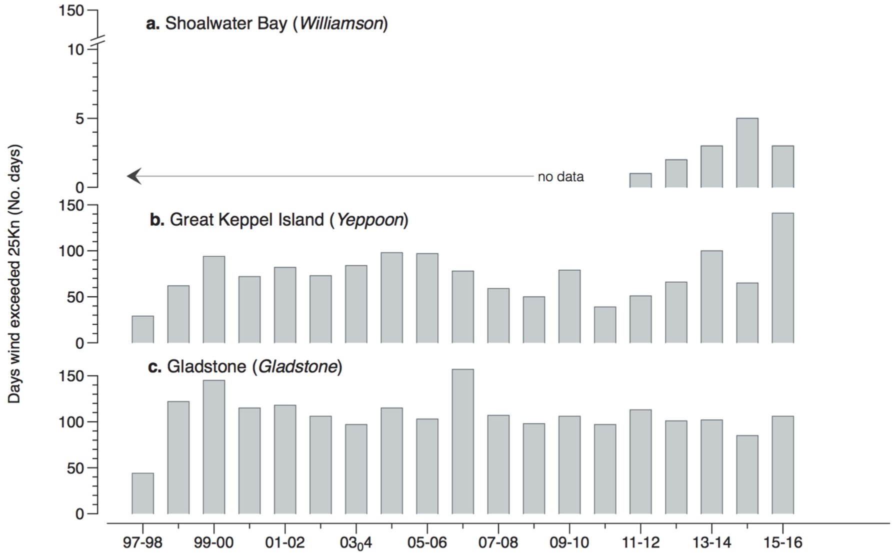

Figure 154. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Fitzroy NRM region. Daily 3pm wind speed from: a) Williamson, Shoalwater Bay (BOM station 033260), located 10km from the monitoring sites; b) Yeppoon (BOM station 033106), approximately 22km from monitoring sites; and c) Gladstone Airport (BOM station 039123), located approximately 13km from monitoring sites.*

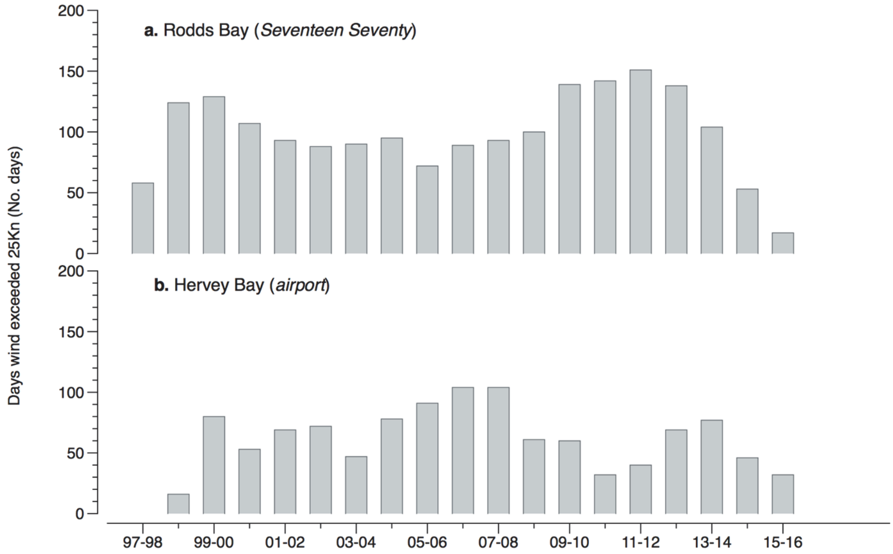

Figure 155. *Number of days wind speed is above 25 km. hr^{-1} each monitoring period in the Burnett Mary NRM region. Daily 3pm wind speed from: a) Seventeen Seventy (BOM station 039314), approximately 27km from Rodds Bay monitoring sites; and b) Hervey Bay Airport (BOM station 040405), approximately 3km from Urangan monitoring sites.*

A4.1.3 Tidal exposure

Table 58. *Height of intertidal monitoring meadows/sites above Lowest Astronomical Tide (LAT) and annual daytime tidal exposure (total hours) when meadows become exposed at a low tide. Year is June - May. Observed tidal heights courtesy Maritime Safety Queensland, 2016. NB: Meadow heights have not yet been determined in the far northern Cape York.*

NRM	Site	Meadow height (above LAT)	Site depth (bMSL)	Meadow height (above LAT) relative to Standard Port	Annual median hours exposed during daylight (long-term)	per cent of annual daylight hours meadow is exposed (long-term)	Annual daytime exposure 2015-16 (hrs)
Cape York	AP1	0.46	1.02	0.46	69.50	1.58 per cent	85.83
	AP2	0.46	1.02	0.46	69.50	1.58 per cent	85.83
Wet Tropics	LI1	0.65	0.90	0.65	178.50	3.96 per cent	184.00
	YP1	0.64	0.94	0.64	169.83	3.78 per cent	178.83
	YP2	0.52	1.06	0.52	97.33	2.15 per cent	114.00
	GI1	0.51	1.03	0.61	116.33	2.60 per cent	161.17
	GI2	0.57	0.97	0.67	153.25	3.44 per cent	195.00
	DI1	0.65	1.14	0.54	75.08	1.65 per cent	84.50
	DI2	0.55	1.24	0.44	43.83	0.97 per cent	44.67
	LB1	0.42	1.37	0.31	18.08	0.39 per cent	16
	LB2	0.46	1.33	0.35	21.75	0.48 per cent	14.33
Burdekin	BB1	0.58	1.30	0.58	88.92	1.94 per cent	80.50
	SB1	0.57	1.31	0.57	68.92	1.58 per cent	76.17
	MI1	0.65	1.19	0.67	190.42	4.04 per cent	126.33
	MI2	0.54	1.30	0.56	176.92	3.62 per cent	72.17
	JR1	0.47	1.32	0.47	65.17	1.48 per cent	76.83
	JR2	0.47	1.32	0.47	65.17	1.48 per cent	76.83
Mackay Whitsunday	PI2	0.28	1.47	0.44	80.67	1.85 per cent	104.33
	PI3	0.17	1.58	0.33	41.50	0.95 per cent	47.33
	HM1	0.68	1.52	0.38	56.67	1.29 per cent	67.50
	HM2	0.68	1.52	0.38	56.67	1.29 per cent	67.50
	SI1	0.60	2.80	0.54	23.75	0.51 per cent	28.67
	SI2	0.60	2.80	0.54	23.75	0.51 per cent	28.67
Fitzroy	RC1	2.03	1.30	1.06	162.67	3.69 per cent	173.00
	WH1	2.16	1.17	1.19	231.75	5.35 per cent	250.00
	GK1	0.52	1.93	0.43	34.92	0.85 per cent	45.17
	GK2	0.58	1.87	0.49	51.67	1.22 per cent	61.50
	GH1	0.80	1.57	0.69	97.33	2.31 per cent	121.67
	GH2	0.80	1.57	0.69	91.53	2.15 per cent	121.67
Burnett Mary	RD1	0.56	1.48	0.56	66.58	1.59 per cent	103.67
	RD2	0.63	1.41	0.63	91.42	2.25 per cent	138.00
	UG1	0.70	1.41	0.70	147.50	3.30 per cent	144.00
	UG2	0.64	1.47	0.64	106.67	2.41 per cent	107.67

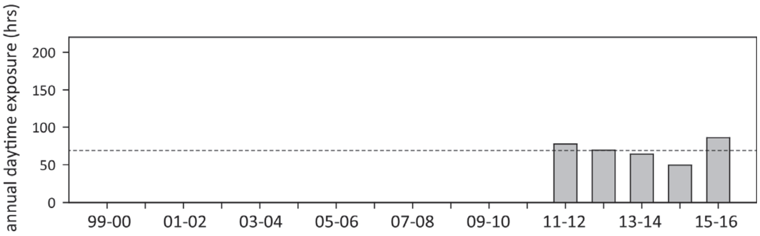

Figure 156. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal reef seagrass meadows at Archer Point, Cape York NRM region; 2011 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016. NB: Meadow heights have not yet been determined in the far northern Cape York sites.*

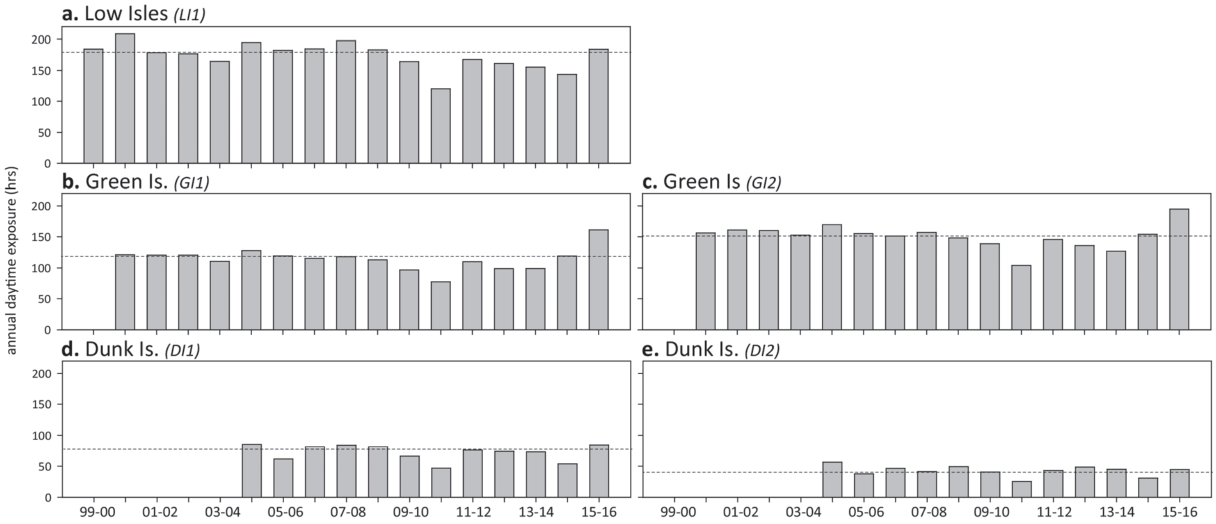

Figure 157. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal reef seagrass meadows in the Wet Tropics NRM region; 1999 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016.*

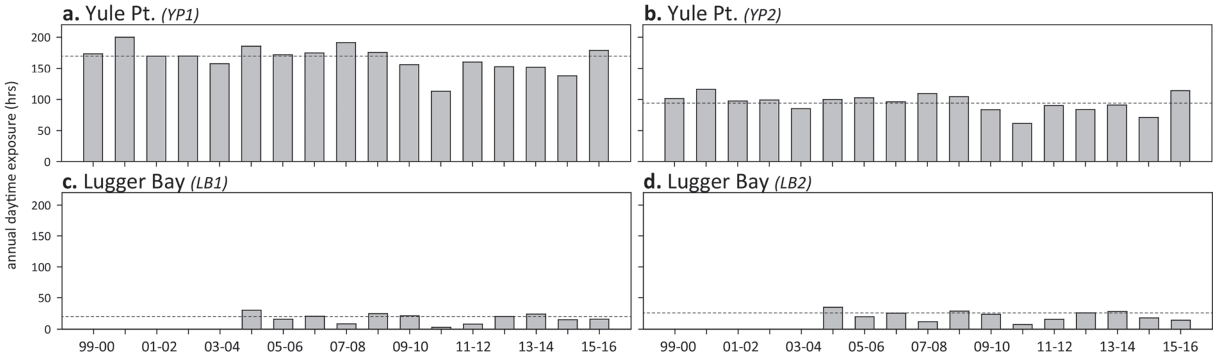

Figure 158. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal coastal seagrass meadows in Wet Tropics NRM region; 1999 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016.*

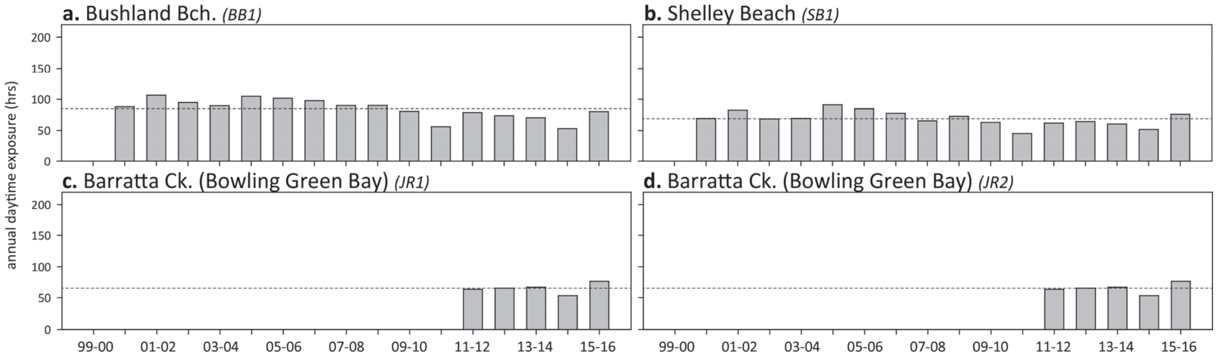

Figure 159. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal coastal seagrass meadows in Burdekin NRM region; 2000 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016.*

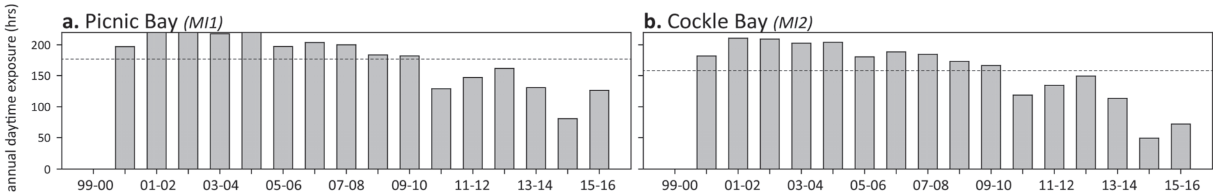

Figure 160. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal reef seagrass meadows in Burdekin NRM region; 2000 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016.*

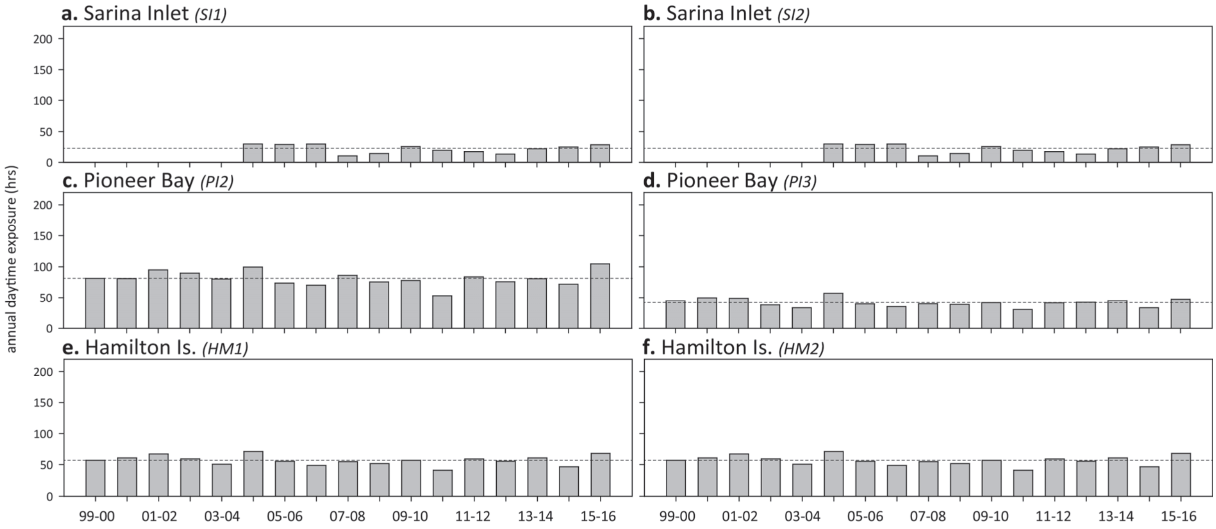

Figure 161. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal estuarine (a, b) coastal (c, d) and reef (e, f) seagrass meadows in Mackay Whitsunday NRM region; 1999 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016.*

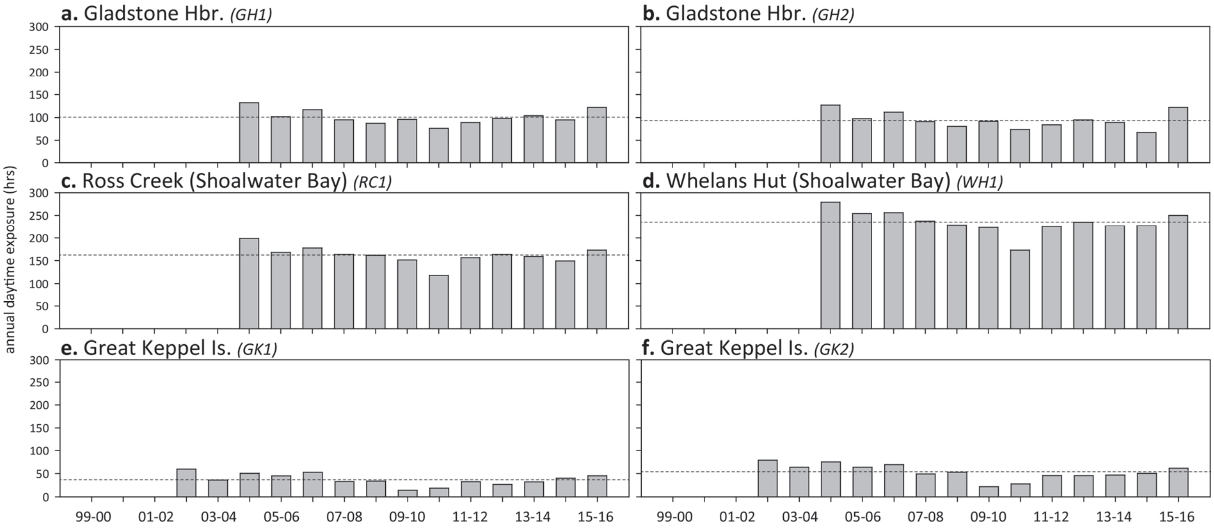

Figure 162. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal estuarine (a, b) coastal (c, d) and reef (e, f) seagrass meadows in the Fitzroy NRM region; 1999 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016.*

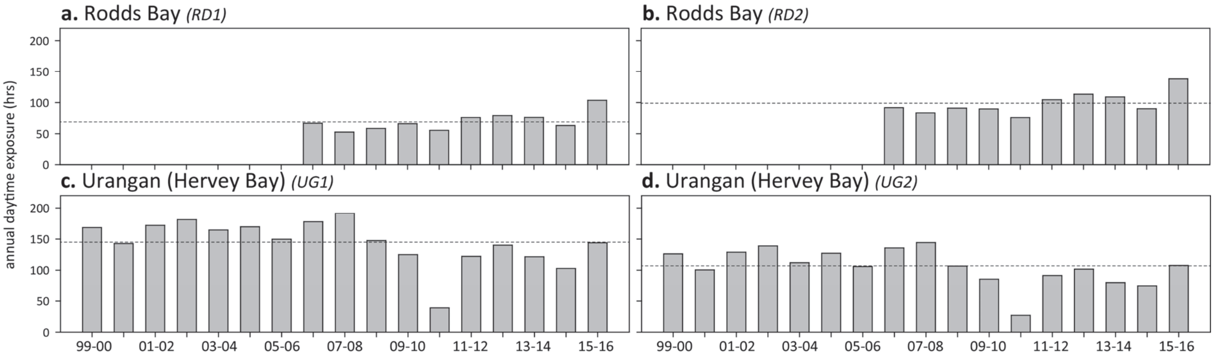

Figure 163. *Annual daytime tidal exposure (total hours) and long-term median (dashed line) of intertidal estuarine seagrass meadows in the Burnett Mary NRM region; 1999 - 2016. Year is June - May. For tidal exposure (when intertidal banks become exposed at a low tide) height at each site, see Table 58. Observed tidal heights courtesy Maritime Safety Queensland, 2016.*

A4.1.4 Light at seagrass canopy

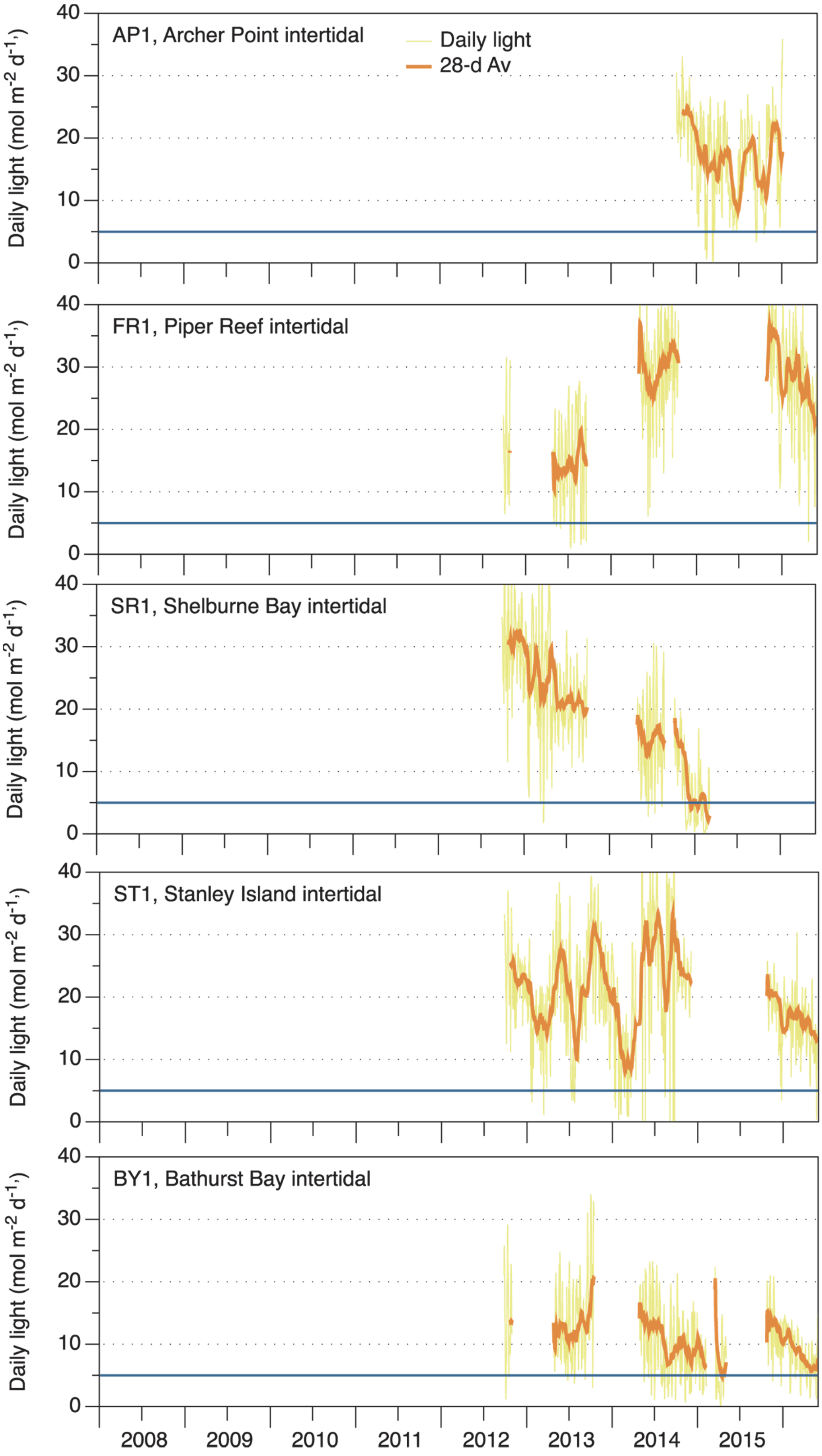

Figure 164. *Daily light (28-day rolling average) at Cape York locations, also showing approximate light threshold required for positive growth in Halodule uninervis dominated communities (5 mol m^{-2} d^{-1}) Collier, et al. 2012b NB threshold is based on 90-day average.*

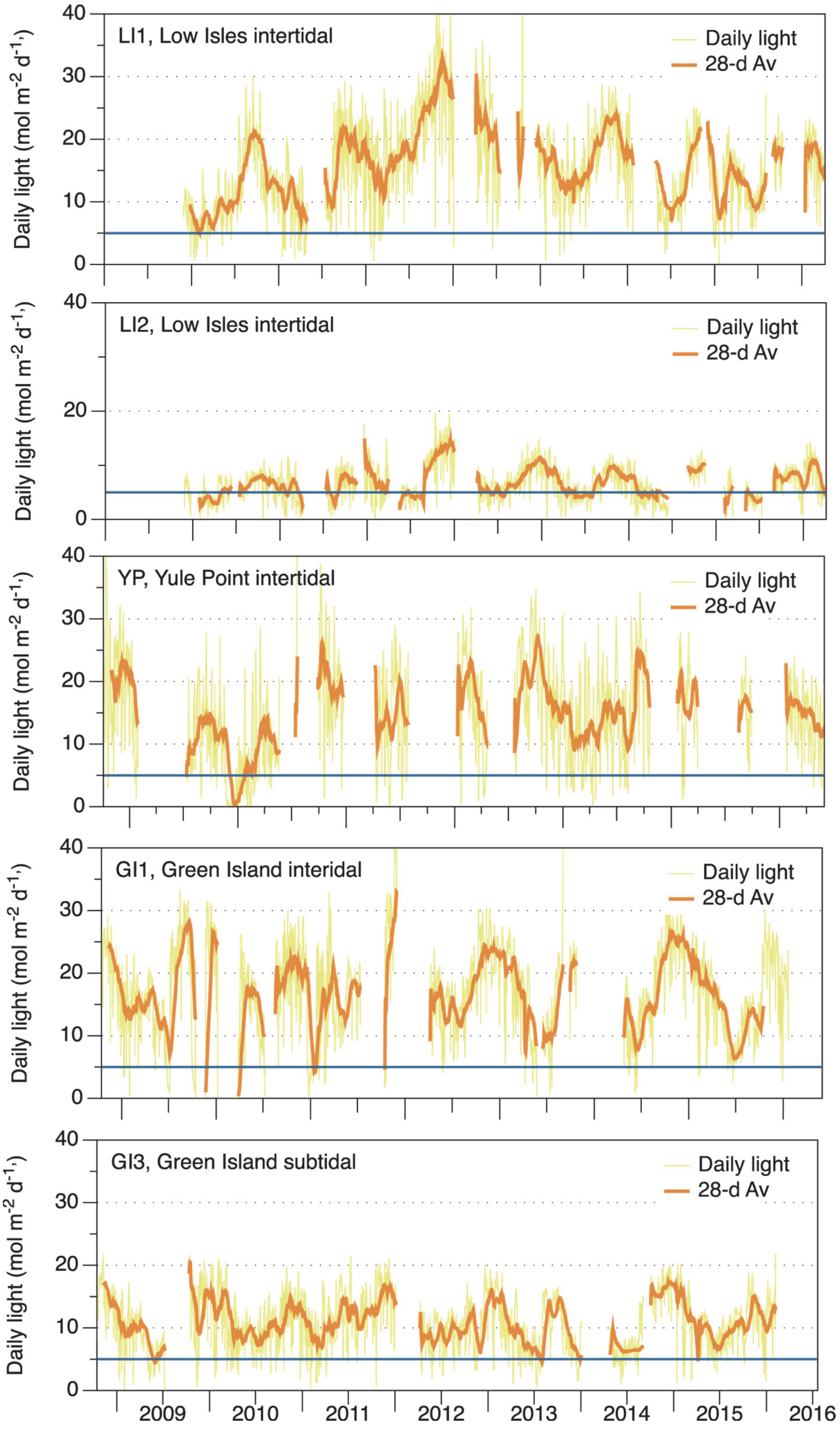

Figure 165. *Daily light (yellow line) and 28-day rolling average (orange, bold line) for locations in the northern Wet Tropics. Also shown is an event-based light threshold (5 mol m^{-2} d^{-1}) for H. uninervis (Collier, et al. 2012b)*

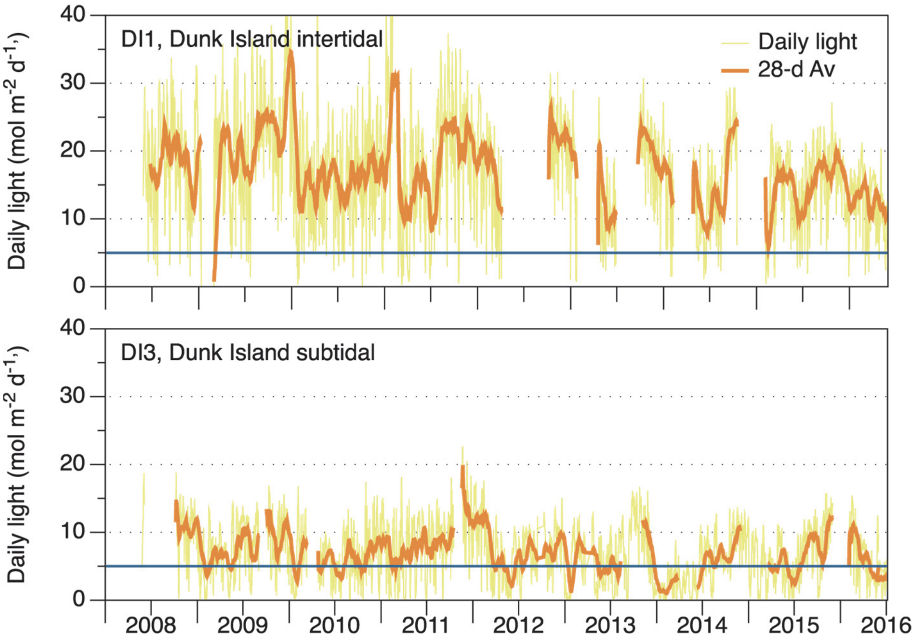

Figure 166. *Daily light (yellow line) and 28-day rolling average (orange, bold line) for locations in the southern Wet Tropics. Also shown is an event-based light threshold (5 mol m^{-2} d^{-1}) for H. uninervis (Collier, et al. 2012b)*

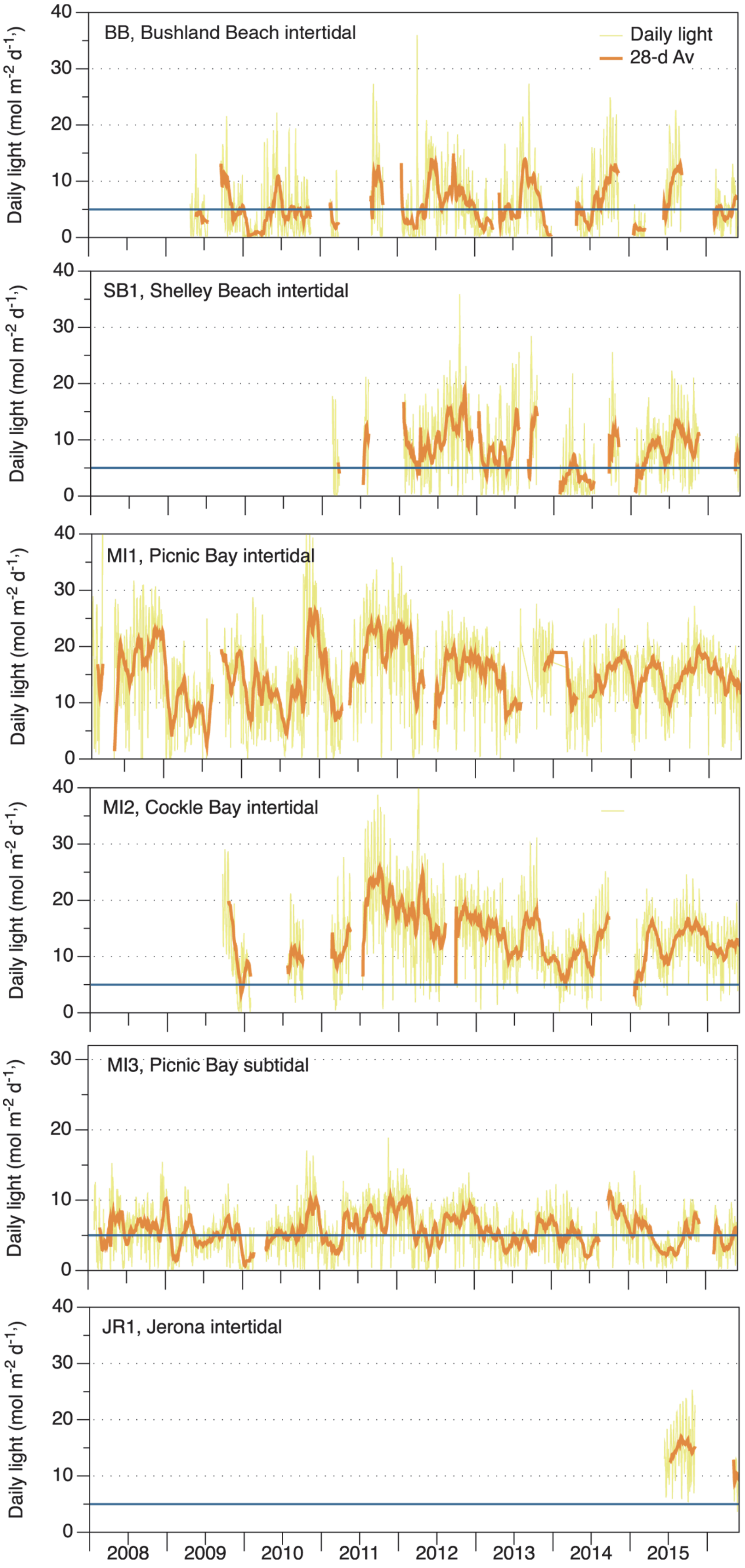

Figure 167. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at locations in the Burdekin region. Also shown is an event-based light threshold (5 mol m^{-2} d^{-1}) for H. uninervis (Collier, et al. 2012b).*

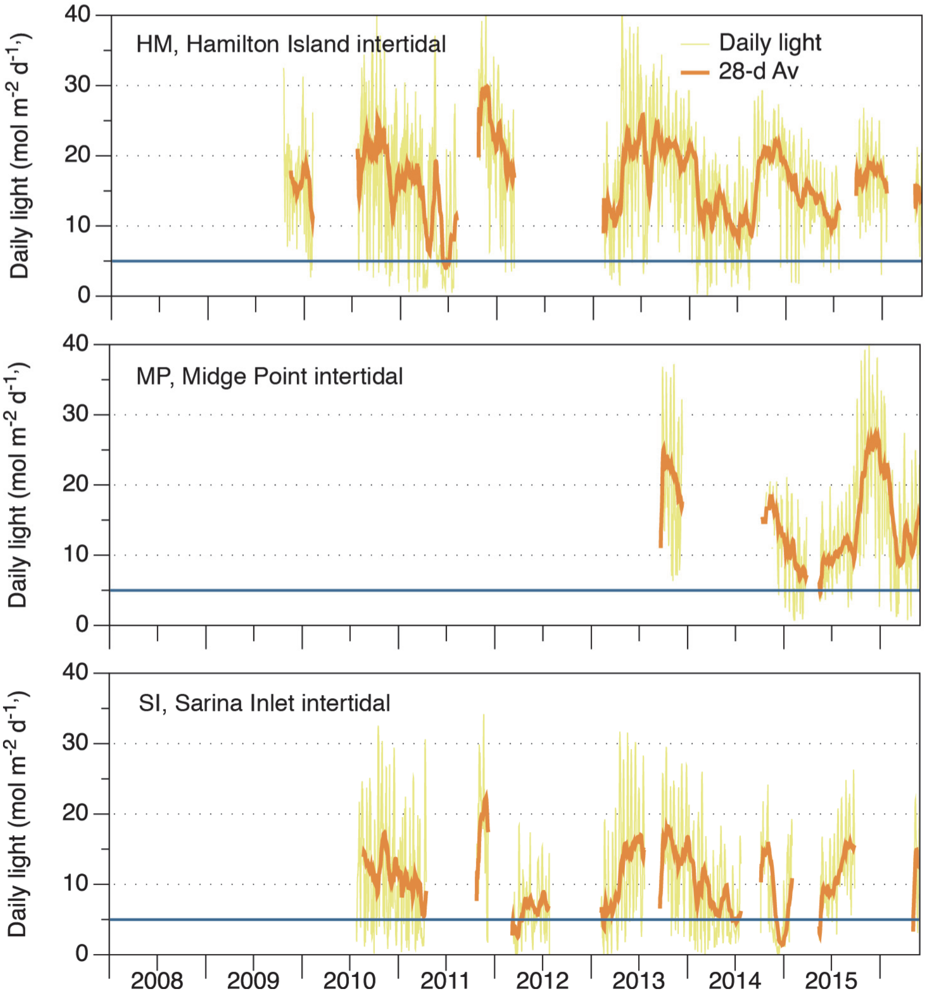

Figure 168. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at Mackay Whitsunday habitats. Also shown is an event-based light threshold (5 mol m*$^{-2}$ *d*$^{-1}$*) for H. uninervis (Collier, et al. 2012b).*

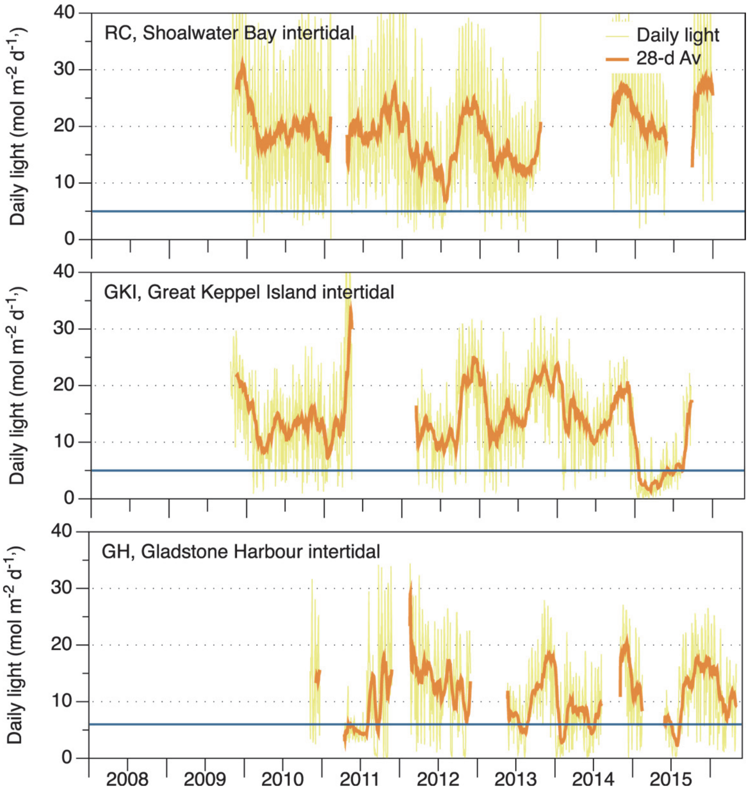

Figure 169. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at monitoring locations in the Fitzroy NRM region. Also displayed is an event based light threshold (5 mol m^{-2} d^{-1}) for* Halodule uninervis *(Collier, et al. 2012b) or for Zostera muelleri (6 mol m^{-2} d^{-1}) (Chartrand, et al. 2016b).*

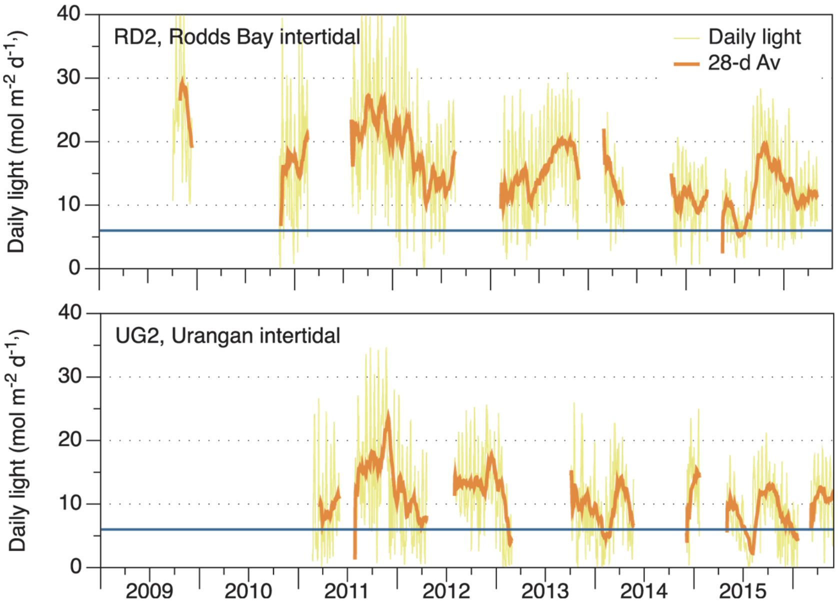

Figure 170. *Daily light (yellow line) and 28-day rolling average (orange, bold line) at monitoring locations in the Burnett Mary NRM region. Also displayed is an event based light threshold (5 mol m^{-2} d^{-1}) for* Halodule uninervis *(Collier, et al. 2012b) or for Zostera muelleri (6 mol m^{-2} d^{-1}) (Chartrand, et al. 2016b).*

A4.2 Seagrass community and environment

A4.2.1 Seagrass abundance

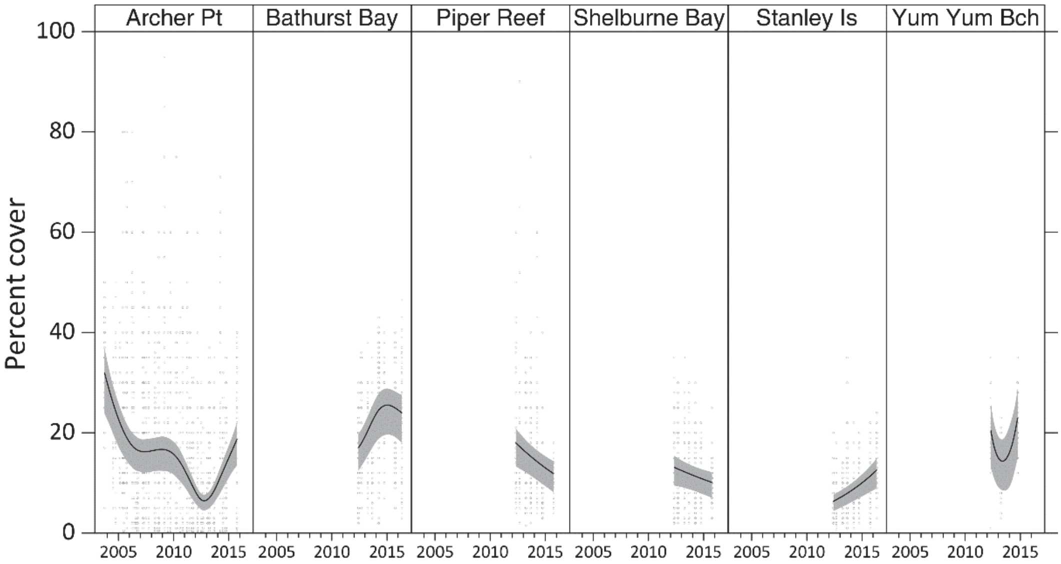

Figure 171. *Temporal trends in seagrass abundance for each location in the Cape York NRM region represented by a GAM plot. Location trend (all sites pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals and quadrat data represented by grey circles.*

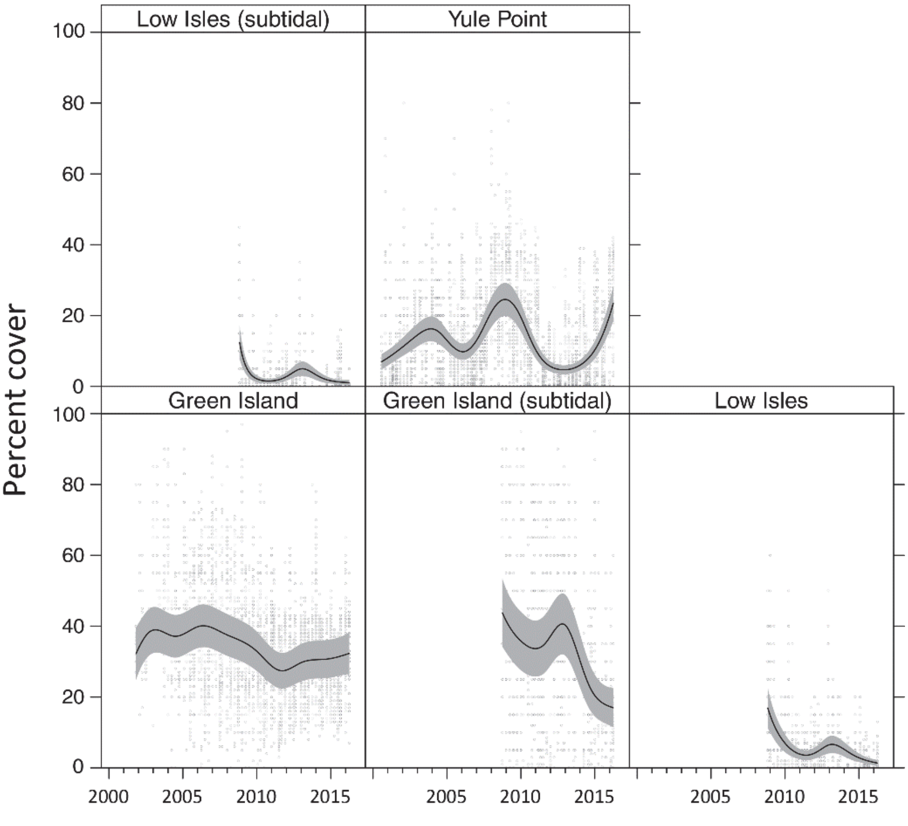

Figure 172. *Temporal trends in seagrass abundance for each location in the northern Wet Tropics NRM region represented by a GAM plot. Location trend (all sites pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals and quadrat data represented by grey circles*

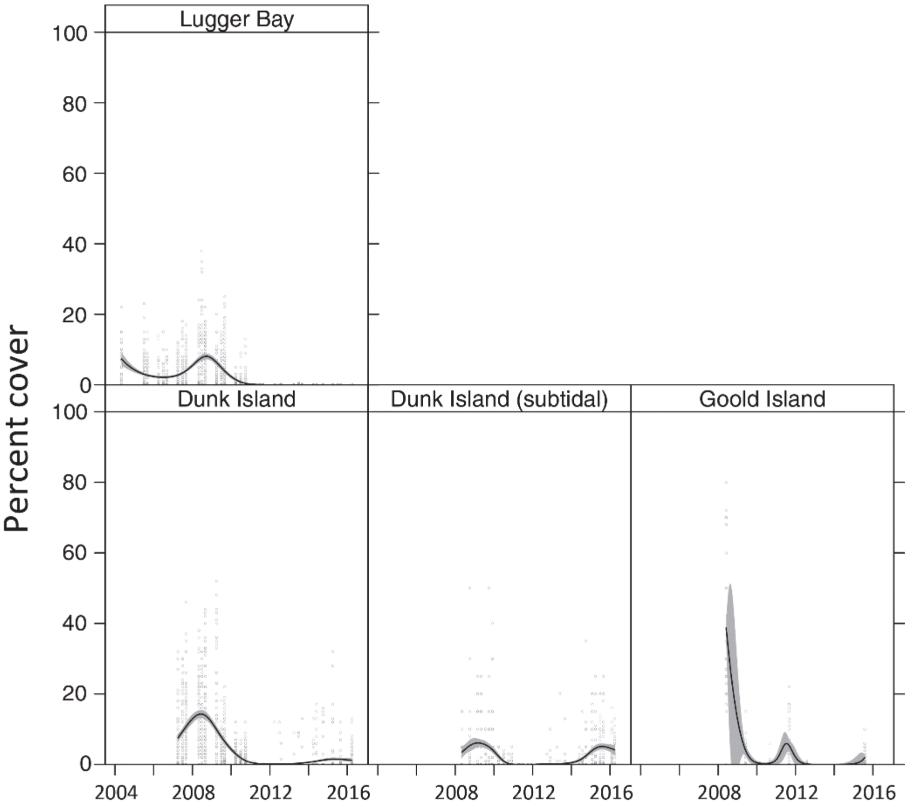

Figure 173. *Temporal trends in seagrass abundance for each location in the southern Wet Tropics NRM region represented by a GAM plot. Location trend (all sites pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals and quadrat data represented by grey circles*

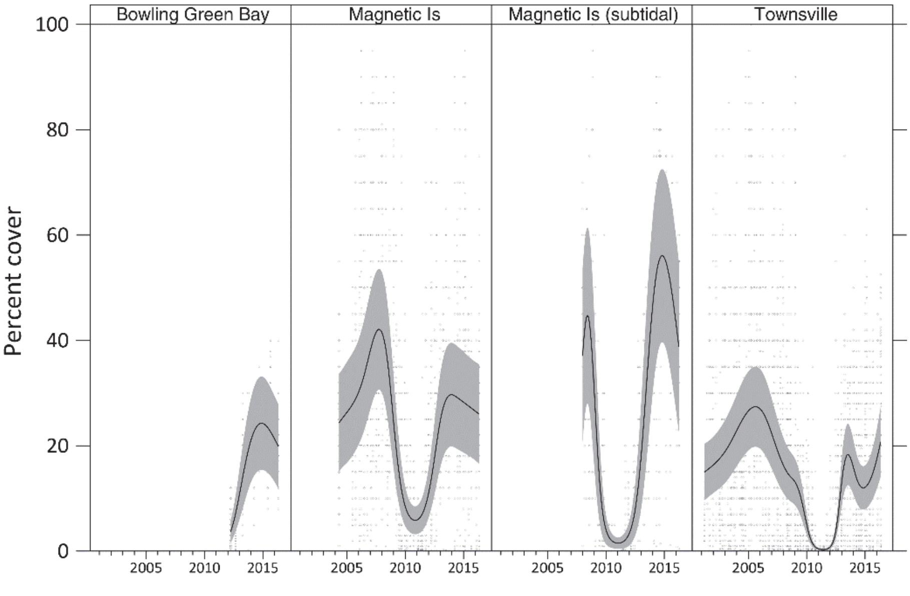

Figure 174. *Temporal trends in seagrass abundance for each location in the Burdekin NRM region represented by a GAM plot. Location trend (all sites pooled) represented by black line with grey shaded areas defining 95 per cent confidence intervals and quadrat data represented by grey circles .*

A4.2.2 Sediments composition

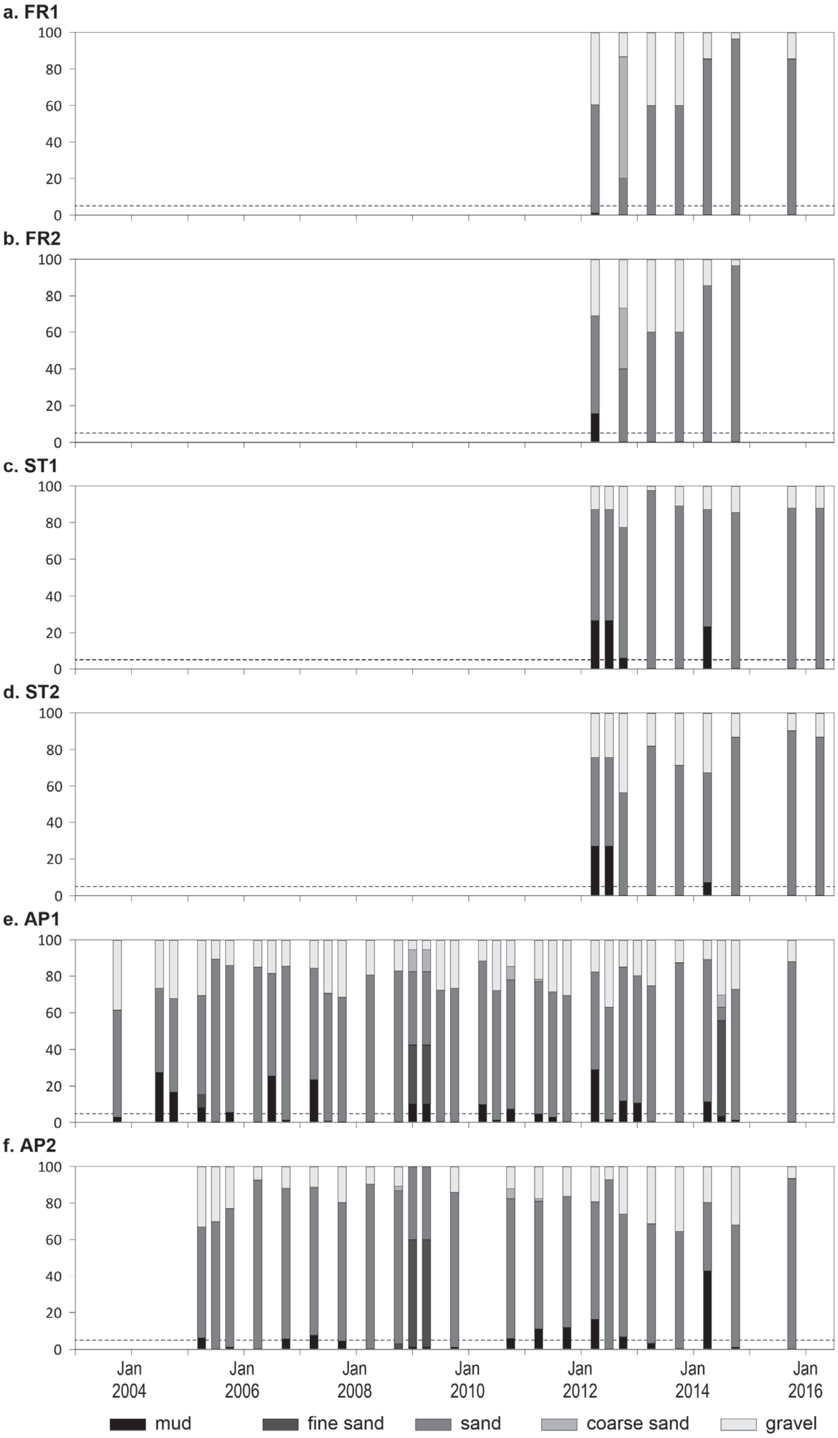

Figure 175. *Sediment grain size composition at reef habitat monitoring sites in the Cape York region, 2003-2016. Dashed line is the GBR long-term average proportion of mud.*

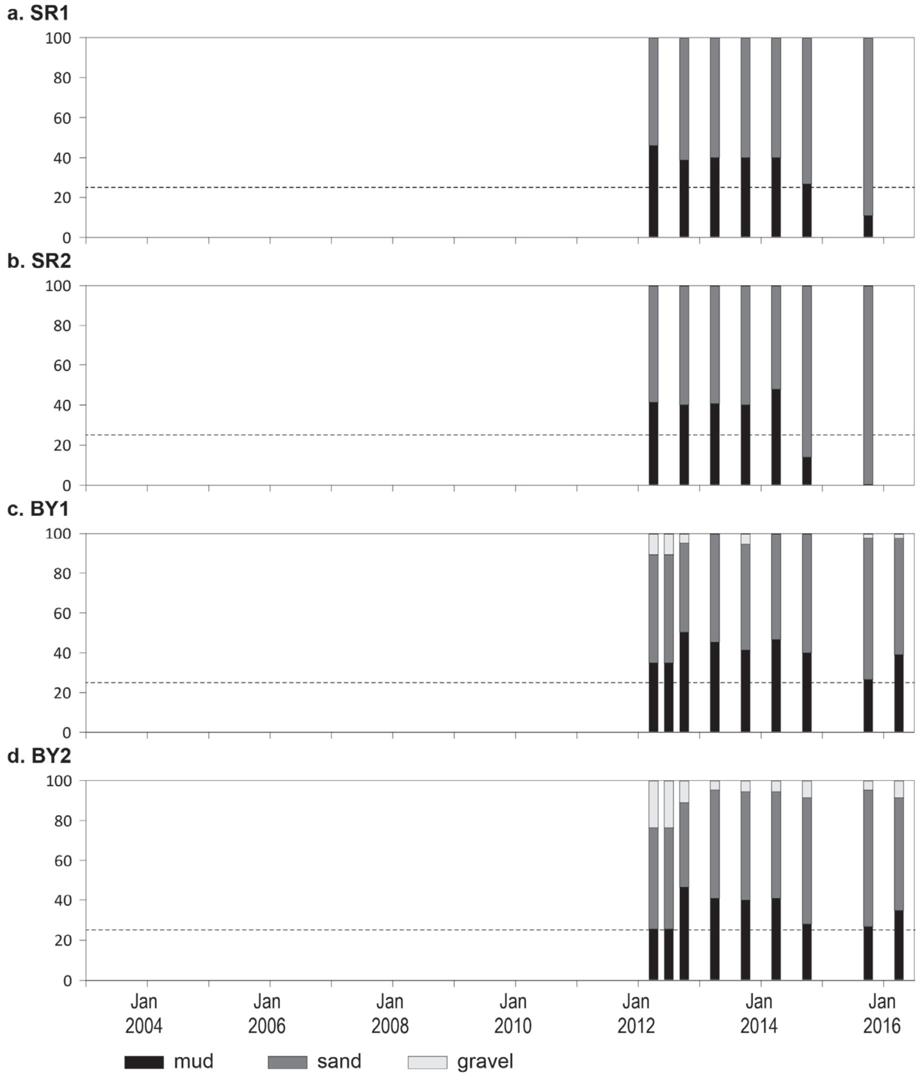

Figure 176. *Sediment grain size composition at coastal habitat monitoring sites in the Cape York region, 2013-2016. Dashed line is the GBR long-term average proportion of mud.*

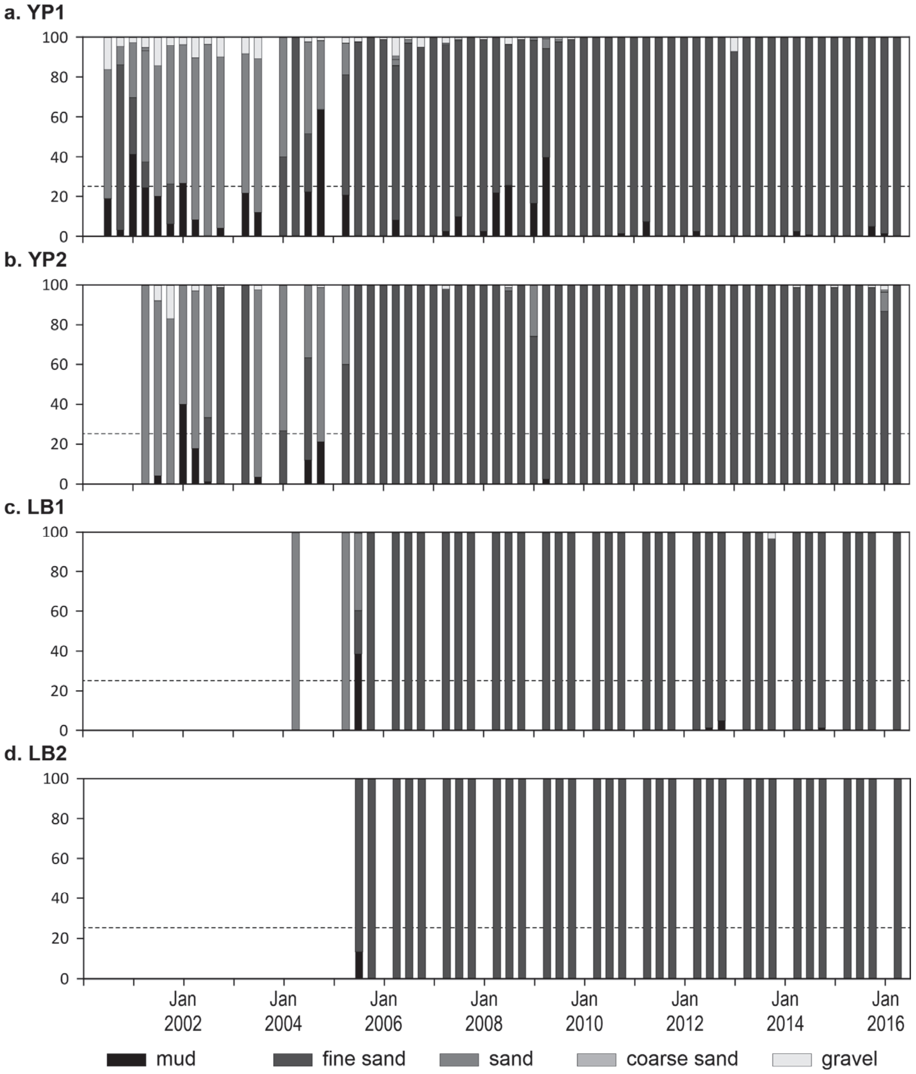

Figure 177. *Sediment grain size composition at intertidal coastal habitat monitoring sites in the Wet Tropics region, 2001-2016. Dashed line is the GBR long-term average proportion of mud.*

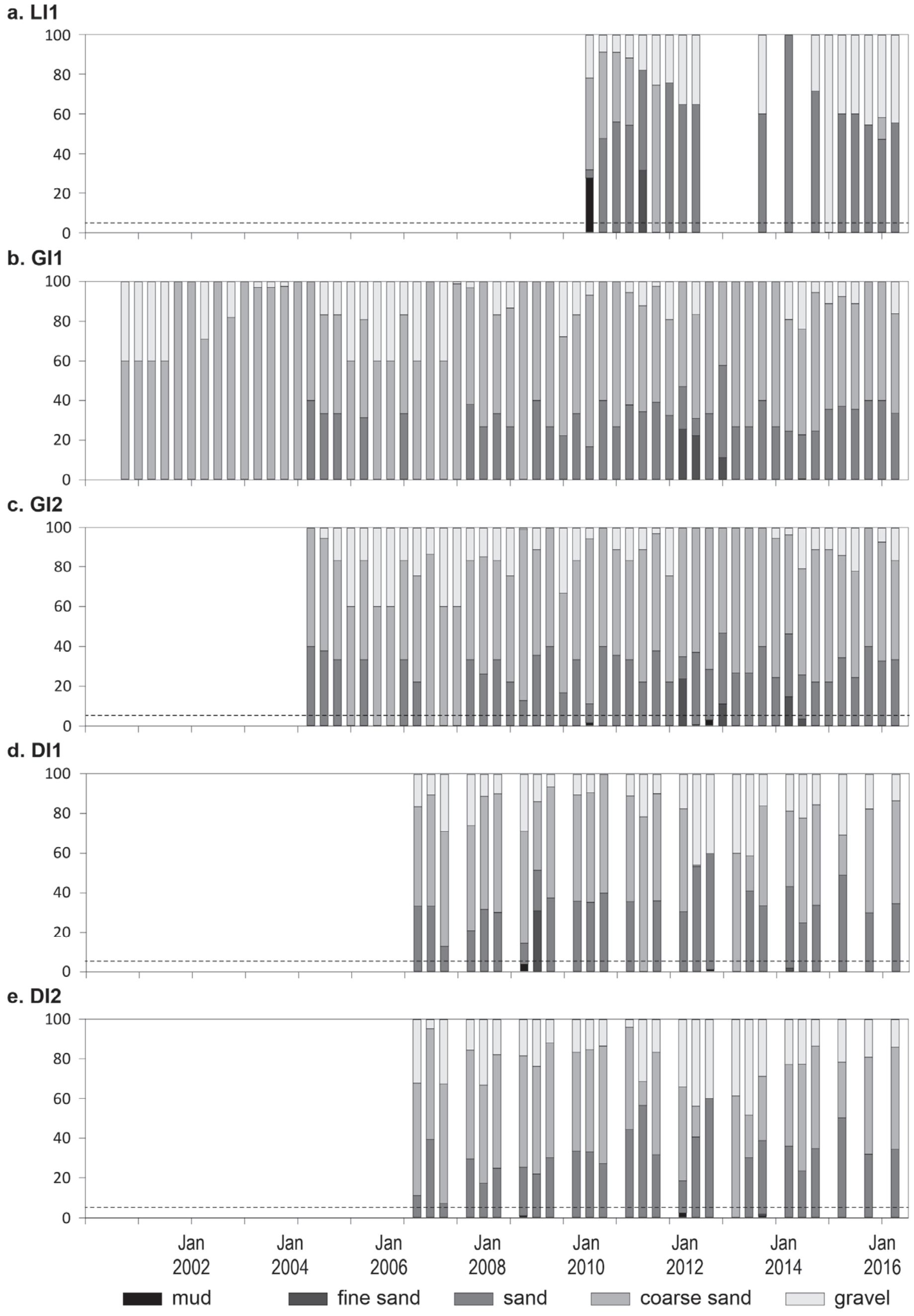

Figure 178. *Sediment grain size composition at intertidal reef habitat monitoring sites in the Wet Tropics region, 2001-2016. Dashed line is the GBR long-term average proportion of mud.*

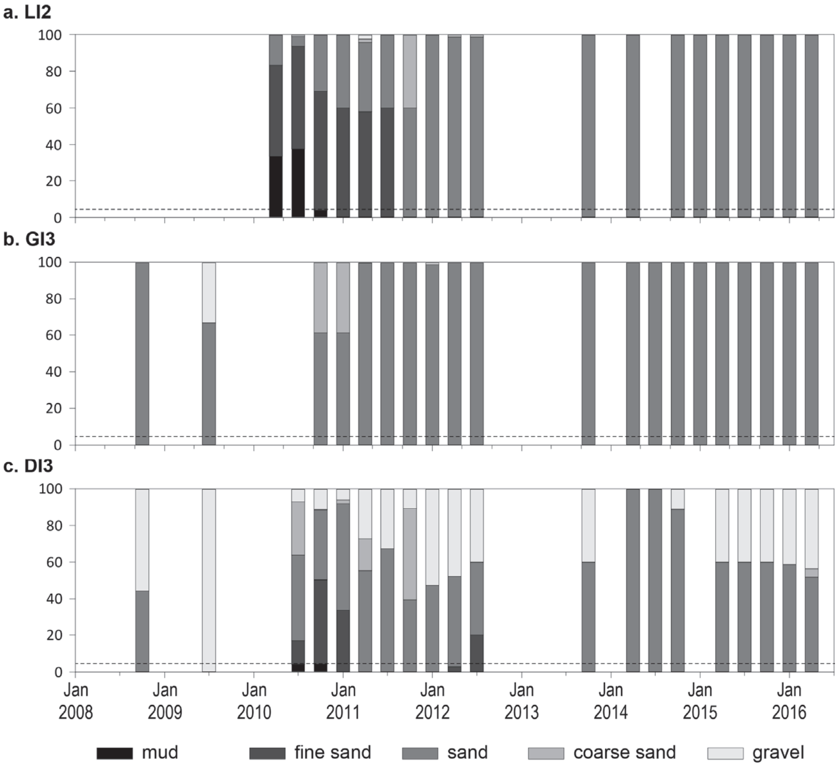

Figure 179. *Sediment grain size composition at subtidal reef habitat monitoring sites in the Wet Tropics region, 2008-2016. Dashed line is the GBR long-term average proportion of mud.*

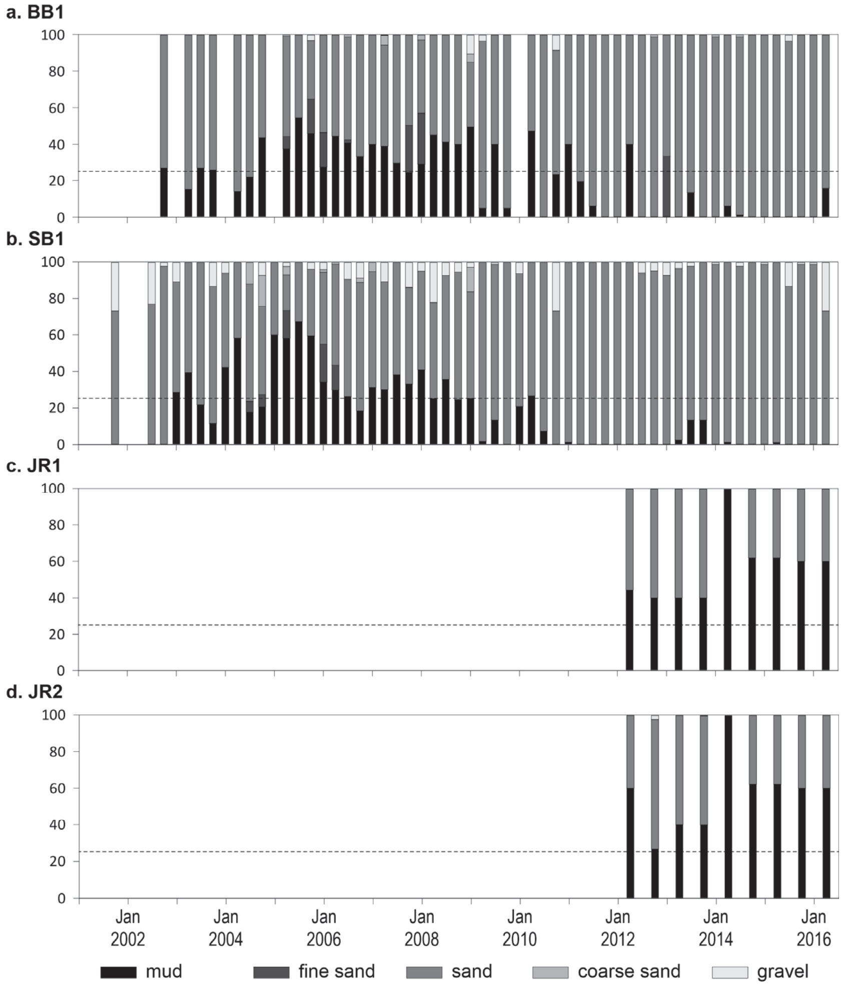

Figure 180. *Sediment grain size composition at intertidal coastal habitat monitoring sites in the Burdekin region, 2001-2016. Dashed line is the GBR long-term average proportion of mud.*

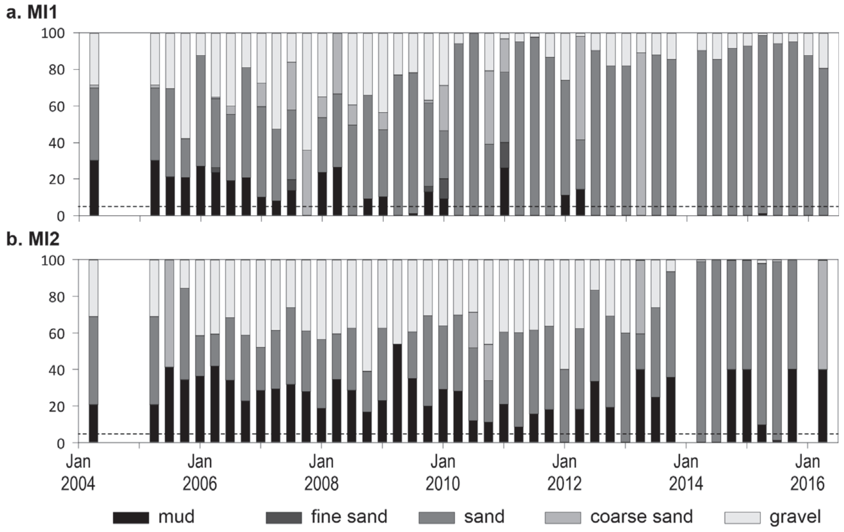

Figure 181. *Sediment grain size composition at intertidal reef habitat monitoring sites in the Burdekin region, 2004-2016. Dashed line is the GBR long-term average proportion of mud.*

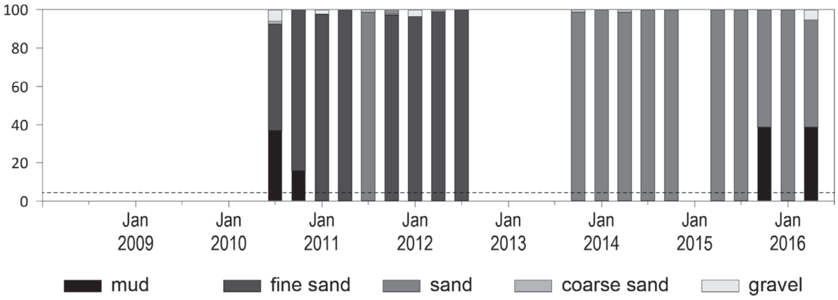

Figure 182. *Sediment grain size composition at subtidal reef habitat monitoring sites in the Burdekin region, 2010-2016. Dashed line is the GBR long-term average proportion of mud.*

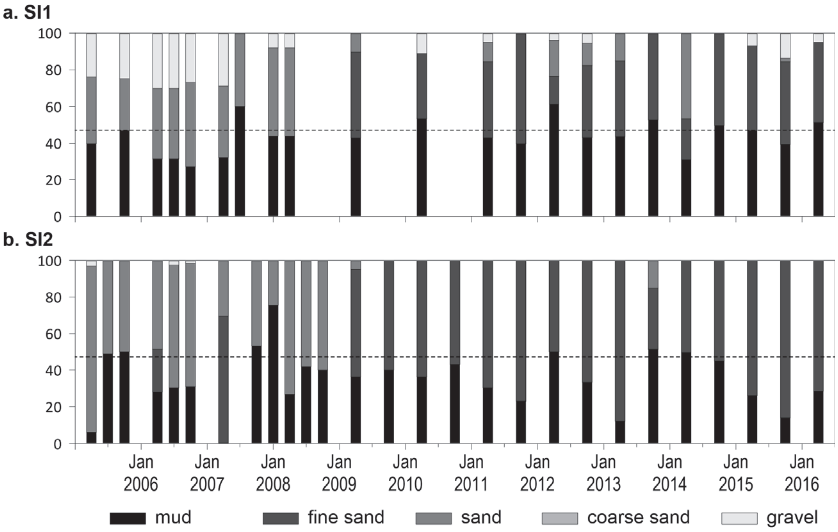

Figure 183. *Sediment grain size composition at intertidal estuary habitat monitoring sites in the Mackay Whitsunday region, 2005-2016. Dashed line is the GBR long-term average proportion of mud.*

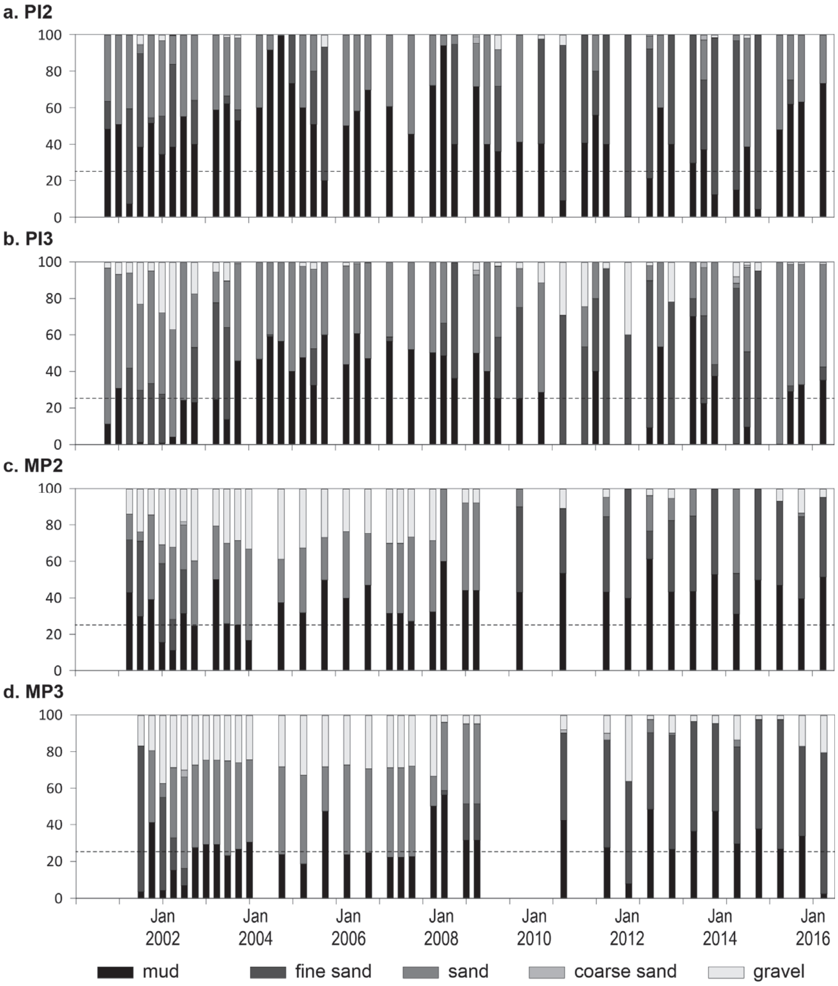

Figure 184. *Sediment grain size composition at intertidal coastal habitat monitoring sites in the Mackay Whitsunday region, 1999-2016. Dashed line is the GBR long-term average proportion of mud.*

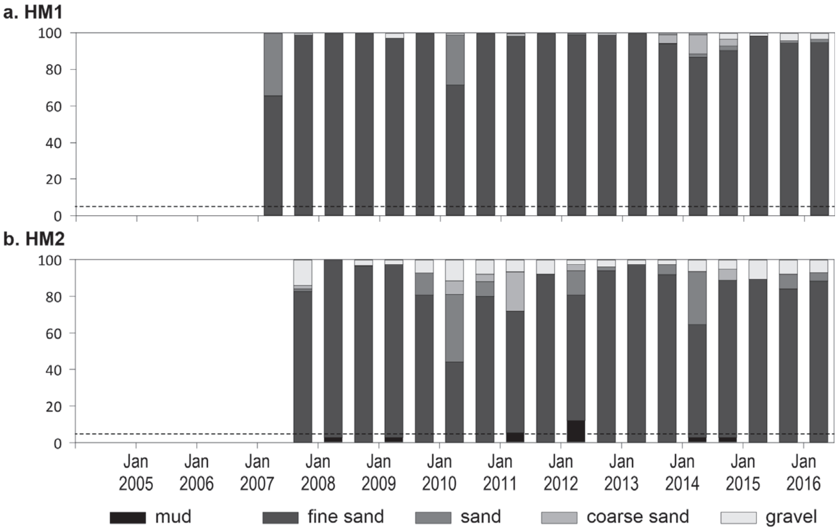

Figure 185. *Sediment grain size composition at intertidal reef habitat monitoring sites in the Mackay Whitsunday region, 2007-2016. Dashed line is the GBR long-term average proportion of mud.*

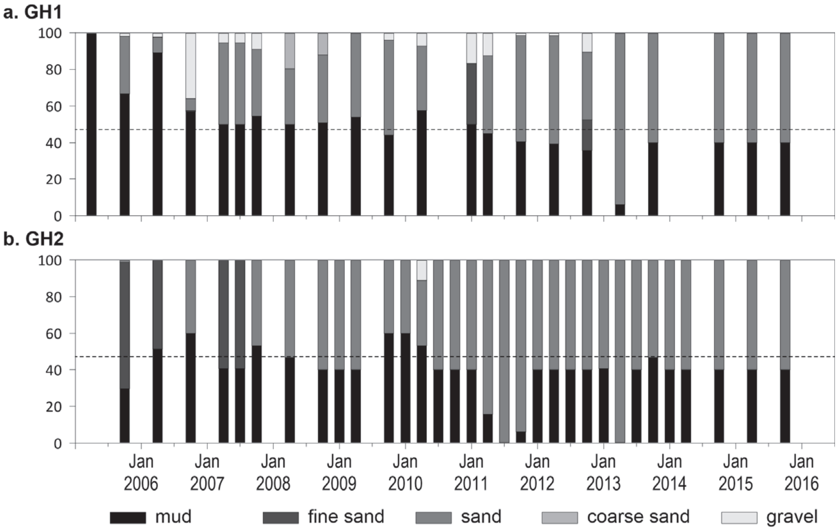

Figure 186. *Sediment grain size composition at intertidal estuary habitat monitoring sites in the Fitzroy region, 2005-2016. Dashed line is the GBR long-term average proportion of mud.*

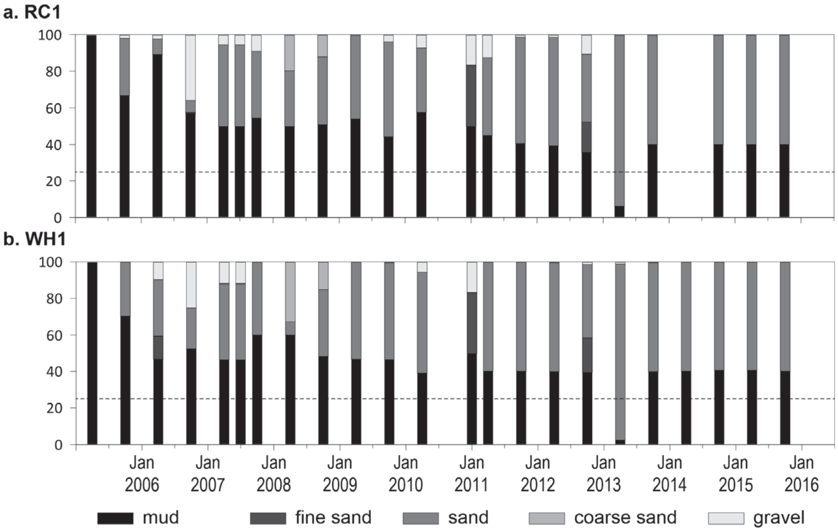

Figure 187. *Sediment grain size composition at intertidal coastal habitat monitoring sites in the Fitzroy region, 2005-2016. Dashed line is the GBR long-term average proportion of mud.*

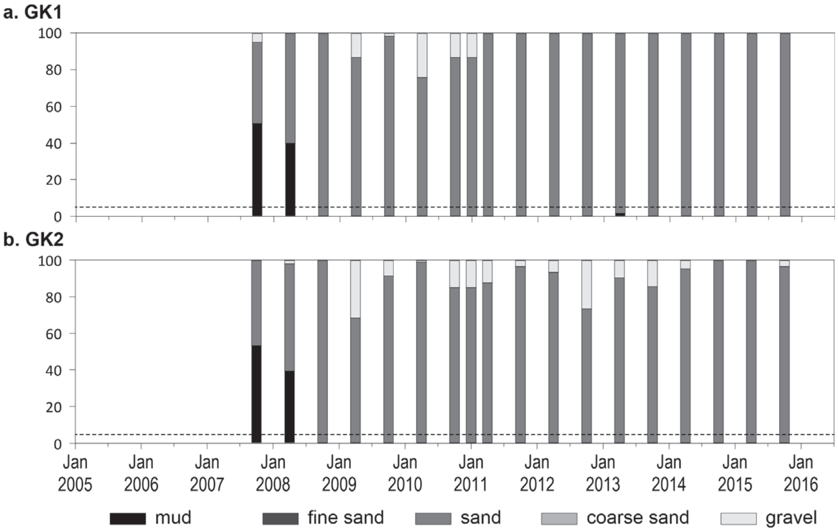

Figure 188. *Sediment grain size composition at intertidal reef habitat monitoring sites in the Fitzroy region, 2007-2015. Dashed line is the GBR long-term average proportion of mud.*

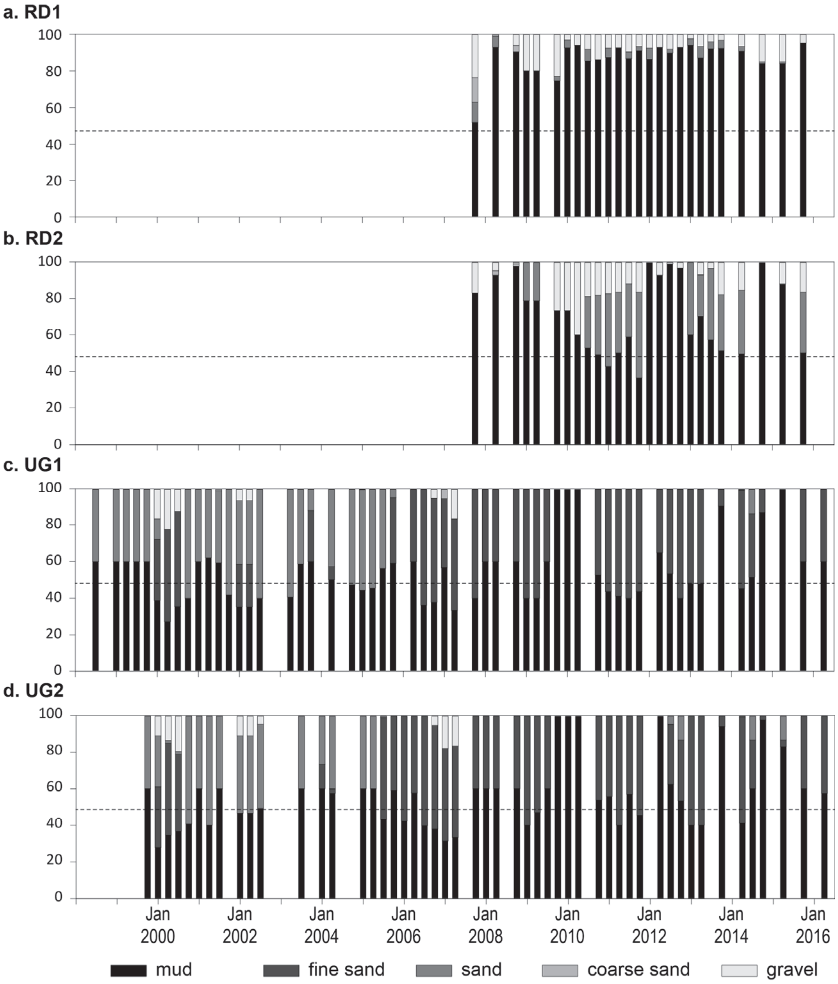

Figure 189. *Sediment grain size composition at intertidal estuary habitat monitoring sites in the Burnett Mary region, 1999-2016. Dashed line is the GBR long-term average proportion of mud.*

A4.2.3 Epiphytes and macroalgae

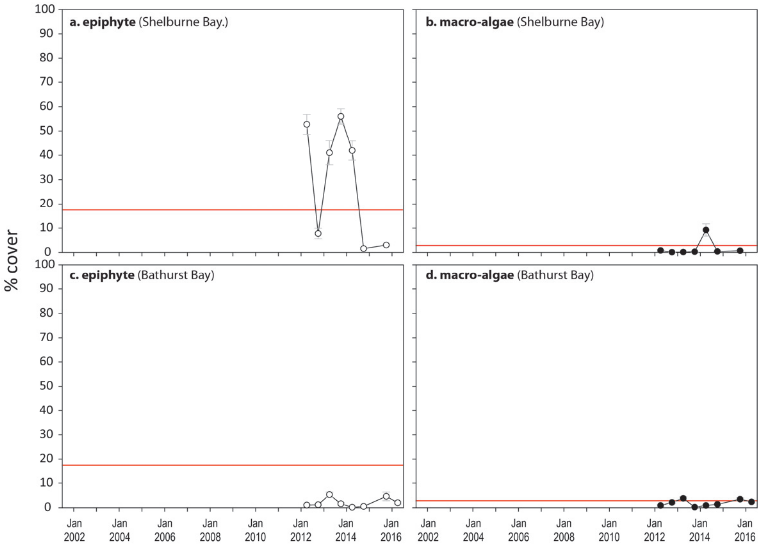

Figure 190. *Long-term trend in mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at intertidal coastal habitats (sites pooled), Cape York NRM region. Red line = GBR long-term average; epiphytes=17.7 per cent, macroalgae=3.0 per cent.*

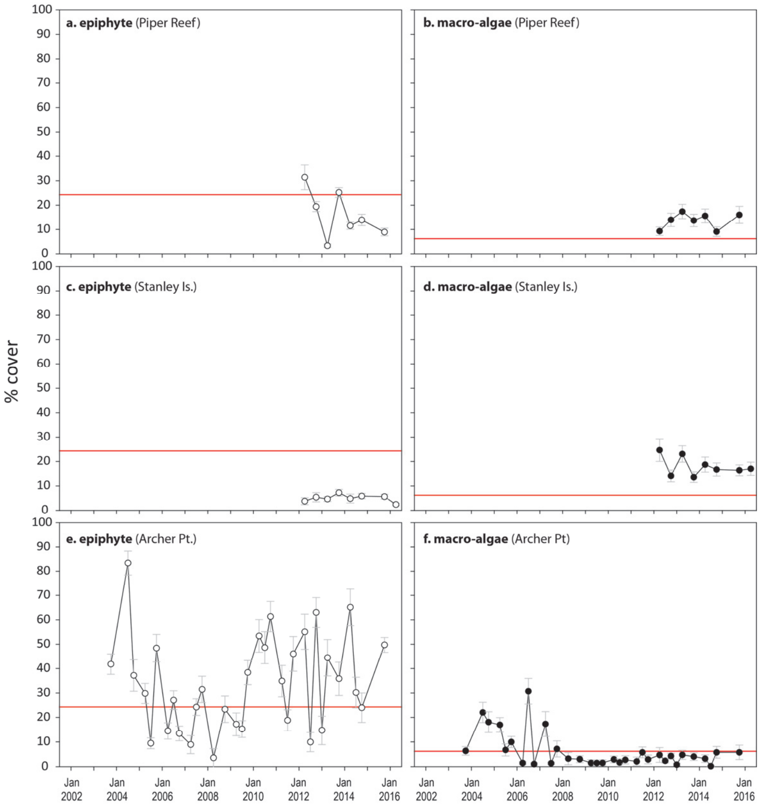

Figure 191. *Long-term trend in mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef habitats (sites pooled), Cape York NRM region. Red line = GBR long-term average; epiphytes=24.3 per cent, macroalgae=6.2 per cent.*

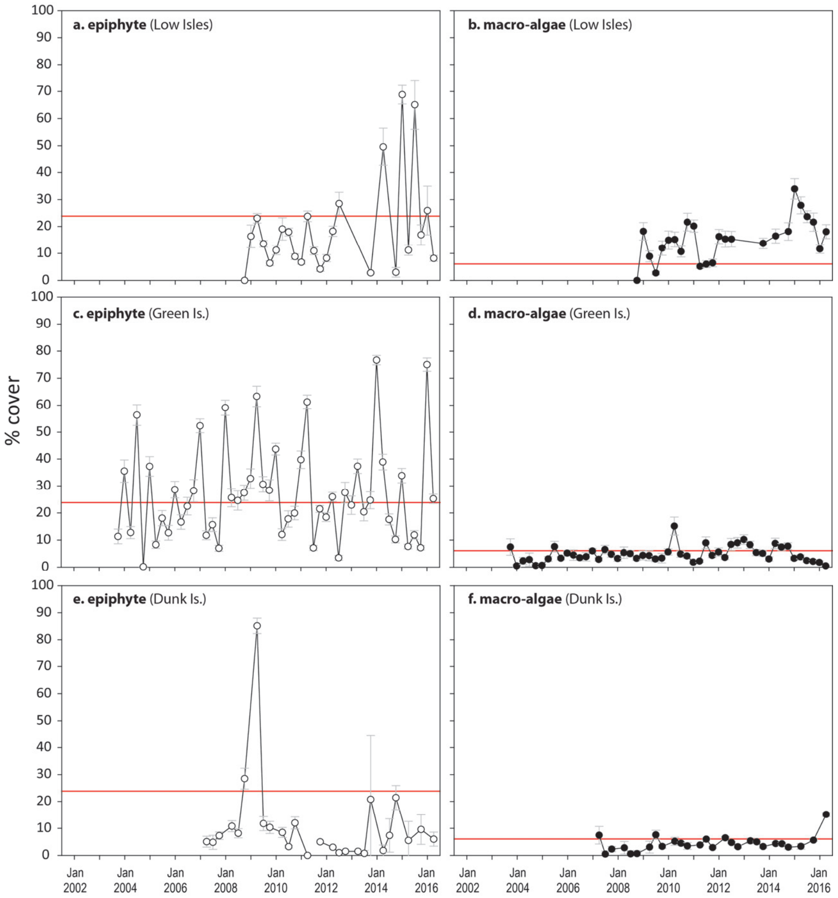

Figure 192. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef seagrass monitoring locations (sites pooled) in the Wet Tropics NRM region. Red line = GBR long-term average; epiphytes=24.3 per cent, macroalgae=6.2 per cent.*

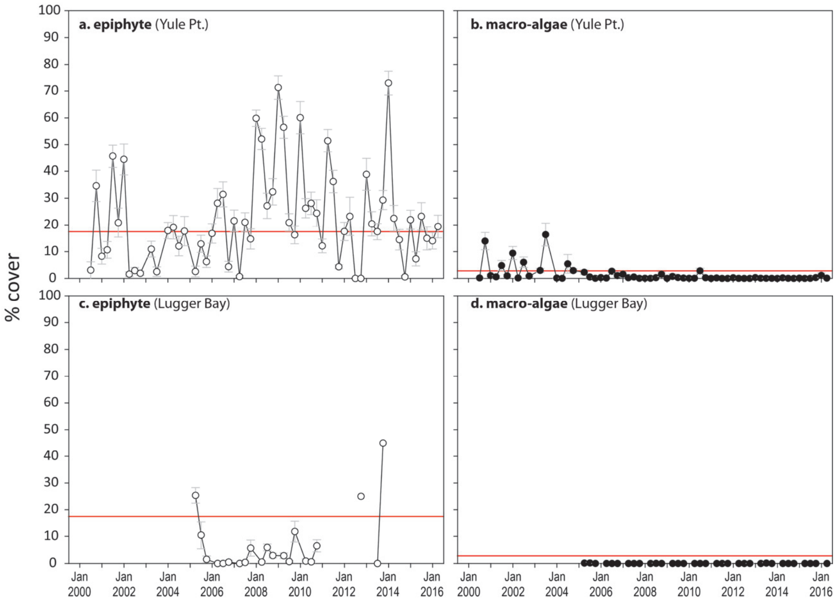

Figure 193. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Wet Tropics NRM region. Red line = GBR long-term average; epiphytes=17.7 per cent, macroalgae=3.0 per cent.*

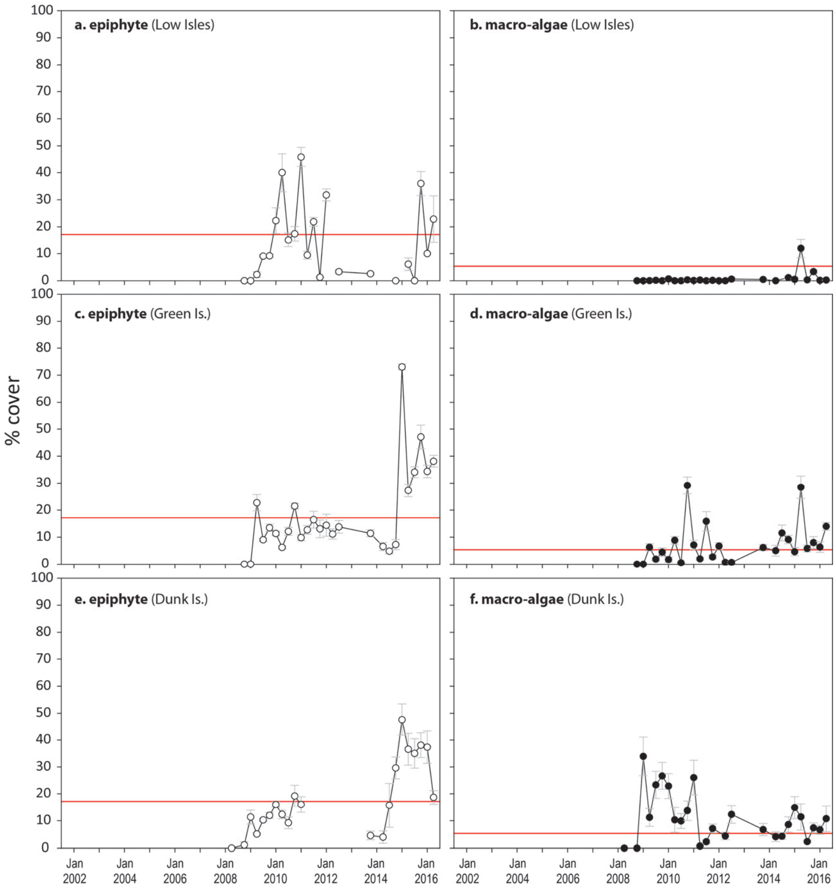

Figure 194. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at subtidal reef seagrass monitoring sites in the Wet Tropics NRM region. Red line = GBR long-term average for subtidal sites; epiphytes=17.1 per cent, macroalgae=5.5 per cent.*

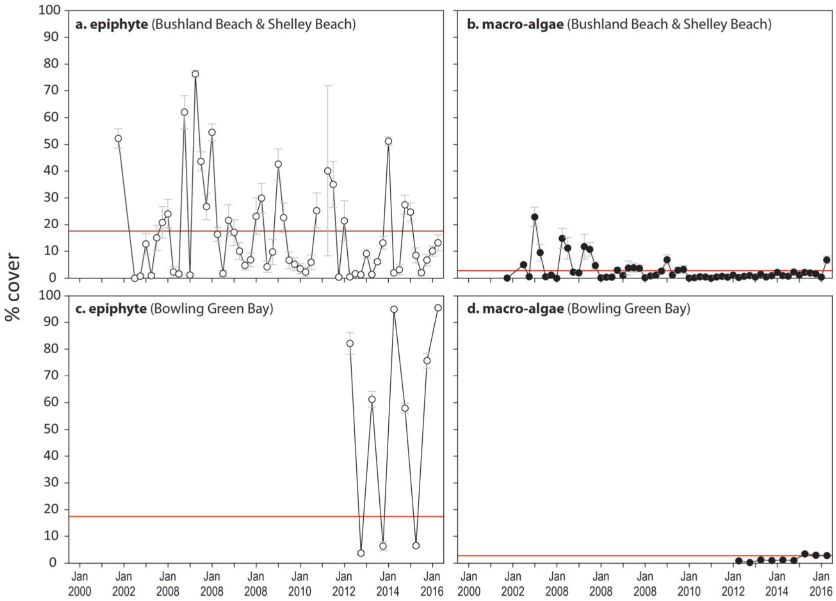

Figure 195. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Burdekin NRM region. Red line = GBR long-term average; epiphytes=17.7 per cent, macroalgae=3.0 per cent.*

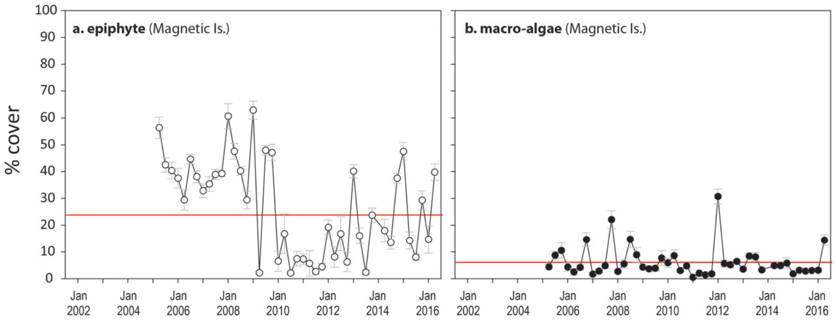

Figure 196. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at intertidal reef seagrass monitoring locations (sites pooled) in the Burdekin NRM region. Red line = GBR long-term average; epiphytes=24.3 per cent, macroalgae=6.2 per cent.*

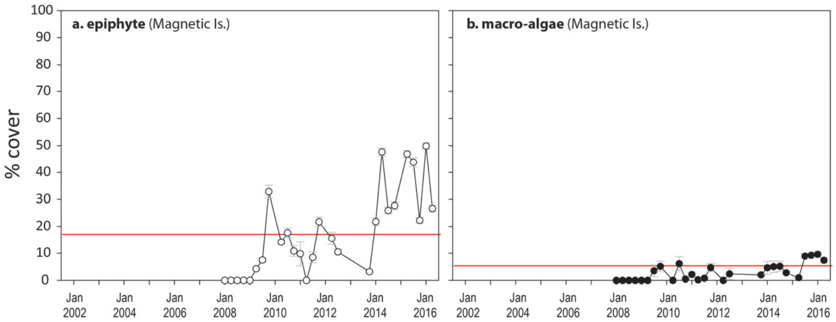

Figure 197. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at subtidal reef monitoring sites in Picnic Bay, Burdekin NRM region. Red line = GBR long-term average; epiphytes=17.1 per cent, macroalgae=5.5 per cent.*

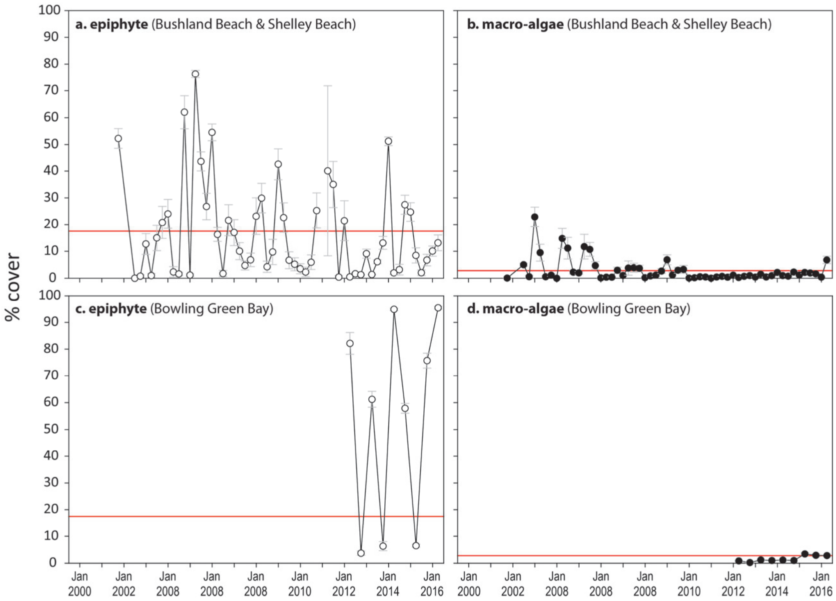

Figure 198. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=17.7 per cent, macroalgae=3.0 per cent.*

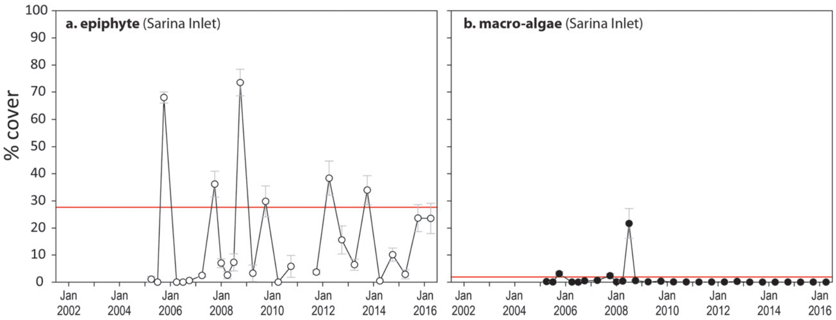

Figure 199. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=27.7 per cent, macroalgae=2.1 per cent.*

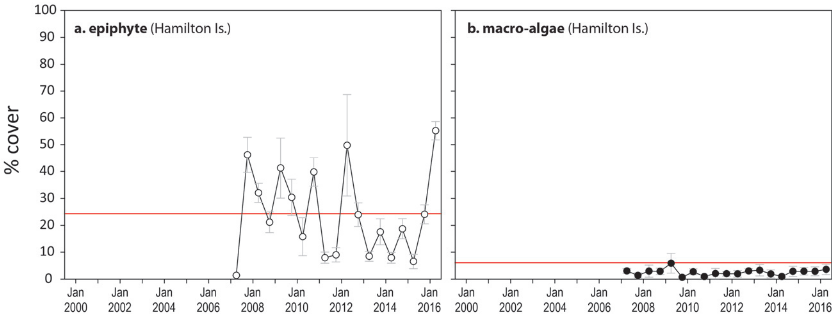

Figure 200. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at reef seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=24.3 per cent, macroalgae=6.2 per cent.*

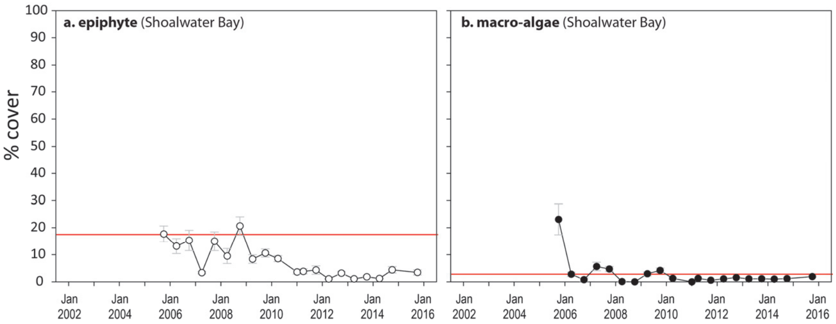

Figure 201. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=17.7 per cent, macroalgae=3.0 per cent.*

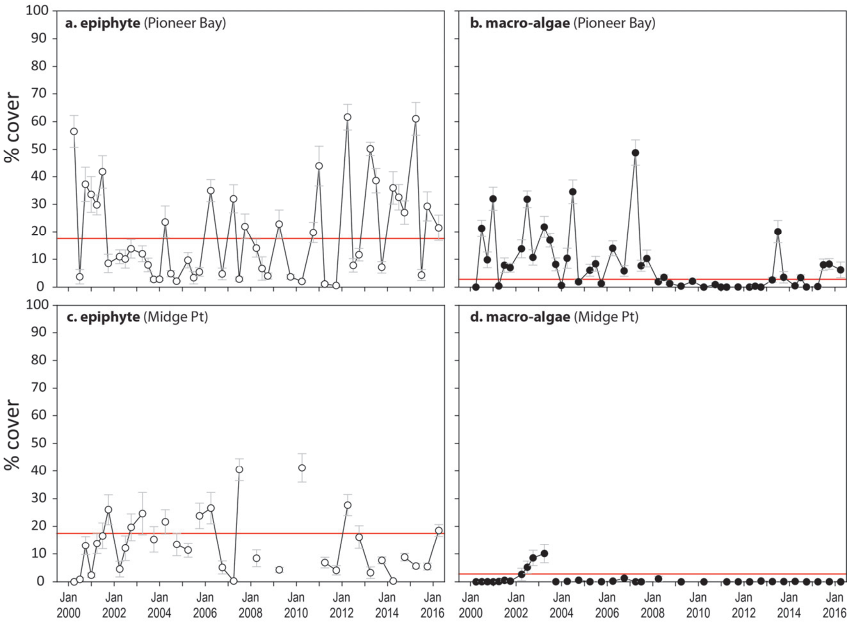

Figure 202. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at coastal intertidal seagrass monitoring locations (sites pooled) in the Mackay Whitsunday NRM region. Red line = GBR long-term average; epiphytes=17.7 per cent, macroalgae=3.0 per cent.*

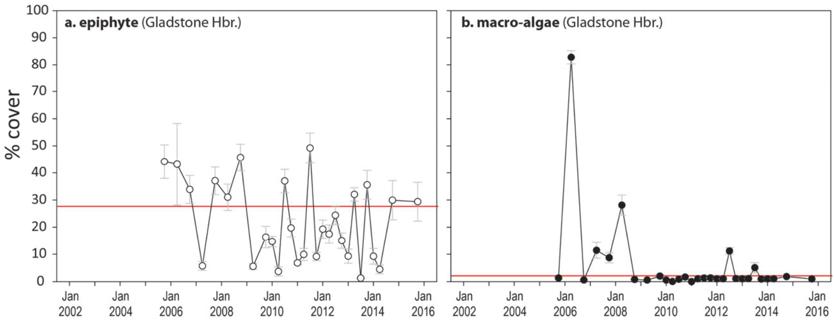

Figure 203. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=27.7 per cent, macroalgae=2.1 per cent.*

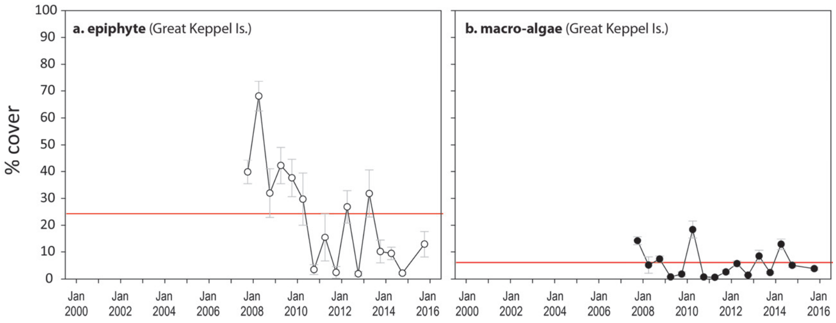

Figure 204. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at reef seagrass monitoring locations (sites pooled) in the Fitzroy NRM region. Red line = GBR long-term average; epiphytes=24.3 per cent, macroalgae=6.2 per cent.*

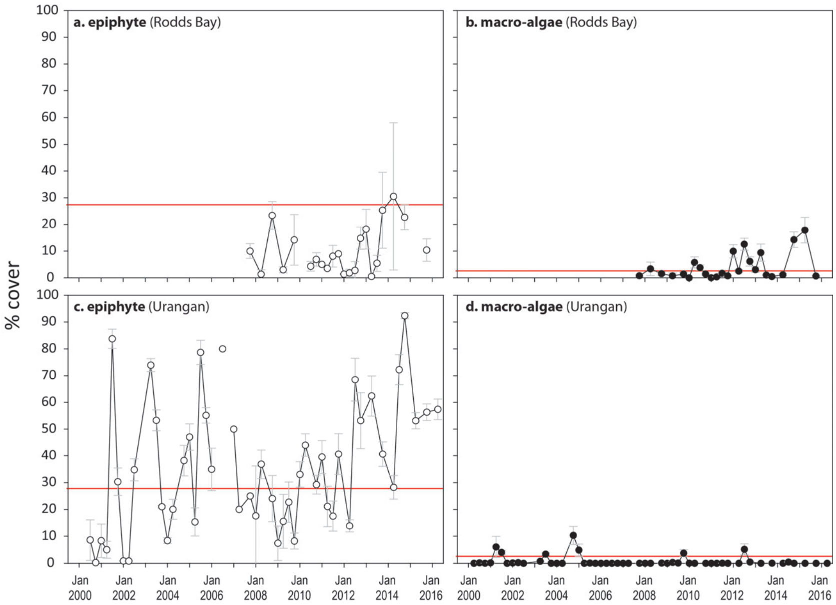

Figure 205. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at estuarine seagrass monitoring locations (sites pooled) in the Burnett Mary NRM region. Red line = GBR long-term average; epiphytes=27.7 per cent, macroalgae=2.1 per cent.*

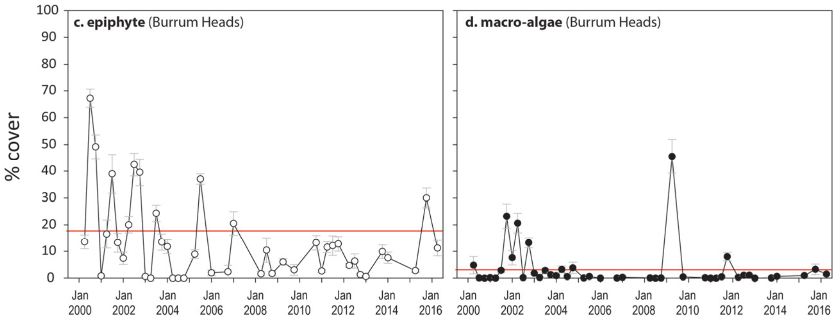

Figure 206. *Mean abundance (per cent cover) (± Standard Error) of epiphytes and macroalgae at coastal seagrass monitoring locations (sites pooled) in the Burnett Mary NRM region. Red line = GBR long-term average; epiphytes=17.7 per cent, macroalgae=3.0 per cent.*

A4.2.4 Seagrass extent

Table 59. *Proportion of area (within 100m radius of each monitoring site) which is covered by seagrass in the Cape York and Wet Tropics NRM regions. For sites codes, see Table 5. Shading indicates area of seagrass declined >5 per cent (or absent) from previous assessment.*

Date	SR1	SR2	FR1	FR2	ST1	ST2	BY1	BY2	AP1	AP2	LI1	LI2	YP1	YP2	GI1	GI2	GI3	LB1	LB2	DI1	DI2	DI3
Oct-05									0.68	0.68			0.25	0.67	0.98	0.86		0.31	0.34			
Apr-06									0.61	0.58			0.33	0.76	0.99	0.86		0.2	0.27			
Oct-06									0.71	0.66			0.33	0.69	0.98	0.878		0.08	0.1			
Apr-07									0.78	0.75			0.45	0.69	0.98	0.86		0.18	0.22	0.59	0.72	
Oct-07									0.77	0.75			0.57	0.82	0.98	0.87		0.22	0.3	0.63	0.76	
Apr-08									0.72	0.64			0.53	0.88	0.99	0.87		0.2	0.27	0.61	0.8	
Oct-08									0.72	0.66			0.54	0.82	0.98	0.87		0.3	0.36	0.61	0.78	
Apr-09									0.62	0.6			0.46	0.87	0.99	0.87		0.23	0.31	0.60	0.8	
Oct-09									0.68	0.66			0.42	0.86	0.98	0.87		0.23	0.29	0.62	0.79	
Apr-10													0.3	0.83	0.99	0.87		0.09	0.09	0.61	0.75	
Oct-10									0.73	0.71			0.31	0.79	0.98	0.86		0.03	0.03	0.62	0.77	
Apr-11									0.72	0.65			0.33	0.81	0.98	0.86		0	0	0	0.002	
Oct-11									0.71	0.67		0.48	0.08	0.38	0.99	0.87	0.26	0	0	0.01	0.05	0
Apr-12	1	0.94	0.72	0.91	0.69	0.94	0.75	0.9	0.69	0.65	0.47	0	0.23	0.67	0.99	0.88	0.7	0	0	0.003	0.03	0
Oct-12	1	0.93	0.7	0.91	0.63	0.96	0.77	0.9	0.58	0.58	0.52	0.01	0.11	0.31	0.98	0.87	0.94	0	0.01	0.01	0.05	0
Apr-13	1	0.94	0.7	0.89	0.71	0.95	0.85	1	0.63	0.64	0.58	0.001	0.46	0.72	0.99	0.87	0.38	0	0.01	0.04	0.12	0
Oct-13	1	0.92	0.7	0.91	0.72	0.96	0.83	0.96	0.64	0.63	0.60	0.002	0.41	0.65	0.98	0.86	0.77	0.01	0.015	0.24	0.21	0
Apr-14	1	0.92	0.75	0.93	0.72	0.96	0.88	0.96	0.67	0.64	0.60	0.002	0.46	0.61	0.97	0.85	0	0	0.001	0.28	0.24	0
Oct-14	1	0.91	0.75	0.90	0.70	0.95	0.88	0.94	0.68	0.66	1.00	0.68	0.36	0.78	0.98	0.86		0.001	0.001	0.32	0.31	1
Apr-15											0.56	0.29	0.49	0.77	0.97	0.85		0.001	0.001	0.31	0.37	
Oct-15	1	0.74	0.75	0.90	0.76	0.97	0.82	0.92	0.78	0.81	0.81	1	0.51	0.77	0.98	0.88	0.80	0	0	0.36	0.44	1
Apr-16					0.68	0.94	0.73	0.88			0.84	0	0.48	0.84	0.99	0.88	0.65	0	0	0.37	0.45	0.61

Table 60. *Proportion of area (within 100m radius of each monitoring site) which is covered by seagrass in the Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary NRM regions. For sites codes, see Table 5. Shading indicates area of seagrass declined >5 per cent (or absent) from previous assessment*

Date	BB1	SB1	MI1	MI2	MI3	JR1	JR2	PI2	PI3	HM1	HM2	MP2	MP3	SI1	SI2	RC1	WH1	GH1	GH2	GK1	GK2	RD1	RD2	UG1	UG2
Oct-05	1	0.81	0.55	0.77				0.65	0.46					0.64	0.71	1	1	1	0.96					0.99	1
Apr-06	1	0.66	0.64	0.82				0.67	0.38					0.33	0.47	1	1	0	0					0	0
Oct-06	1	0.54	0.32	0.77				0.72	0.74					0.84	0.7	1	1	1	1					0	0
Apr-07	0.96	0.74	0.49	0.78				0.79	0.84					0.78	0.67	1	1	1	0.96					0	0
Oct-07	0.98	0.85	0.59	0.78				0.8	0.8	0.3	0.12			0.9	0.9	1	1	0.77	0.88	0.81	0.78	0.18	0.66	0.001	0
Apr-08	0.96	0.39	0.51	0.79				0.77	0.79	0.34	0.04			0.32	0.35	1	1	0.83	0.94	0.17	0.46	0.24	0.65	0.07	0.29
Oct-08	0.99	0.31	0.52	0.81				0.78	0.81	0.28	0.07			0.68	0.71	1	1	0.94	0.9	0.3	0.62	0.22	0.67	0.06	0.52
Apr-09	0.43	0.22	0.5	0.98				0.85	0.84	0.25	0.04			0.33	0.27	1	1	0.93	0.98	0.58	0.43	0	0.66	0.01	0.09
Oct-09	0.87	0.51	0.73	0.66				0.99	0.91	0.18	0.02			0.47	0.46	1	1	0.88	0.93	0.78	0.72	0.01	0.51	0.06	0.19
Apr-10	0.47	0.39	0.48	0.39				0.87	0.67	0.13	0.01			0.13	0.17	1	1	0.96	0.98	0.76	0.74	0	0	0.34	0.7
Oct-10	0.21	0.67	0.43	0.75				0.96	0.96	0.26	0.04			0.27	0.23	1	1	0.96	0.95	0.3	0.73	0.1	0	0.27	0.7
Apr-11	0.48	0.05	0.21	0.22				0.29	0.19	0.15	0.01			0.12	0.05	1	1	0.92	0.91	0.12	0.54	0.04	0.02	0.06	0.38
Oct-11	0.4	0.16	0.42	0.75	0.63			0.22	0.16	0.32	0.03			0.73	0.69	1	1	0.88	0.9	0.09	0.25	0.05	0.01	0.07	0.43
Apr-12	0.21	0.16	0.46	0.77	0.34	1	0.83	0.46	0.49	0.54	0.03			0.5	0.5	1	1	0.89	0.91	0.09	0.25	0	0	0.09	0.54
Oct-12	1	0.94	0.48	0.97	0.39	1	0.83	0.33	0.4	0.64	0.05			0.8	0.7	1	1	0.88	0.87	0.38	0.18	0.22	0.03	0.2	0.67
Apr-13	0.98	0.87	0.49	0.99	0.6	1	0.83	0.7	0.72	0.62	0.04			0.65	0.7	1	1	0.88	0.94	0.2	0.22	0.17	0	0.21	0.61
Oct-13	1	0.72	0.48	0.9	0.59	1	1	0.83	0.95	0.67	0.06			0.76	0.76	1	1	0.89	0.86	0.4	0.15	0	0	0.2	0.53
Apr-14	1	0.96	0.53	0.99	0.34	1	1	0.97	0.97	0.53	0.04			0.67	0.69	1	1	0.85	0.83	0.28	0.04	0.02	0.02	0.27	0.64
Oct-14	1	0.96	0.55	0.80	1	1	1	0.98	1	0.21	0.08	0.99	1	0.71	0.80	1	1	0.92	0.88	0.50	0.69	0.28	0.45	0.71	0.81
Apr-15	1	0.96	0.55	0.80	1					0.21	0.03	0.99	0.99	0.58	0.72							0	0	0.93	0.81
Oct-15	1	0.97	0.57	0.78	1	1	1			0.24	0.04	1	0.99	0.71	0.71	1	1	0.92	0.93	0.51	0.69	0.28	0.07	0.98	1
Apr-16	1	0.94	0.57	0.78	1					0.61	0.09	1	0.99	0.53	0.63									0.98	1

A4.2.5 Species composition and distribution

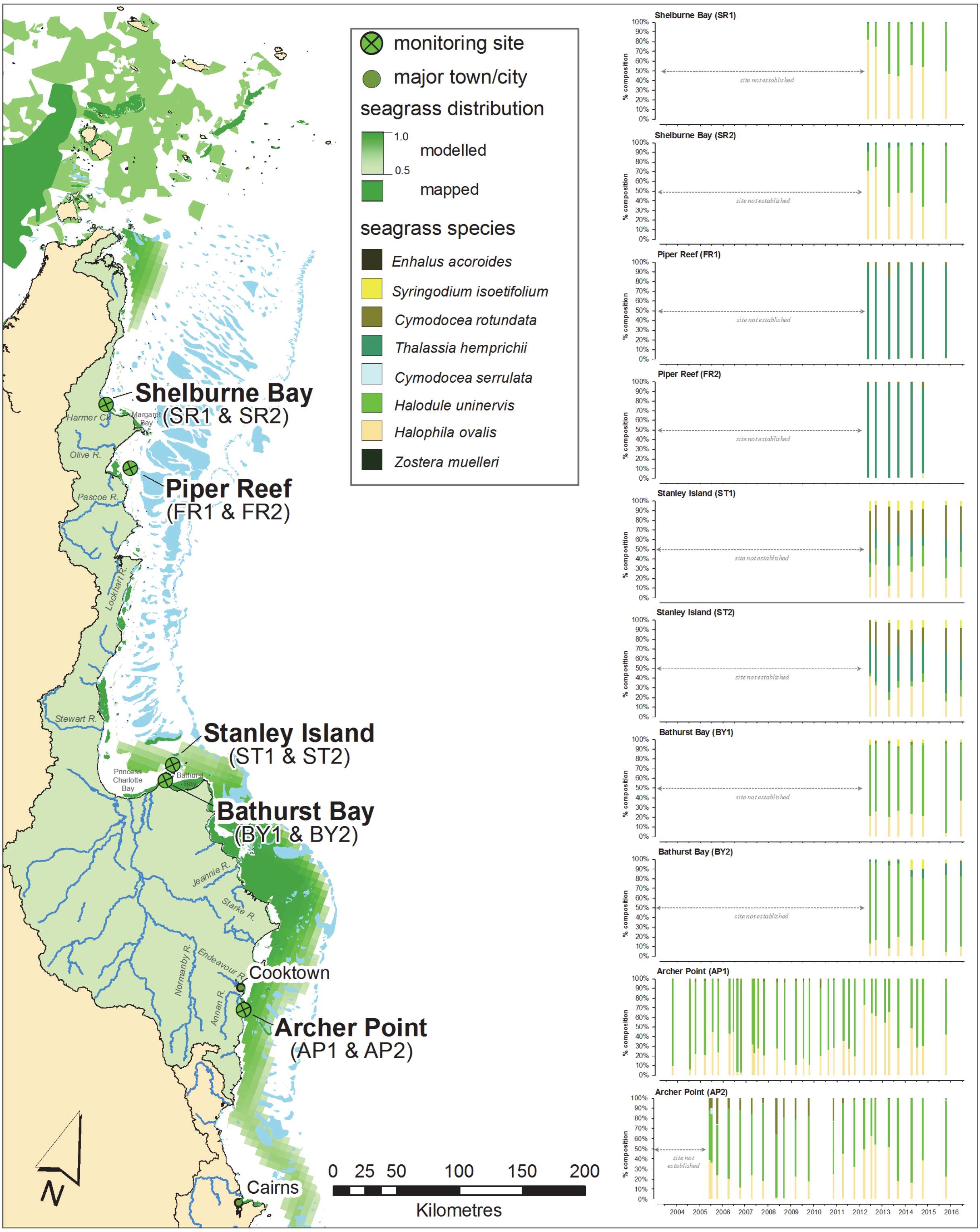

Figure 207. *Location and species composition of each long-term seagrass monitoring site (MMP) in the Cape York region. Please note: replicate sites within 500m of each other. Also shown is distribution of seagrass as the modelled distribution (including likelihood of presence from 0.5-1.0 McKenzie, et al. 2010c) and composite of mapped distribution (McKenzie, et al. 2014c).*

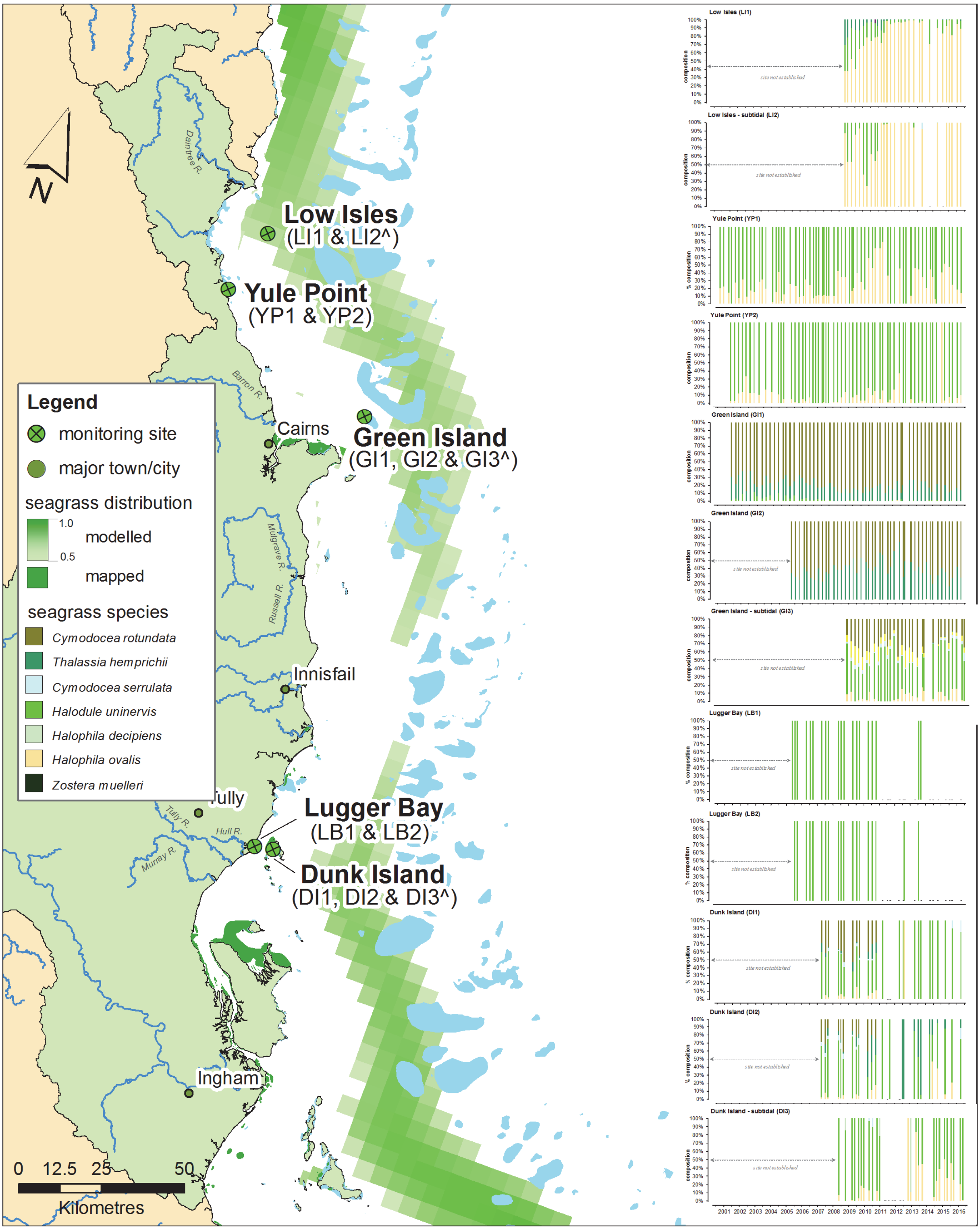

Figure 208. *Location and species composition of each long-term seagrass monitoring site (MMP) in the Wet Tropics region.Please note: replicate sites within 500m of each other. Also shown is distribution of seagrass as the modelled distribution (including likelihood of presence from 0.5-1.0 McKenzie, et al. 2010c) and composite of mapped distribution (McKenzie, et al. 2014c).*

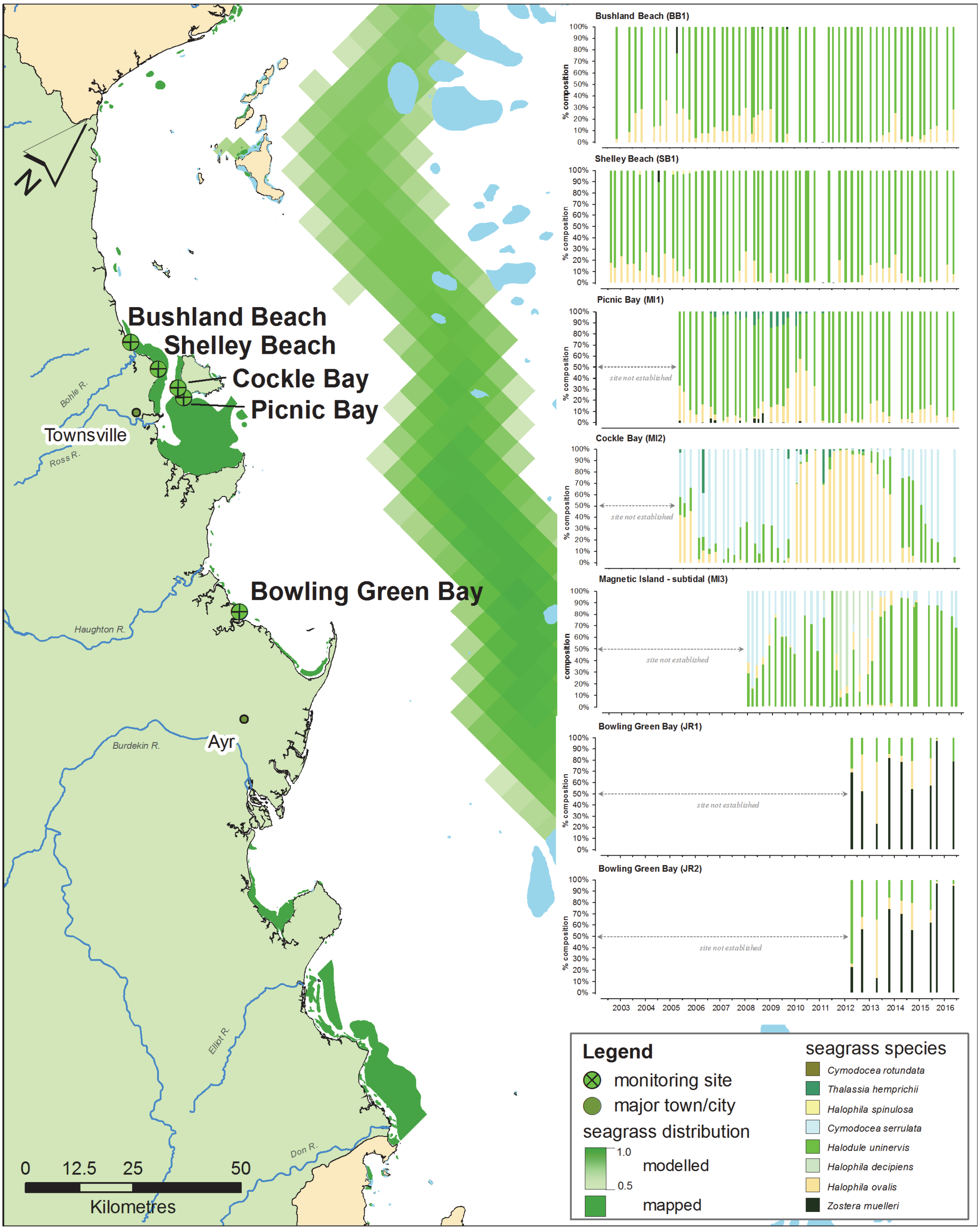

Figure 209. *Location and species composition of each long-term seagrass monitoring site (MMP) in the Burdekin region. Please note: replicate sites within 500m of each other. Also shown is distribution of seagrass as the modelled distribution (including likelihood of presence from 0.5-1.0 McKenzie, et al. 2010c) and composite of mapped distribution (McKenzie, et al. 2014c).*

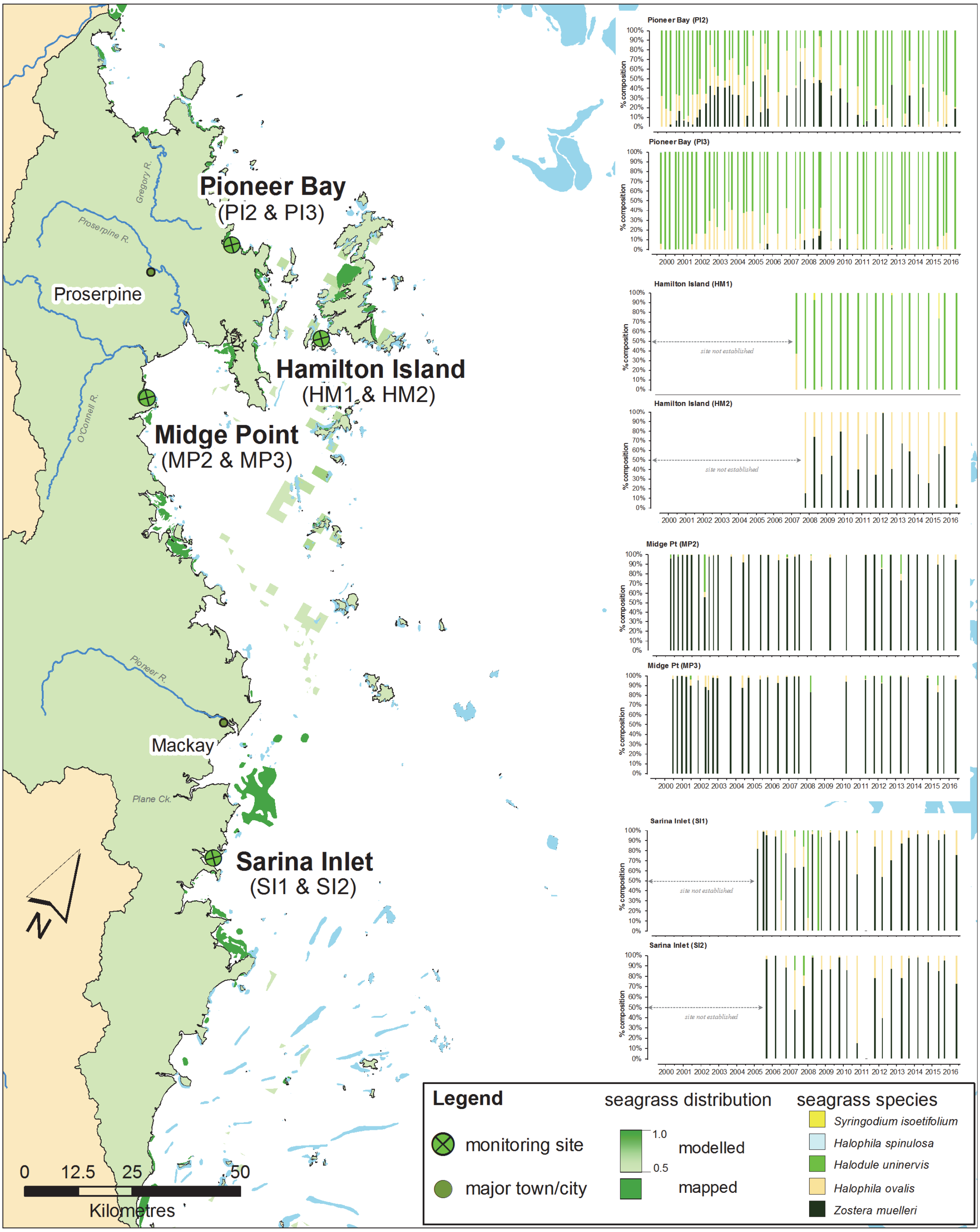

Figure 210. *Location and species composition of each long-term seagrass monitoring site (MMP) in the Mackay Whitsunday region. Please note: replicate sites within 500m of each other. Also shown is distribution of seagrass as the modelled distribution (including likelihood of presence from 0.5-1.0 McKenzie, et al. 2010c) and composite of mapped distribution (McKenzie, et al. 2014c).*

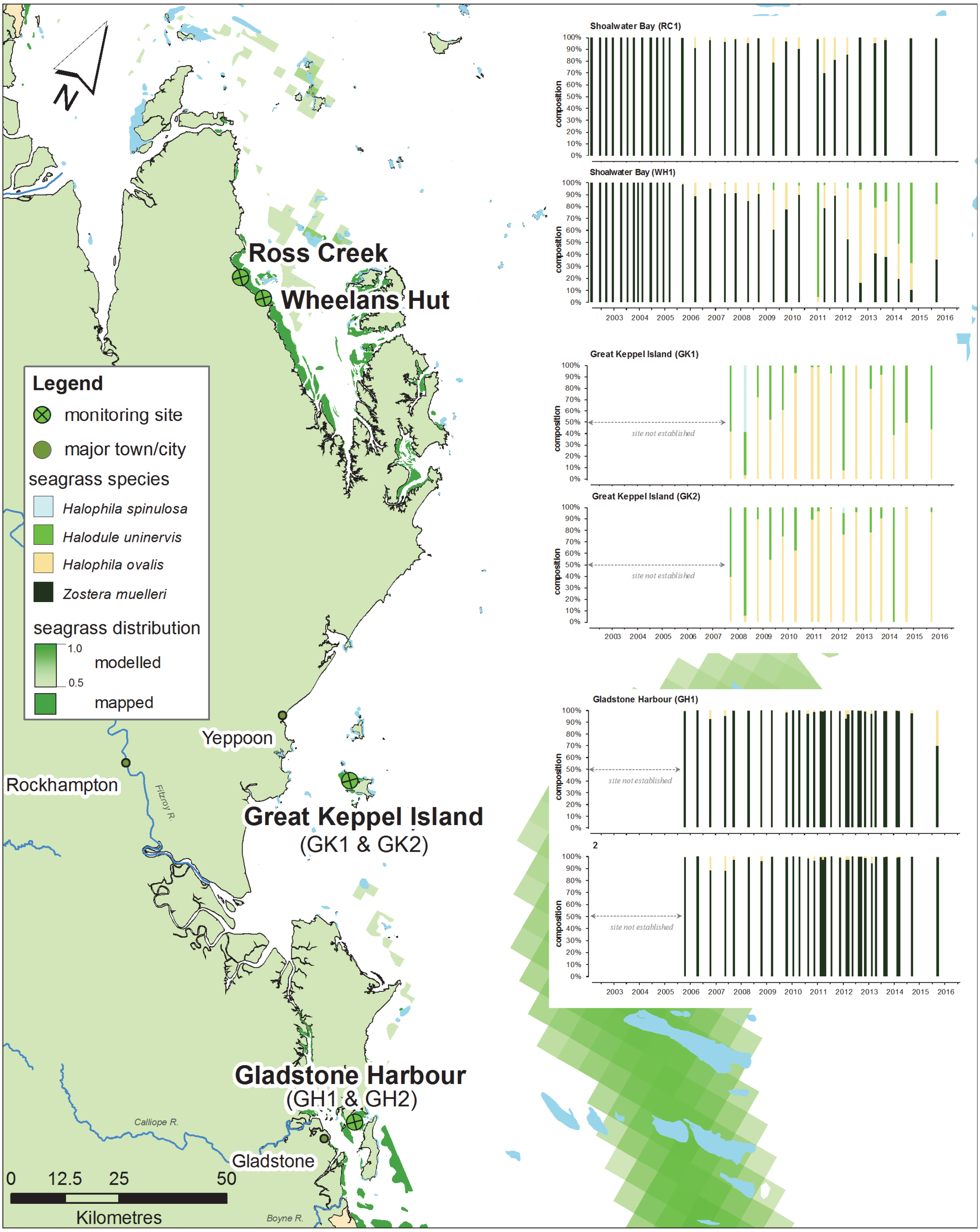

Figure 211. *Location and species composition of each long-term seagrass monitoring site (MMP) in the Fitzroy region. Please note: replicate sites within 500m of each other. Also shown is distribution of seagrass as the modelled distribution (including likelihood of presence from 0.5-1.0 McKenzie, et al. 2010c) and composite of mapped distribution (McKenzie, et al. 2014c).*

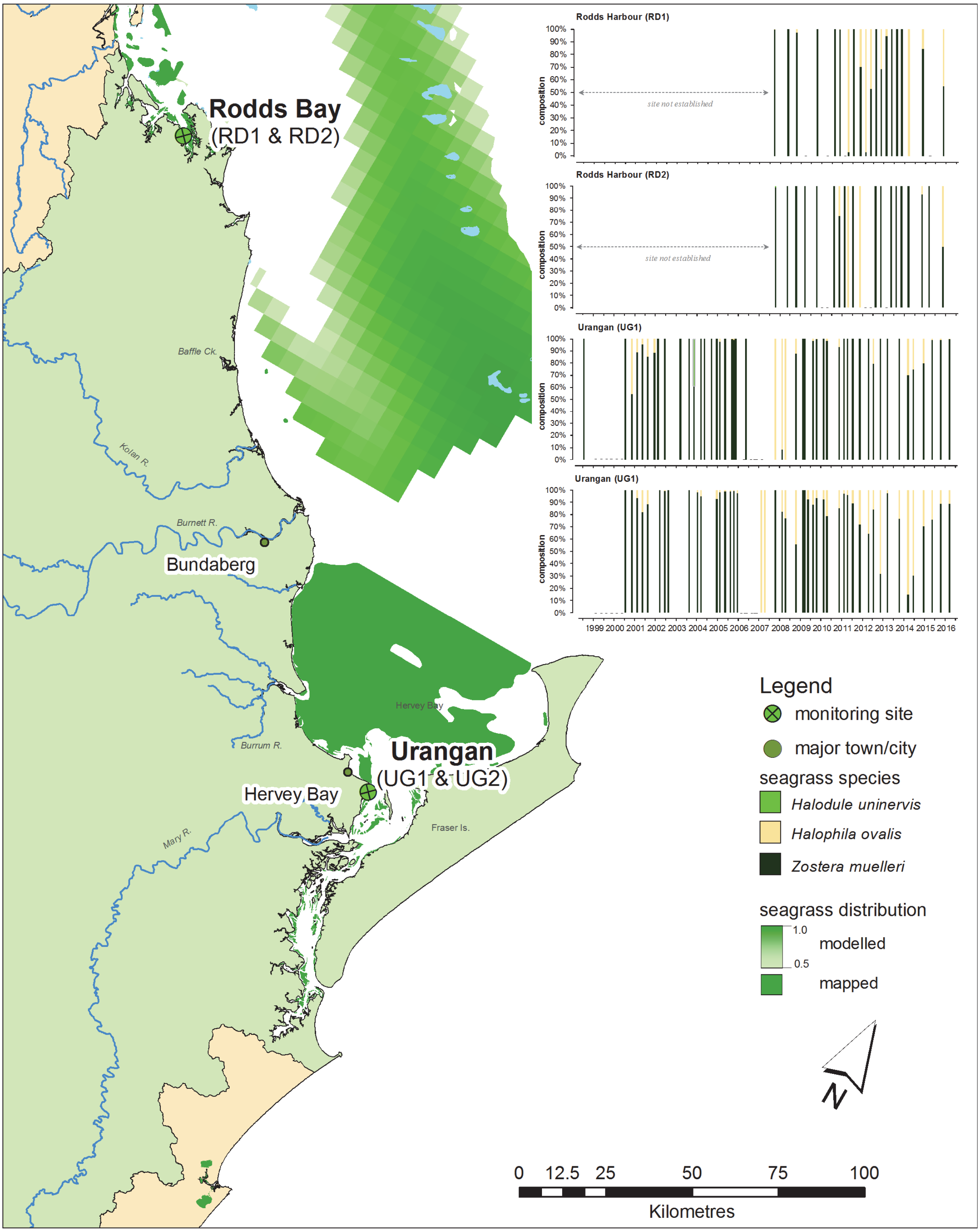

Figure 212. *Location and species composition of each long-term seagrass monitoring site (MMP) in the Burnett Mary region. Please note: replicate sites within 500m of each other. Also shown is distribution of seagrass as the modelled distribution (including likelihood of presence from 0.5-1.0 McKenzie, et al. 2010c) and composite of mapped distribution (McKenzie, et al. 2014c).*

A4.2.6 Seagrass leaf tissue

The following graphs display the elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each habitat or location in the NRM regions of the Great Barrier Reef. The horizontal shaded band on the C:N ratio panels represent the accepted guideline seagrass "Redfield" ratio of 20:1 (Abal*, et al.* 1994; Grice*, et al.* 1996). C:N ratios below this line may indicate reduced light availability and/or N enrichment. The horizontal shaded band on the N:P ratio panels represent the range of value associated with N:P balance ratio in the plant tissues, i.e. a seagrass "Redfield" ratio (Atkinson and Smith 1983; Duarte 1990; Fourqurean*, et al.* 1992b; Fourqurean and Cai 2001). N:P ratio above this band indicates P limitation, below indicates N limitation and within indicates replete. Shaded portion on the C:P panel ≤500 represents the value associated with C:P balance ratio in the plant tissues, C:P values <500 may indicate nutrient rich habitats (large P pool).

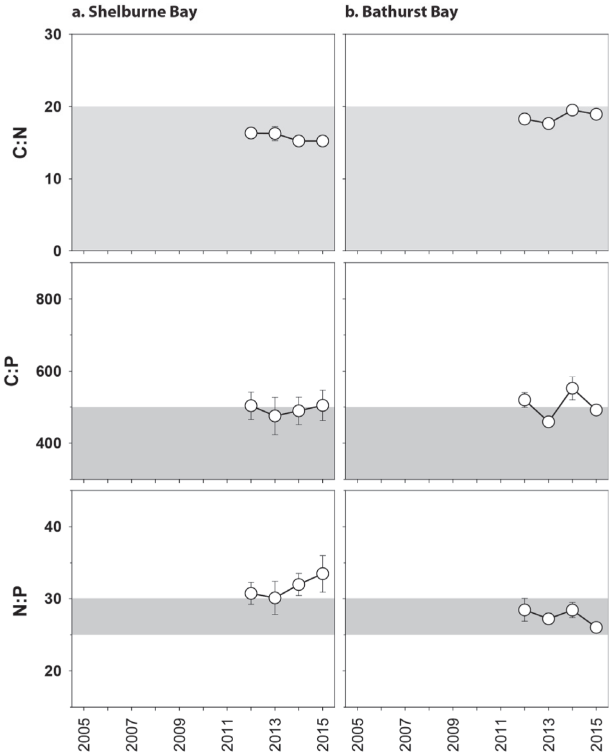

Figure 213. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each coastal location in the Cape York region each year (species pooled) (mean ± Standard Error).*

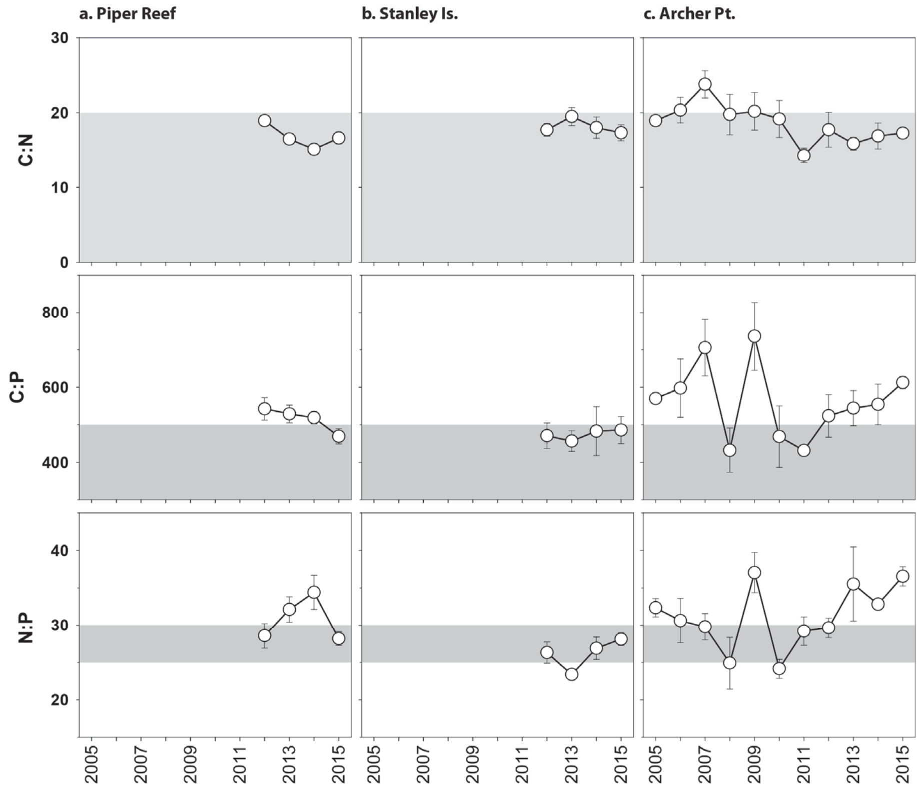

Figure 214. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each reef location in the Cape York region each year (species pooled) (mean ± Standard Error).*

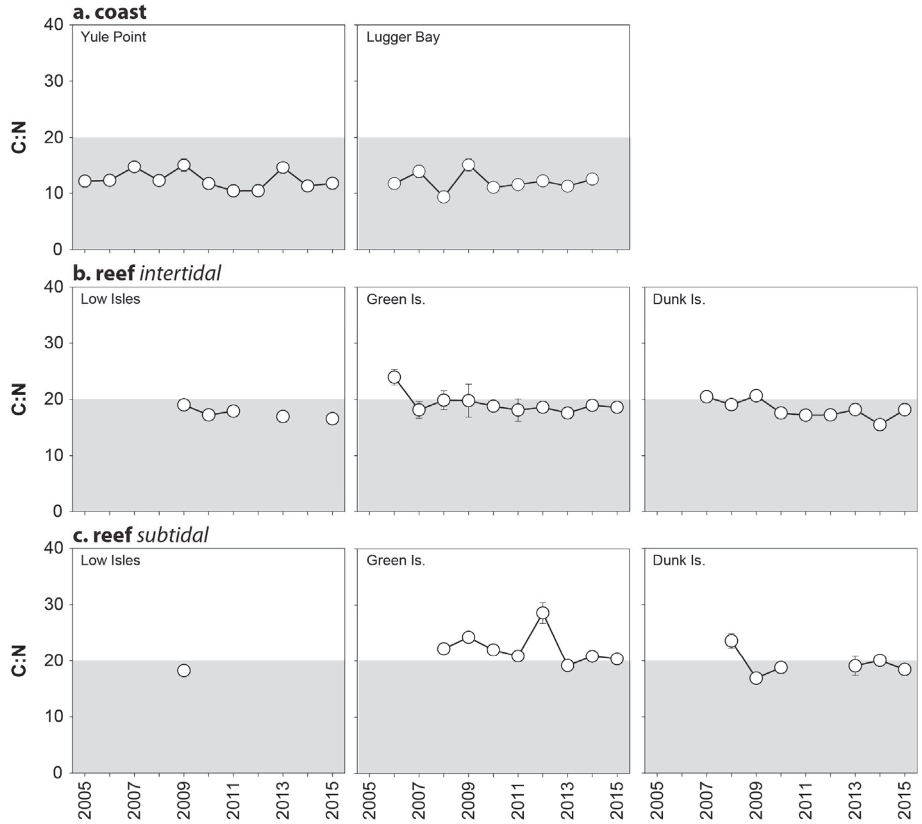

Figure 215. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat and location in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

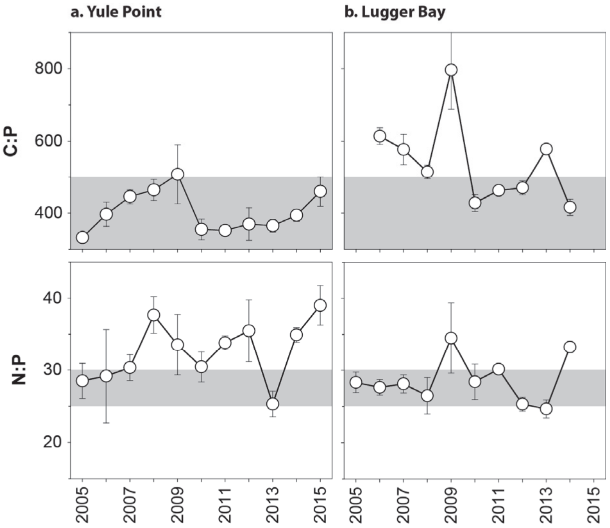

Figure 216. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for the foundation seagrass species examined at intertidal coastal habitats in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

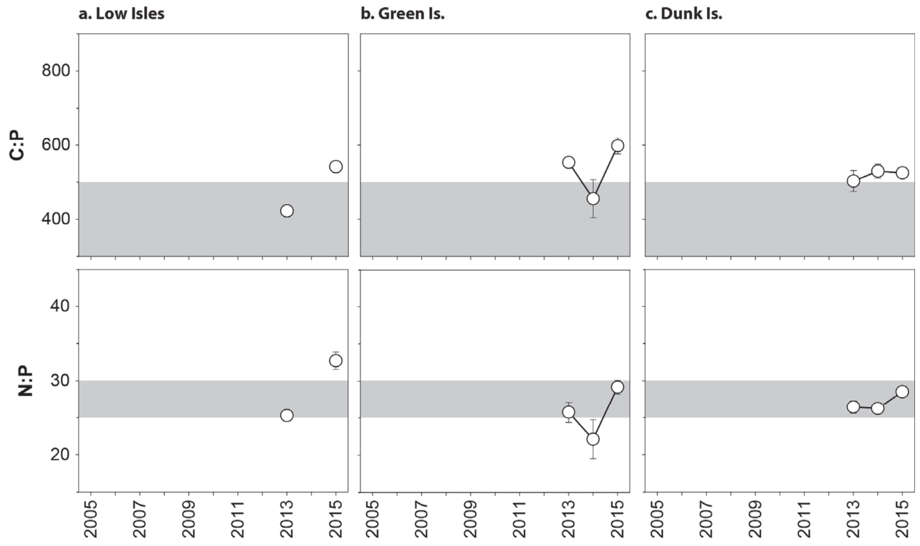

Figure 217. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for the foundation seagrass species examined at intertidal reef habitats in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

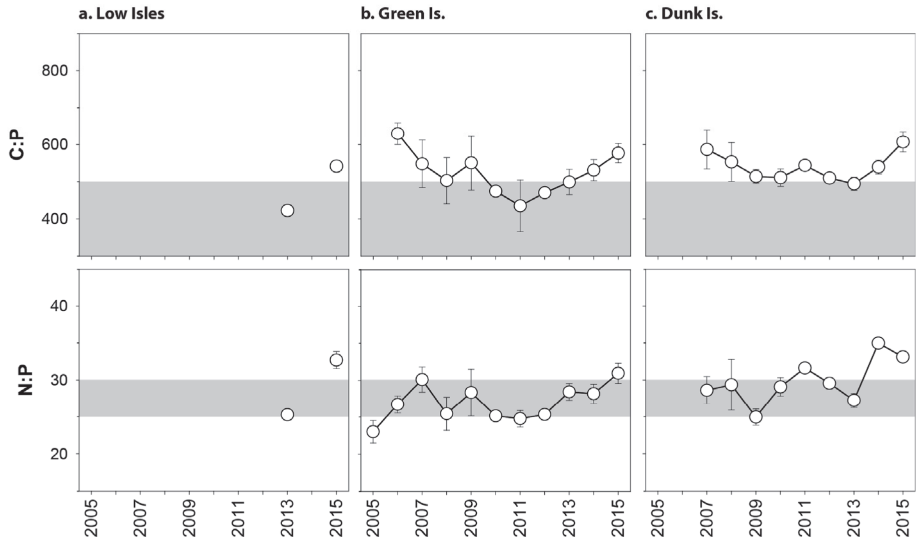

Figure 218. *Elemental ratios (atomic) of seagrass leaf tissue C:P and N:P for the foundation seagrass species examined at subtidal reef habitats in the Wet Tropics region each year (species pooled) (mean ± Standard Error).*

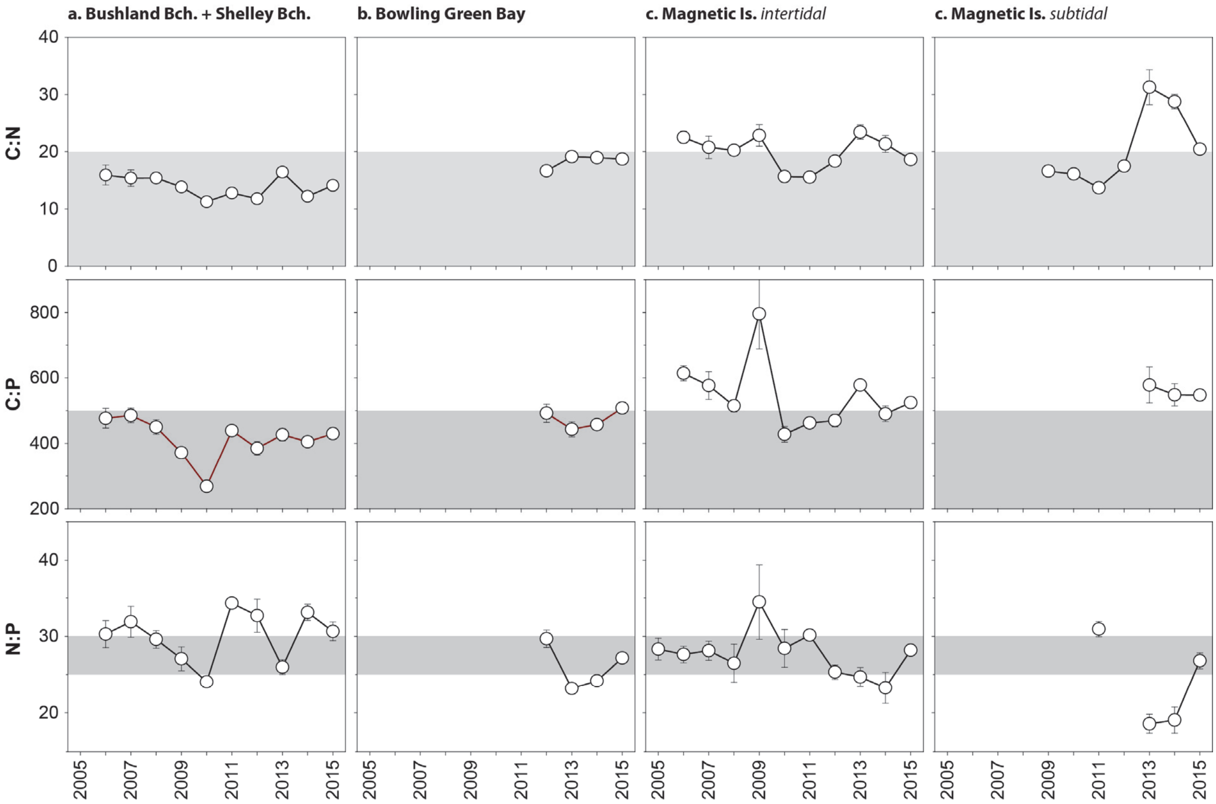

Figure 219. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at each habitat and location in the Burdekin region each year (species pooled) (mean ± Standard Error).*

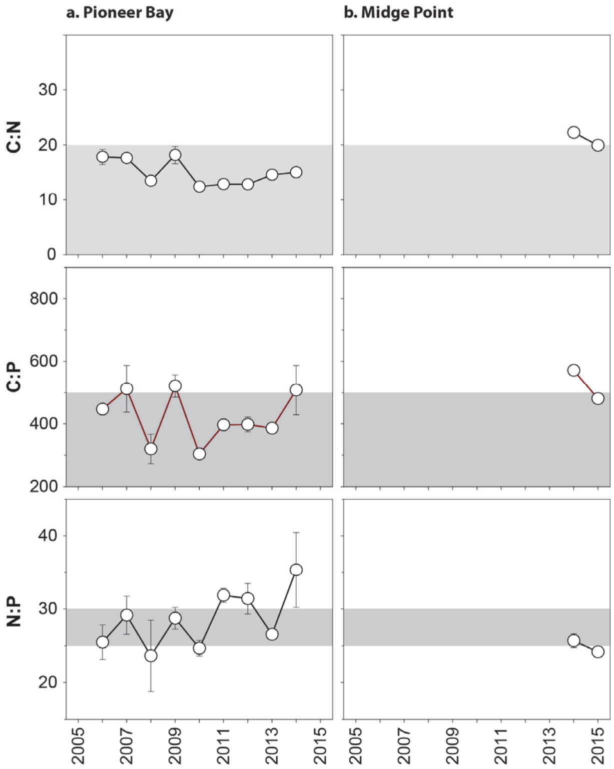

Figure 220. *Elemental ratios (atomic) of seagrass leaf tissue C:N, N:P and C:P for the foundation seagrass species examined at coastal habitats in the Mackay Whitsunday region each year (species pooled) (mean ± Standard Error).*

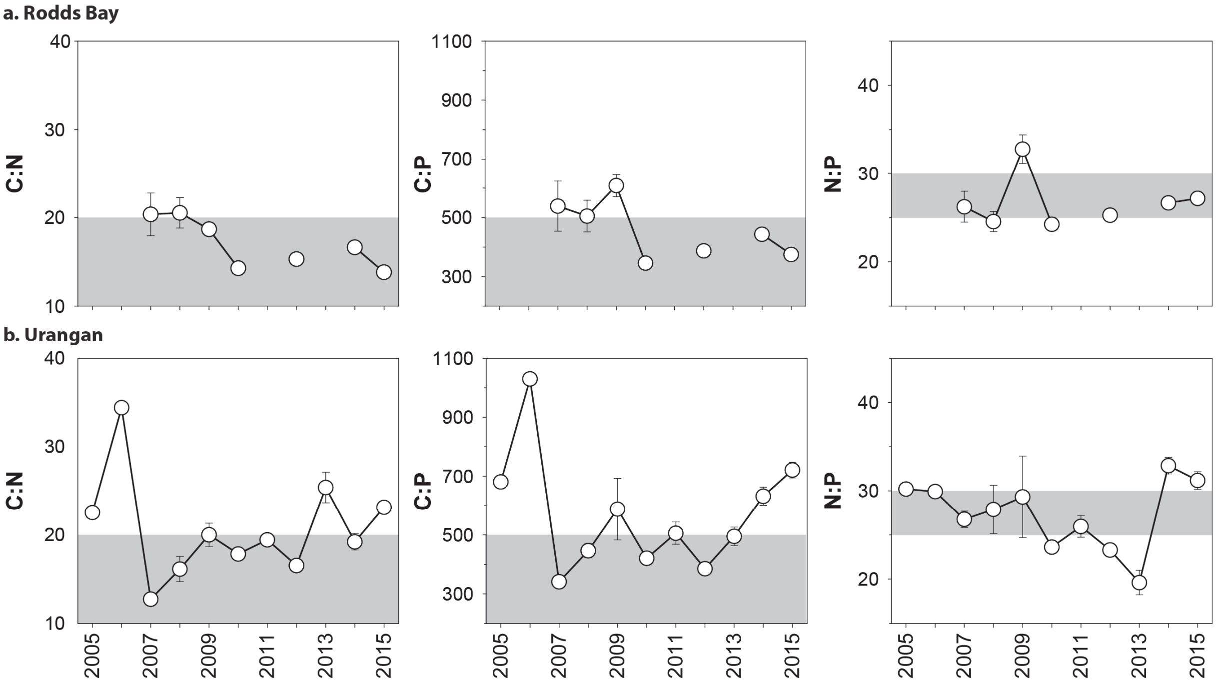

Figure 221. *Elemental ratios (atomic) of seagrass leaf tissue C:N for the foundation seagrass species examined at each habitat in the Burnett Mary region each year (species pooled) (mean ± Standard Error).*

Table 61. *Seagrass leaf tissue nutrient, δ^{13}C and δ^{15}N concentrations from each NRM region in the late dry 2011 to 2014.Leaf tissues with low per centC (see Table 38), low C:N (<20:1), and isotopically depleted δ^{13}C may indicate that growth is light limited (Grice et al. 1996; Fourqurean et al. 2005). Global δ^{13}C averages from Hemminga and Mateo 1996). Shading indicates values lower than literature. CR=Cymodocea rotundata, EA=Enhalus acoroides, HO=Halophila ovalis, HS=Halophila spinulosa, HU=Halodule uninervis, TH=Thalassia hemprichii, ZM=Zostera muelleri.*

NRM	**Habitat**	**Species**	**Year**	**per centC**	**C:N**	**δ^{13}C ‰**	**δ^{15}N ‰**	**per centC lit median**	**δ^{13}C ‰ global average**
Cape York	coastal intertidal	EA	2012	36.68	14.72	-13.07	-9.41	*38.3*	*-5.8 (-6.7 to -4.9)*
		HU	2012	40.61	15.92	-11.00 ±0.46	0.06 ±0.26	*38.5*	*-11.2 (-13.0 to -7.8)*
			2013	39.86	15.74	-11.71 ±0.25	-1.77 ±0.93		
			2014	40.62	19.15	-11.22 ±0.12	-0.08 ±0.51		
			2015	38.98	16.34	-9.57 ±0.99	0.89 ±0.78		
		SI	2012	36.74	16.52	-4.78	0.35	*28*	*-6.0 (-8.3 to -3.6)*
			2013	36.34	18.07	-6.10 ±0.09	-0.58 ±0.34		
			2014	36.69	24.00	-4.28 ±0.25	0.20 ±0.1		
			2015	33.00	22.65	-8.48 ±1.65	0.55 ±0.45		
		TH	2012	35.74	15.37	-9.97 ±0.22	-1.28 ±0.60	*35.6*	*-6.9 (-8.1 to -5.2)*
			2013	36.15	17.97	-10.50 ±0.15	-1.33 ±0.47		
			2014	37.68	16.78	-10.21 ±0.18	-0.37 ±0.18		
			2015	36.95	16.09	-10.53 ±1.08	-0.86 ±0.83		
		ZM	2012	38.94	17.28	-10.23	1.84	*32*	*-10.8 (-12.4 to -9.2)*
			2014	38.08	26.47	-9.38 ±0.20	1.39 ±0.05		
			2015	38.10	20.96	-10.17 ±0.86	1.73 ±0.26		
	reef intertidal	CR	2012	39.65	18.03	-7.96 ±0.25	-2.44 ±0.61	*39*	*-8.1 (-8.9 to -7.4)*
			2013	36.89	24.16	-8.32	-0.83		
			2014	37.42	18.66	-7.95 ±0.12	-1.87 ±0.32		
			2015	39.51	17.77	-9.65 ±0.63	0.48 ±0.43		
		CS	2012	40.34	19.12	-8.57	0.37	*40.4*	*-10.7 (-12.4 to -8.0)*
			2015	42.10	25.77	-12.34 ±1.46	-0.32 ±0.88		
		HU	2011	42.48	15.50	-8.78 ±0.30	0.72 ±0.44	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	41.22	16.13	-8.74 ±0.22	0.15 ±1.34		
			2013	41.93	16.86	-8.97 ±0.04	-1.58 ±0.51		
			2014	39.53	17.89	-8.82 ±0.19	-1.71 ±0.69		
			2015	41.15	16.05	-9.08 ±0.84	0.82 ±0.88		
		SI	2012	22.27	19.83	-4.01 ±0.24	1.11 ±0.94	*28*	*-6.0 (-8.3 to -3.6)*
			2013	37.52	19.46	-5.27	0.24		
			2014	34.75	20.24	-3.15	0.66		
			2015	36.90	22.76	-5.82 ±0.02	0.15 ±0.28		
		TH	2012	37.42	15.91	-6.26 ±0.27	0.65 ±0.84	*35.6*	*-6.9 (-8.1 to -5.2)*
			2013	37.61	16.79	-6.99 ±0.12	0.42 ±0.59		
			2014	36.02	17.54	-7.11 ±0.13	-0.24 ±0.55		
			2015	37.53	15.58	-8.77 ±0.89	-1.99 ±0.43		
		ZM	2011	39.70	22.27	-9.27	1.57	*32*	*-10.8 (-12.4 to -9.2)*
			2013	36.86	20.08	-9.03 ±0.08	-0.66 ±0.38		
Wet Tropics	coastal intertidal	HU	2011	44.90	10.65	-10.35	0.64	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	42.08	11.13	-9.59 ±0.16	0.85 ±0.27		
			2013	41.29	11.82	-10.12 ±0.25	0.42 ±0.19		
			2014	43.64	11.59	-9.76 ±0.18	1.73 ±0.38		
			2015	44.52	11.76	-8.39 ±0.91	1.45 ±0.48		
	reef intertidal	CR	2011	42.38	18.17	-7.88 ±0.27	-0.71 ±0.31	*39*	*-8.1 (-8.9 to -7.4)*
			2012	40.83	17.64	-6.71 ±0.11	-0.27 ±0.36		
			2013	39.96	18.35	-7.67 ±0.34	0.76 ±0.89		
			2014	42.10	20.27	-7.59 ±0.13	0.22 ±0.31		
			2015	42.98	17.23	-7.74 ±0.07	0.9 ±0.43		
		CS	2013	41.81	22.61	-10.63 ±0.07	3.64 ±0.22	*40.4*	*-10.7 (-12.4 to -8.0)*
			2014	42.15	21.61	-9.10 ±0.02	1.97 ±0.09		

NRM	Habitat	Species	Year	per centC	C:N	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	per centC lit median	$\delta^{13}C$ ‰ global average
			2015	42.38	22.30	-7.2 ±0.86	0.54 ±0.07		
		HU	2009	34.29	19.45	-11.05 ±0.14	0.23 ±1.08	*38.5*	*-11.2 (-13.0 to -7.8)*
			2010	34.34	17.22	-12.86 ±1.14	1.75 ±0.17		
			2011	39.84	19.02	-9.32 ±0.43	1.66 ±0.35		
			2012	41.74	17.08	-7.83 ±0.23	1.76 ±0.66		
			2013	41.41	19.38	-9.01 ±0.22	1.78 ±0.54		
			2014	42.02	17.58	-8.68 ±0.26	2.35 ±0.19		
			2015	43.37	18.02	-8.51 ±0.45	1.97 ±0.46		
		SI	2015	39.50	22.84	-7.31 ±0.28	1.59 ±0.85	*28*	*-6.0 (-8.3 to -3.6)*
		TH	2009	30.41	18.55	-8.66 ±0.24	1.22 ±0.17	*35.6*	*-6.9 (-8.1 to -5.2)*
			2011	40.43	17.29	-7.02 ±0.11	1.80 ±0.24		
			2012	38.71	15.97	-7.40 ±0.21	1.24 ±0.15		
			2013	37.95	17.12	-6.34 ±0.18	2.88 ±0.47		
			2014	40.29	17.36	-6.80 ±0.19	1.84 ±0.28		
			2015	41.11	15.76	-8.79 ±0.15	1.67 ±0.18		
	reef subtidal	CR	2013	40.91	16.77	-9.50 ±0.20	-0.37 ±0.37	*39*	*-8.1 (-8.9 to -7.4)*
			2014	41.73	17.00	-9.85 ±0.16	1.09 ±0.23		
			2015	41.43	17.59	-7.65 ±1.35	1.87 ±0.89		
		CS	2008	33.35	22.74	-9.65 ±0.26	1.91 ±0.33	*40.4*	*-10.7 (-12.4 to -8.0)*
			2009	33.69	24.27	-9.87 ±0.03	2.19 ±0.15		
			2010	32.70	22.87	-9.78 ±0.24	1.34 ±0.36		
			2011	37.88	22.89	-9.91 ±0.13	2.79 ±0.29		
			2012	40.60	28.58	-9.73 ±0.13	2.11 ±0.35		
			2013	38.59	22.56	-10.11 ±0.43	3.04 ±0.44		
			2014	39.65	21.72	-9.46 ±0.22	3.47 ±0.13		
			2015	41.23	22.84	-9.44 ±0.09	-1.96 ±0.31		
		HU	2008	35.25	22.63	-10.62 ±0.17	2.19 ±0.23	*38.5*	*-11.2 (-13.0 to -7.8)*
			2009	34.46	17.24	-11.25 ±0.36	0.95 ±0.15		
			2010	33.50	19.96	-11.69 ±1.11	2.23 ±0.48		
			2011	38.94	18.88	-9.64 ±0.04	1.82 ±0.23		
			2013	39.19	19.58	-9.85 ±0.17	2.71 ±0.29		
			2014	41.26	18.96	-10.10 ±0.15	2.82 ±0.19		
			2015	43.03	19.09	-8.83 ±1.19	1.88 ±0.27		
		SI	2013	37.10	20.92	-4.71 ±0.14	0.86 ±0.34	*28*	*-6.0 (-8.3 to -3.6)*
			2014	35.53	22.30	-5.03 ±0.20	1.47 ±0.19		
			2015	37.63	21.35	-9.57 ±0.07	1.58 ±0.44		
Burdekin	coastal intertidal	HU	2012	40.30	12.82	-11.23 ±0.13	1.22v0.19	*38.5*	*-11.2 (-13.0 to -7.8)*
			2013	38.81	15.75	-11.49 ±0.03	2.34 ±0.17		
			2014	40.56	12.74	-11.64 ±0.25	2.82 ±0.16		
			2015	39.63	15.58	-10.18 ±0.6	0.68 ±0.35	0	0
		ZM	2012	36.33	17.76	-10.44 ±0.23	2.18 ±0.39	*32*	*-10.8 (-12.4 to -9.2)*
			2013	35.75	18.56	-10.75 ±0.06	2.59 ±0.15		
			2014	34.85	20.12	-11.71 ±0.17	2.80 ±0.06		
			2015	37.60	18.89	-10.43 ±0.78	1.18 ±1.39		
	reef intertidal	CS	2012	40.47	21.91	-9.07 ±0.02	1.54 ±0.60	*40.4*	-10.7 (-12.4 to -8.0)
			2013	40.71	19.46	-10.00 ±0.09	2.06 ±0.04		
			2015	40.17	20.11	-8.99 ±0.09	1.59 ±0.4		
		HO	2011	39.50	13.44	-10.79	1.88	*30.5*	*-10 (-15.5 to -6.4)*
		HU	2011	44.57	12.62	-9.84 ±0.18	0.96 ±0.04	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	41.63	16.53	-9.11 ±0.07	1.32 ±0.50		
			2013	39.50	20.04	-10.03 ±0.17	2.23 ±0.13		
			2014	38.02	22.11	-9.40 ±0.30	2.32 ±0.20		
			2015	40.40	18.49	-9.87 ±0.44	1.37 ±0.26		
		TH	2012	39.61	15.14	-8.31	0.09 ±0.45	*35.6*	*-6.9 (-8.1 to -5.2)*
			2013	36.48	15.65	-8.85 ±0.05	1.58 ±0.09		
	reef subtidal	CS	2009	35.10	18.83	-10.96 ±0.18	1.03 ±0.38	*40.4*	-10.7 (-12.4 to -8.0)
			2013	40.28	24.21	-11.59 ±0.24	3.39 ±0.22		
			2014	41.99	28.24	-10.38 ±0.46	3.08 ±0.22		

NRM	Habitat	Species	Year	per centC	C:N	δ^{13}C ‰	δ^{15}N ‰	per centC lit median	δ^{13}C ‰ global average
			2015	40.63	21.24	-10.52 ±0.25	1.05 ±1.11		
		HS	2013	37.35	31.12	-12.32	3.11		
		HU	2009	38.29	16.60	-10.69 ±1.00	1.05 ±0.48	*38.5*	*-11.2 (-13.0 to -7.8)*
			2010	30.12	16.10	-12.35 ±0.40	-0.16 ±0.13		
			2011	40.31	13.70	-10.88 ±0.03	0.20 ±0.24		
			2012	42.78	17.47	-11.16 ±0.06	1.82 ±0.10		
			2013	40.41	22.55	-11.62 ±0.15	3.02 ±0.04		
			2014	41.01	23.26	-9.47 ±0.14	3.17 ±0.07		
			2015	41.47	19.62	-9.93 ±0.19	3.61 ±0.06		
Mackay Whitsunday	estuarine intertidal	ZM	2011	43.22	12.13	-10.02 ±0.12	0.53 ±0.47	*32*	*-10.8 (-12.4 to -9.2)*
			2012	40.47	12.92	-10.45 ±0.19	2.08 ±0.22		
			2013	38.77	15.66	-10.16 ±0.24	2.06 ±0.22		
			2014	37.55	18.16	-11.12 ±0.26	2.15 ±0.03		
			2015	37.60	17.39	-10.57 ±0.2	1.29 ±0.54		
	coastal intertidal	HU	2012	43.02	10.84	-11.42 ±0.06	-0.98 ±0.15	*38.5*	*-11.2 (-13.0 to -7.8)*
			2013	42.31	12.84	-10.93 ±0.19	3.25 ±0.10		
			2014	40.88	13.86	-11.56 ±0.15	2.20 ±0.24		
		ZM	2012	40.00	12.85	-11.10 ±0.13	4.13 ±0.33	*32*	*-10.8 (-12.4 to -9.2)*
			2013	41.05	13.56	-11.47 ±0.14	4.15 ±0.55		
			2014	39.53	19.60	-10.16 ±0.22	2.97 ±0.13		
			2015	36.48	19.93	-9.43 ±0.76	1.6 ±0.26		
	reef intertidal	HU	2011	45.40	9.81	-10.23	1.44	*38.5*	*-11.2 (-13.0 to -7.8)*
			2012	42.80	10.04	-9.22 ±0.03	-0.20 ±0.19		
			2013	42.19	10.67	-8.91 ±0.08	0.80 ±0.72		
			2014	43.89	11.24	-8.79 ±0.09	0.89 ±0.25		
			2015	44.55	10.57	-9.66 ±0.17	1.91 ±0.16		
		ZM	2011	42.50	13.77	-9.3	0.74	*32*	*-10.8 (-12.4 to -9.2)*
			2012	39.80	14.35	-9.15 ±0.05	2.47 ±0.34		
			2013	36.06	19.49	-9.94 ±0.08	2.34 ±0.19		
			2014	38.90	20.28	-9.30 ±0.22	2.87 ±0.11		
			2015	42.63	12.74	-7.93 ±0.58	0.9 ±1.41		
Fitzroy	estuarine intertidal	ZM	2012	39.56	22.70	-9.51 ±0.23	2.27 ±0.13	*32*	*-10.8 (-12.4 to -9.2)*
			2013	36.53	18.45	-9.19 ±0.25	2.27 ±0.28		
			2014	35.59	20.27	-9.27 ±0.17	1.84 ±0.13		
			2015	35.02	19.46	-10.53 ±0.4	0.39 ±1.17		
	coastal intertidal	HU	2013	40.34	20.40	-11.17	1.07	*38.5*	*-11.2 (-13.0 to -7.8)*
			2015	36.55	14.49	-8.82 ±0.15	0.73 ±0.27		
		ZM	2011	40.08	18.36	-9.28 ±0.07	0.72 ±0.10	*32*	*-10.8 (-12.4 to -9.2)*
			2012	37.64	16.57	-8.24 ±0.17	0.94 ±0.35		
			2013	36.59	18.26	-9.58 ±0.16	0.90 ±0.12		
			2014	33.38	17.31	-8.49 ±0.15	1.03 ±0.17		
			2015	37.73	16.83	-8.62 ±0.59	0.48 ±0.51		
	reef intertidal	HU	2013	41.22	17.15	-9.40	-0.72	*38.5*	*-11.2 (-13.0 to -7.8)*
			2014	40.66	16.07	-7.14 ±0.10	0.56 ±0.12		
			2015	40.80	16.47	-10.1 ±0.56	-0.95 ±1.03		
		ZM	2012	39.88	13.38	-6.39 ±0.19	-0.47 ±0.29	*32*	*-10.8 (-12.4 to -9.2)*
			2013	39.79	16.05	-7.36 ±0.15	0.92 ±0.37		
			2014	36.19	21.48	-7.43 ±0.00	-0.08 ±0.00		
			2015	37.70	16.41	-8.68 ±0.89	-0.45 ±0.78		
Burnett Mary	estuarine intertidal	HO	2011	36.90	15.89	-10.46 ±	4.55	*30.5*	*-10 (-15.5 to -6.4)*
		ZM	2011	41.03	17.80	-8.94 ±0.21	3.11 ±0.42	*32*	*-10.8 (-12.4 to -9.2)*
			2012	39.48	15.75	-10.78 ±0.05	1.72 ±0.33		
			2013	35.02	18.92	-10.540.08	3.79 ±0.30		
			2014	37.86	18.67	-10.75 ±0.24	2.26 ±0.10		
			2015	39.19	20.02	-9.81 ±0.89	1.75 ±0.7		

Table 62. *Percent carbon in seagrass leaf tissue from published literature.*

Species	per centC	Citation	Location
Cymodocea rotundata	38.9	Yamamuro & Chirapart 2005	Trang, Thailand
Cymodocea serrulata	42.7	Grice et al. (1996)	Green Island
	38	Atkinson & Smith (1984)	Cockle Bay
	40.4	median	
Enhalus acoroides	38.3	Duarte (1990)	Palau
Halophila ovalis	32 ± 0.5	McMahon (2005)	Moreton Bay - Aug
	29 ± 0.4	McMahon (2005)	Moreton Bay - Jan
	30.5	median	
Halophila spinulosa			
Halodule uninervis	40.9	Grice et al. 1996	Green Island
	36	Atkinson & Smith (1984)	N Queensland
	38.5	median	
Syringodium isoetifolium	28	Grice et al. 1996	Green Island
Thalassia hemprichii	32..61	Erftemeijer and Herman 1994	Kudingareng, Indonesia
	35.58	Erftemeijer and Herman 1994	Barang Lompo, South Sulawesi, Indonesia
	37.4	Koike et al (1987)	Port Moresby, PNG
	40.4	Koike et al (1987)	Port Moresby, PNG
	33	Atkinson & Smith (1984)	Cockle Bay
	33.5	Yamamuro & Chirapart 2005	
	35.6	median	
Zostera muelleri (capricorni)	32	Atkinson & Smith (1984)	Pallerenda
	32 ±04	McMahon (2005)	Urangan - April
	25 ±1.8	McMahon (2005)	Urangan -Dec
	32	*median*	
Global	33.6 ±0.31	Duarte 1990	

Appendix 5 Results of statistical analysis

Table 63. *Summary of GAMM for average cover vs time analysis for 2015-16. For site/location details, see Tables 3 & 4. n = number of data points analysed, EDF = array of estimated degrees of freedom for the model terms.*

MODELS	N	EDF	F	*P*-VALUE	R-SQ (ADJ)
GBR-WIDE					
per cent COVER = S(DATE) + RANDOM(SITE)	55851	8.953	602.1	<2E-16	0.0695
per cent COVER = S(DATE) + HABITAT + RANDOM(SITE)	55851				0.0758
COASTAL INTERTIDAL		8.886	284.8	<2E-16	
ESTUARINE INTERTIDAL		8.916	357.6	<2E-16	
REEF INTERTIDAL		8.649	193.3	<2E-16	
REEF SUBTIDAL		4.837	110.4	<2E-16	
per cent COVER = S(DATE) + NRM REGION + RANDOM(SITE)	55851				0.107
CAPE YORK		5.903	46.97	<2E-16	
WET TROPICS		8.485	180.09	<2E-16	
BURDEKIN		8.926	453.15	<2E-16	
MACKAY WHITSUNDAY		8.831	119.21	<2E-16	
FITZROY		7.469	34.37	<2E-16	
BURNETT MARY		8.782	337.42	<2E-16	
CAPE YORK					
per cent COVER = S(DATE) + RANDOM(SITE)	3911	6.812	55.88	<2e-16	0.034
per cent COVER = S(DATE) + HABITAT + RANDOM(SITE)	3911				0.092
COASTAL INTERTIDAL		1.000	8.066	0.0045	
REEF INTERTIDAL		6.688	58.807	<2e-16	
per cent COVER = S(DATE) + LOCATION + RANDOM(SITE)	3911				0.177
COASTAL INTERTIDAL [SR]		1.000	4.621	0.032	
REEF INTERTIDAL [FR]		1.000	11.072	<0.001	
REEF INTERTIDAL [ST]		1.000	30.292	<0.001	
COASTAL INTERTIDAL [BY]		2.021	6.748	<0.001	
REEF INTERTIDAL [AP]		7.764	53.53	<2e-16	
NORTHERN WET TROPICS					
per cent COVER = S(DATE) + RANDOM(SITE)	14023	8.733	188.8	<2e-16	0.0467
per cent COVER = S(DATE) + HABITAT + RANDOM(SITE)	14023				0.138
COASTAL INTERTIDAL		8.557	158.40	<2e-16	
REEF INTERTIDAL		7.786	79.88	<2e-16	
REEF SUBTIDAL		6.173	33.37	<2e-16	
per cent COVER = S(DATE) + LOCATION + RANDOM(SITE)	14023				0.608
REEF INTERTIDAL [LI1]		5.484	31.34	<2e-16	
REEF SUBTIDAL [LI2]		5.536	30.07	<2e-16	
COASTAL INTERTIDAL [YP]		8.605	134.90	<2e-16	
REEF INTERTIDAL [GI]		6.924	37.14	<2e-16	
REEF SUBTIDAL [GI3]		5.917	25.27	<2e-16	
SOUTHERN WET TROPICS					
per cent COVER = S(DATE) + RANDOM(SITE)	5187	8.349	188.8	<2e-16	0.279
per cent COVER = S(DATE) + HABITAT + RANDOM(SITE)	5187				0.368
COASTAL INTERTIDAL		4.933	66.08	<2e-16	
REEF INTERTIDAL		7.435	244.37	<2e-16	
REEF SUBTIDAL		7.238	29.88	<2e-16	
per cent COVER = S(DATE) + LOCATION + RANDOM(SITE)	5187				0.449
COASTAL INTERTIDAL [LB]		5.084	57.56	<2e-16	
REEF INTERTIDAL [DI]		7.511	122.61	<2e-16	
REEF SUBTIDAL [DI3]		7.468	21.89	<2e-16	
REEF INTERTIDAL [GO]		5.084	57.56	<2e-16	
BURDEKIN					
per cent COVER = S(DATE) + RANDOM(SITE)	9987	8.952	363.9	<2e-16	0.204
per cent COVER = S(DATE) + HABITAT + RANDOM(SITE)	9987				0.361
COASTAL INTERTIDAL		8.97	164.5	<2e-16	
REEF INTERTIDAL		7.691	161.7	<2e-16	

MODELS	N	EDF	F	*P*-VALUE	R-SQ (ADJ)
REEF SUBTIDAL		5.869	189.8	<2e-16	
per cent COVER = S(DATE) + LOCATION + RANDOM(SITE)	9987				0.366
COASTAL INTERTIDAL [JR]		2.667	22.6	<6e-13	
COASTAL INTERTIDAL [TSV]		8.971	151.5	<2e-16	
REEF INTERTIDAL [MI1]		7.691	161.9	<2e-16	
REEF INTERTIDAL [MI2]		5.869	191.1	<2e-16	
REEF SUBTIDAL [MI3]	9987	8.952	363.9	<2e-16	0.204
MACKAY WHITSUNDAY					
per cent COVER = S(DATE) + RANDOM(SITE)	10727	8.805	120.5	<2e-16	0.0831
per cent COVER = S(DATE) + HABITAT + RANDOM(SITE)	10727				0.263
COASTAL INTERTIDAL		8.835	81.45	<2e-16	
ESTUARINE INTERTIDAL		6.979	100.73	<2e-16	
REEF INTERTIDAL		6.913	48.33	1.3e-12	
per cent COVER = S(DATE) + LOCATION + RANDOM(SITE)	10727				0.352
COASTAL INTERTIDAL [MP]		7.766	14.15	< 2e-16	
COASTAL INTERTIDAL [PI]		8.929	108.67	< 2e-16	
REEF INTERTIDAL [HM]		4.081	25.66	< 2e-16	
ESTUARINE INTERTIDAL [SI]		6.980	109.12	< 2e-16	
REEF INTERTIDAL [HB]		7.985	41.21	< 2e-16	
FITZROY					
per cent COVER = S(DATE)	7390	8.824	43.54	<2e-16	0.0223
per cent COVER = S(DATE) + LOCATION	7390				0.321
COASTAL INTERTIDAL [SWB]		8.003	90.543	< 2e-16	
REEF INTERTIDAL [GK]		4.449	9.606	<0.001	
ESTUARINE INTERTIDAL [GH]		7.956	90.543	< 2e-16	
BURNETT MARY					
per cent COVER = S(DATE)	8262	8.603	203.2	<2e-16	0.199
per cent COVER = S(DATE) + LOCATION	8262				0.307
ESTUARINE INTERTIDAL [RD]		7.605	45.12	<2e-16	
ESTUARINE INTERTIDAL [UG]		8.831	228.83	<2e-16	
PER CENT COVER = S(DATE) + LOCTN (no rand – convrg pb)	8262				0.447
ESTUARINE INTERTIDAL [RD]		4.721	173.82	<2E-16	
ESTUARINE INTERTIDAL [UG]		8.917	12.04	< 2E-16	
COASTAL INTERTIDAL [BH]		8.258	64.74	<2E-16	

Table 64. *Summary of GAMM statistical output for light vs time analysis for 2015-16.For site/location details, see Tables 3 & 4. n = number of data points analysed, EDF = array of estimated degrees of freedom for the model terms.*

MODELS	N	EDF	F	*P*-VALUE	R-SQ (ADJ)
GBR-WIDE					
LIGHT = S(DATE)	41130	15.96	194.9	<2E-16	0.0728
LIGHT = S(DATE) + HABITAT	41130				0.268
COASTAL INTERTIDAL		14.04	64.46	<2E-16	
ESTUARINE INTERTIDAL		12.97	50.03	<2E-16	
REEF INTERTIDAL		15.91	93.08	<2E-16	
REEF SUBTIDAL		15.91	103.61	<2E-16	
LIGHT = S(DATE) + NRM REGION	41130				0.183
CAPE YORK		7.41	44.28	<2E-16	
WET TROPICS		15.91	111.86	<2E-16	
BURDEKIN		15.82	85.03	<2E-16	
MACKAY WHITSUNDAY		13.37	92.83	<2E-16	
FITZROY		13.28	31.05	<2E-16	
BURNETT MARY		11.72	29.38	<2E-16	
CAPE YORK					
LIGHT = S(DATE)	3380	5.948	87.31	<2E-16	0.113
LIGHT = S(DATE) + HABITAT	3380				0.403
COASTAL INTERTIDAL		5.912	257.48	<2E-16	
REEF INTERTIDAL		5.912	45.17	<2E-16	
LIGHT = S(DATE) + LOCATION	3380				0.5

MODELS	N	EDF	F	*P*-VALUE	R-SQ (ADJ)
COASTAL INTERTIDAL [SR]		4.126	275.35	<2E-16	
REEF INTERTIDAL [FR]		4.527	66.04	<2E-16	
REEF INTERTIDAL [ST]		4.384	25.85	<2E-16	
COASTAL INTERTIDAL [BY]		5.813	54.46	<2E-16	
REEF INTERTIDAL [AP]		2.680	21.58	5.43E-14	
WET TROPICS					
LIGHT = S(DATE)	14869	14.91	93.76	<2E-16	0.0712
LIGHT = S(DATE) + HABITAT	14869				0.41
COASTAL INTERTIDAL		12.45	44.06	<2E-16	
REEF INTERTIDAL		14.85	56.96	<2E-16	
REEF SUBTIDAL		14.90	124.68	<2E-16	
LIGHT = S(DATE) + LOCATION	14869				0.479
REEF INTERTIDAL [LI1]		14.76	73.90	<2E-16	
REEF SUBTIDAL [LI2]		14.72	40.75	<2E-16	
COASTAL INTERTIDAL [YP]		12.51	50.47	<2E-16	
REEF INTERTIDAL [GI]		14.40	26.22	<2E-16	
REEF SUBTIDAL [GI3]		14.10	30.71	<2E-16	
REEF INTERTIDAL [DI]		14.41	24.03	<2E-16	
REEF SUBTIDAL [DI3]		14.83	81.94	<2E-16	
BURDEKIN					
LIGHT = S(DATE)	10446	15.74	62.84	<2E-16	0.0946
LIGHT = S(DATE) + HABITAT	10446				0.435
COASTAL INTERTIDAL		13.13	55.04	<2E-16	
REEF INTERTIDAL		15.29	26.99	<2E-16	
REEF SUBTIDAL		15.66	28.17	<2E-16	
LIGHT = S(DATE) + LOCATION	10446				0.448
COASTAL INTERTIDAL [TSV]		13.18	42.46	<2E-16	
REEF INTERTIDAL [MI1]		15.18	15.58	<2E-16	
REEF INTERTIDAL [MI2]		11.51	21.76	<2E-16	
REEF SUBTIDAL [MI3]		15.66	28.57	<2E-16	
MACKAY WHITSUNDAY					
LIGHT = S(DATE)	4829	11.9	102.4	<2E-16	0.195
LIGHT = S(DATE) + HABITAT	4829				0.313
COASTAL INTERTIDAL		10.75	102.11	<2E-16	
ESTUARINE INTERTIDAL		9.496	28.14	<2E-16	
REEF INTERTIDAL		10.70	17.93	<2E-16	
LIGHT = S(DATE) + LOCATION	4829				0.342
COASTAL INTERTIDAL [MP]		4.771	36.57	<2E-16	
COASTAL INTERTIDAL [PI]		9.539	58.89	<2E-16	
REEF INTERTIDAL [HM]		10.71	18.42	<2E-16	
ESTUARINE INTERTIDAL [SI]		9.507	28.68	<2E-16	
FITZROY					
LIGHT = S(DATE)	4982	8.353	14.15	<2E-16	0.035
LIGHT = S(DATE) + LOCATION	4982				0.284
COASTAL INTERTIDAL [SWB]		9.28	18.15	<2E-16	
REEF INTERTIDAL [GK]		10.81	110.58	<2E-16	
ESTUARINE INTERTIDAL [GH]		9.68	26.06	<2E-16	
BURNETT MARY					
LIGHT = S(DATE)	2624	10.83	41.7	<2E-16	0.179
LIGHT = S(DATE) + LOCATION	2624				0.331
ESTUARINE INTERTIDAL [RD]		10.7	35.95	<2E-16	
ESTUARINE INTERTIDAL [UG]		11.2	19.94	<2E-16	