Australian Government

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Marine Monitoring

Results

Reef Water Quality Report Card 2017 and 2018

Reef 2050 Water Quality Improvement Plan

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Acknowledgements

The Great Barrier Reef Marine Park Authority's Marine monitoring program is jointly funded by the Australian Government's Reef Program, the Reef 2050 Integrated Monitoring and Reporting Program, and co-funding or support from our monitoring partners including the Australian Institute of Marine Science, James Cook University, Howley Environmental Consulting and the Cape York Water Monitoring Partnership, the University of Queensland, Queensland Parks and Wildlife Service, Reef Catchments, Traditional Owners and community volunteers.

We thank our long-term partners and collaborators for their dedication to monitoring, evaluation and synthesis of science about the Reef. The annual technical reports for seagrass (McKenzie et al. 2018, McKenzie et al. 2019) and coral (Thompson et al. 2018, Thompson et al. 2019), *in situ* water quality (Waterhouse et al. 2018, Gruber et al. 2019) and pesticides (Grant et al. 2018, Gallen et al. 2019) underpin this report. The Marine monitoring program also acknowledge Seagrass-Watch and the AIMS Long Term Monitoring Program for providing information that is integrated into the annual technical reports.

SUMMARY: INSHORE GREAT BARRIER REEF ECOSYSTEM HEALTH

This report summarises the condition of coral and seagrass in 2016-2017 (Table 1) and 2017-2018 (Table 1 and Figure 1) in the inshore Great Barrier Reef from the Marine monitoring program.

Trends since the last reporting period show:
Inshore coral scores remained moderate in the Great Barrier Reef, and in the Wet Tropics and Burdekin regions. Coral declined from good in 2016-2017 to moderate in the Mackay Whitsunday region, primarily due to the impacts of Severe Tropical Cyclone Debbie and continued high turbidity, and remained poor in the Fitzroy region (Thompson et al. 2018, Thompson et al. 2019).

Inshore seagrass remained in poor condition in the Great Barrier Reef and in all regions except the Burdekin, where it remained moderate, and Burnett Mary, where it declined from poor in 2015-2016 and 2016-2017 to very poor in 2017-2018 (McKenzie et al. 2018, McKenzie et al. 2019).

Table 1. Inshore coral, seagrass scores for the Reef and natural resource management regions in 2016-2017 and 2017-2018.

Region (inshore)	Year	Coral index	Seagrass Index
Great Barrier Reef	2016-2017	43	36
	2017-2018	41	29
Cape York	2016-2017		34
	2017-2018		25
Wet Tropics	2016-2017	55	22
	2017-2018	57	36
Burdekin	2016-2017	46	54
	2017-2018	45	47
Mackay Whitsunday	2016-2017	52	33
	2017-2018	42	21
Fitzroy	2016-2017	23	24
	2017-2018	29	22
Burnett Mary	2016-2017		21
	2017-2018		19

Note: The Great Barrier Reef inshore score is the average of scores for six natural resource management regions. Grey shading indicates that there is no coral monitoring occurring in the Cape York or Burnett Mary. 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. Data source: coral (Thompson et al. 2018, Thompson et al. 2019) and seagrass (McKenzie et al. 2018, McKenzie et al. 2019).

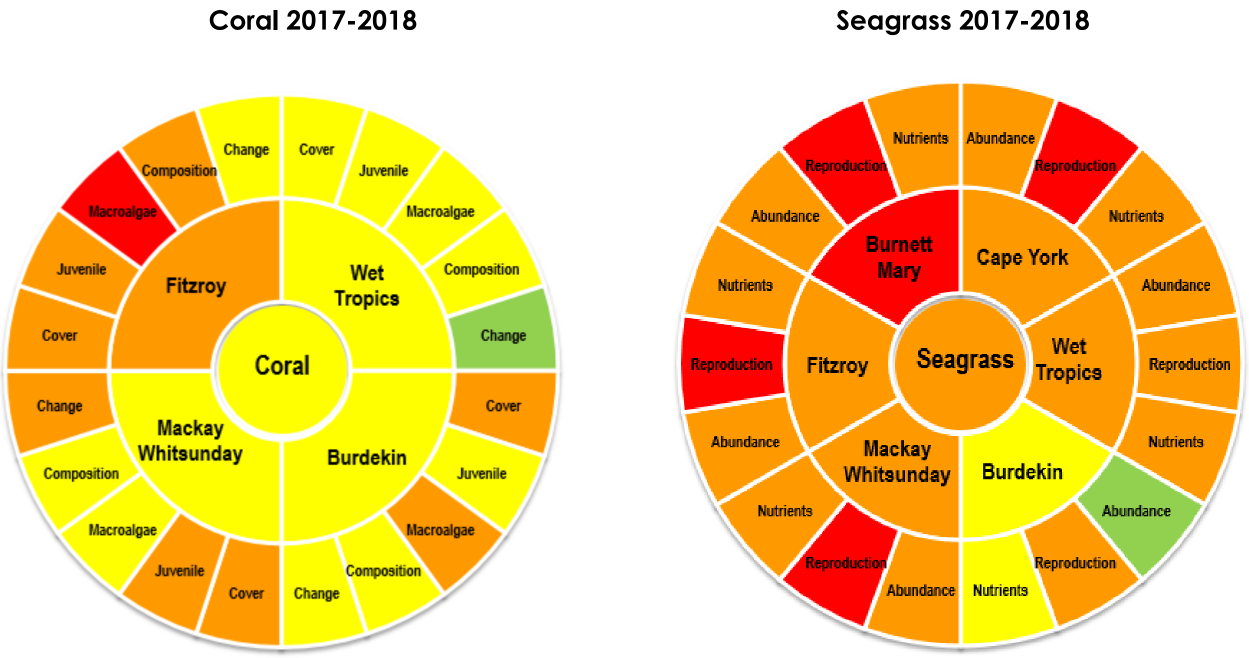

Figure 1. Overall condition of the inshore ecosystem health in 2017–18 for coral (left) and seagrass (right). Colour code: ■ = very good (A), ■ = good (B), ■ = moderate (C), ■ = poor (D), ■ = very poor (E) Note: Coral is only assessed in four regions: the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy Natural Resource Management regions.

The current condition of the coral and seagrass indicators for the Great Barrier Reef and regions is shown in Figure 1, and is described further in this report. An analysis of environmental pressures on coral and seagrass is also presented, including the risks from pesticides, and exposure and risk to marine communities from the analysis of flood plumes pollutants, as well as *in situ* water quality trends in three natural resource management regions and at specific locations, from the Marine monitoring program. In brief, the analysis of trends reveals:

- Water quality monitored *in situ* over the long term was stable in the Burdekin but has obviously declined in the Mackay Whitsunday region (Waterhouse et al. 2018, Gruber et al. 2019) (Section 1).
- Pesticides were detected year-round at all sites monitored across the inshore Reef. Marine water quality guideline values (Australian and New Zealand governements 2018) were not exceeded for individual pesticide concentrations.

Detailed results are available in annual technical reports for coral (Thompson et al. 2018, Thompson et al. 2019), seagrass (McKenzie et al. 2018, McKenzie et al. 2019), *in situ* water quality (Waterhouse et al. 2018, Gruber et al. 2019) and pesticides (Grant et al. 2018, Gallen et al. 2019).

Since the 2015-2016 water year, the marine score has been based on averaging scores for water quality from the eReefs models (Robillot et al. 2018) with scores for coral and seagrass condition from the Marine monitoring program. Scores for water quality are generated from eReefs model outputs (Robillot et al. 2018) and are reported separately this year (Robillot et al. 2019).

1. Is water quality improving in the Reef and the regions?

1.1. What happened in the wet seasons?

Most catchment run-off and associated pollutants (primarily nutrients, pesticides and sediment) occurs during the summer wet season (December-April). Cyclones also have a major influence on rainfall and river discharge from rivers in the wet season. In the 2016-2017 year, Severe Tropical Cyclone Debbie, a category 4 system, passed through the Whitsunday Islands and crossed at Airlie Beach in the Mackay Whitsunday region on 28 March 2017 (Bureau of Meteorology 2018a). No cyclones crossed the coast in 2017-2018 but Severe Tropical Cyclone Iris tracked off the coast between Cairns and Rockhampton from mid-March to early April 2018 (Bureau of Meteorology 2018b), resulting in extensive flooding in the Herbert River, and the Burdekin River flowed over the dam.

1.2. How much catchment run-off was there?

Thirty-five major rivers flowing into the Reef lagoon drain an area of 424,000km^2 along the Great Barrier Reef catchment.

In 2016-2017, a number of southern rivers had wet season discharge above their long-term median flow including a majority of rivers in the Mackay Whitsunday region and Fitzroy (coastal catchments) and Burnett Mary regions, largely due to Severe Tropical Cyclone Debbie. The Mackay Whitsunday and Fitzroy regions had two to three times the long-term median discharge, whereas the other four regions had discharge close to the long-term median (Figure 2) (Waterhouse et al. 2018).

In 2017-2018, most regions had annual discharge close to the long-term median, with the exception of above-median discharge in the Burnett Mary region associated with heavy rainfall events in October 2017 and below-median discharge in the Mackay Whitsunday region (Figure 2) (Gruber et al. 2019).

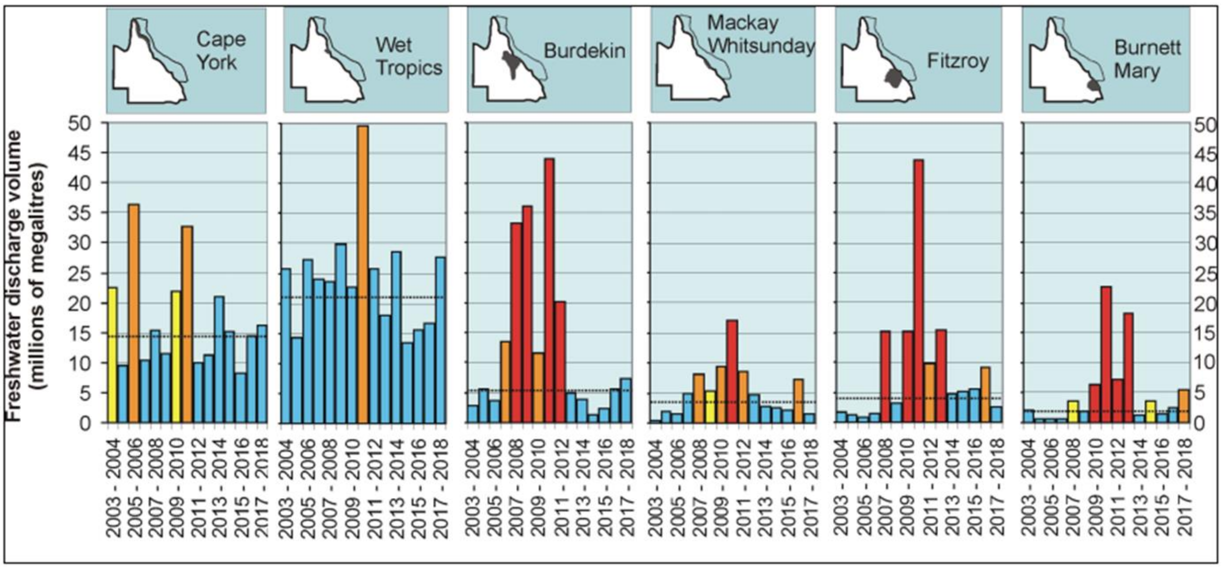

Figure 2. Annual freshwater discharge from major rivers, 2003-2018 Freshwater entering the Great Barrier Reef lagoon has generally been below-average since 2012. Long-term annual total discharge in millions of megalitres (ML) (hydrological year: 1 October to 30 September) for the 35 main Great Barrier Reef rivers, combined for each natural resource management region. Bar colours: Bar colours: ■ = >3 times long term median flow, ■ = 2-3 times, ■ = 1.5-2 times, ■ = <1.5. Black line indicates long-term median for each natural resource management region. Source: Data supplied by Department of Natural Resources, Mines and Energy (https://water-monitoring.information.qld.gov.au/). Compiled by James Cook University (Gruber et al. 2019)

1.1. Where did the run-off go and what was in it?

Catchment run-off contains multiple pollutants (primarily nutrients, pesticides and sediment) and often forms distinctive river plumes, especially with elevated flow events during the wet season (December-April). Plume impacts depend on the area they inundate, how long the plume persists for, the pollutant load that they carry (constituents and concentrations), and whether ecosystems are exposed and sensitive to plumes. Resuspension of material delivered to the marine environment can occur for extended periods of time, primarily by wind, but also by tides.

Modelling and mapping helps us to understand where plumes and resuspension occur (Waterhouse et al. 2018, Gruber et al. 2019). An ocean colour-based model has been used to estimate the dispersion of dissolved inorganic nitrogen and total suspended solids delivered by rivers discharging to Reef waters (Álvarez-Romero et al. 2013) described in (Gruber et al. 2019)). This model, which shows the average dissolved inorganic nitrogen and total suspended solids concentration for marine waters the wet season, revealed that:

- the greatest exposure to high dissolved inorganic nitrogen values occurred in the Wet Tropics region in both years.
- the greatest exposure to high total suspended solids values occurred in the Burdekin region.
- The distribution of three water types (primary, secondary, and tertiary) that correspond to distinguishable colour classes based on satellite imagery were analysed during the wet season. These wet season water types reflect ecological processes influenced by river plumes and resuspension during the wet season (Petus et al. 2019). The mapping of water types revealed the following:

In 2016-2017:

- More than three quarters of the total area of the Marine Park was exposed to combined primary, secondary and tertiary water-types (classified by satellite imagery interpretation equating to the brownish, greenish and greenish-blue turbid waters), respectively), which was a larger area than the long-term average. The four southern regions (Burdekin, Mackay Whitsunday, Fitzroy, Burnett Mary) were most affected (Figure 3) as a consequence of Severe Tropical Cyclone Debbie (Waterhouse et al. 2018).
- Both primary and secondary water types covered less area than the long-term average (i.e. the tertiary water-type was extensive) (Waterhouse et al. 2018).
- Mean concentrations of water quality parameters measured across the wet season water types were generally similar to their long-term average concentrations, although some parameters remain above target concentration (Waterhouse et al. 2018).
- With respect to exceedance of water quality guidelines (Great Barrier Reef Marine Park Authority 2018):
    - mean chlorophyll *a*, and particulate phosphorus were above wet season (event flow) water quality guidelines in the primary and secondary water-types
    - total suspended solids concentrations were above the wet season water quality guidelines in the three water-types, albeit marginally in tertiary waters (Waterhouse et al. 2018).

In 2017–18:

- The total area of the Great Barrier Reef Marine Park exposed to wet season waters was less than the long-term average (Figure 4). Primary and secondary plume-type waters covered much less area than the long-term average (Gruber et al. 2019).

- Mean concentrations of water quality parameters measured across the wet season water types were all below their long-term average monitored concentrations, although some parameters remain above target concentration (Gruber et al. 2019). With respect to exceedance of water quality guidelines (Great Barrier Reef Marine Park Authority 2018):

  - mean chlorophyll a, particulate phosphorus and particulate nitrogen were above wet season water quality guidelines in the primary water type
  - total suspended solids concentrations were above the wet season water quality guidelines in the primary and secondary water type
  - tertiary waters met water quality guidelines (Gruber et al. 2019).

1.2. What was the potential risk to coral and seagrass?

Land-based run-off influences water quality in the Great Barrier Reef with flow-on effects for ecosystem health (Álvarez-Romero et al. 2013, Schaffelke et al. 2017). Modelling and mapping helps us to understand risk to marine ecosystems of exposure to wet season water types (Waterhouse et al. 2018, Gruber et al. 2019). The frequency of exposure to water types is assessed (as a proportion of the 22 weeks of the wet season) and the consequent potential exposure risk to coral and seagrass ecosystems is modelled. Risk is calculated from the proportional exceedance of pollutants to the water quality guidelines (Great Barrier Reef Marine Park Authority 2018) (magnitude score) multiplied by the likelihood of exposure in each of the wet season water types. Exposure risk is termed 'potential' because the risk from surface plumes is not proven to have ecological consequences. Field monitoring characterises and validates the model outputs.

The area and percentage of coral reefs and seagrass meadows potentially affected by different categories of exposure (or potential risk) was calculated for 2016-2017 (Figure 3) and 2017-2018 (Figure 4). In 2016-2017 only 2% of the Reef was in the higher exposure categories (categories III and IV), characteristic of an average wet season. Only 0.2% of corals were in the highest potential exposure category (IV) and only 0.1% of corals were in category III. Ten per cent of seagrasses were in the highest potential exposure category (IV) and 5% were in category III (Waterhouse et al. 2018).

In 2017-2018 the Great Barrier Reef was mostly exposed to the lowest risk categories for sediments and nutrients (potential exposure categories I and II) (Gruber et al. 2019). Consistent with the relatively low river discharge, no corals or seagrass were exposed to the higher risk category (potential exposure category IV) and only 0.1% of coral reefs and 6 % of seagrasses were in category III in this year.

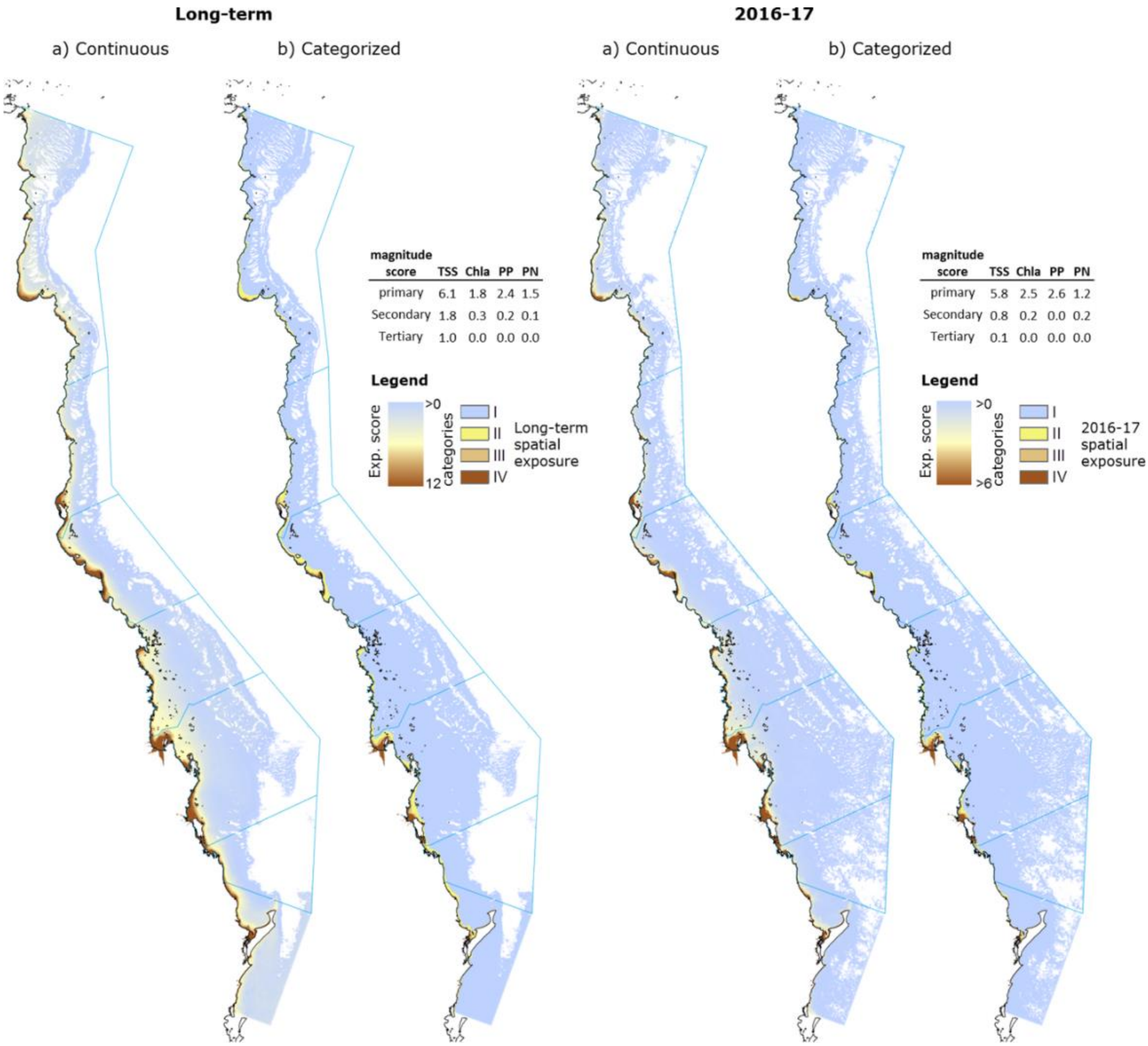

Figure 3. Long-term (2003-2017) and 2016-2017 maps of potential exposure risk categories: a) continuous exposure scores and b) categorised exposure scores : [>0-3] = cat. I, [3-6] = cat. II, [6-9] = cat III and [> 9] = cat IV Reproduced from (Waterhouse et al. 2018).

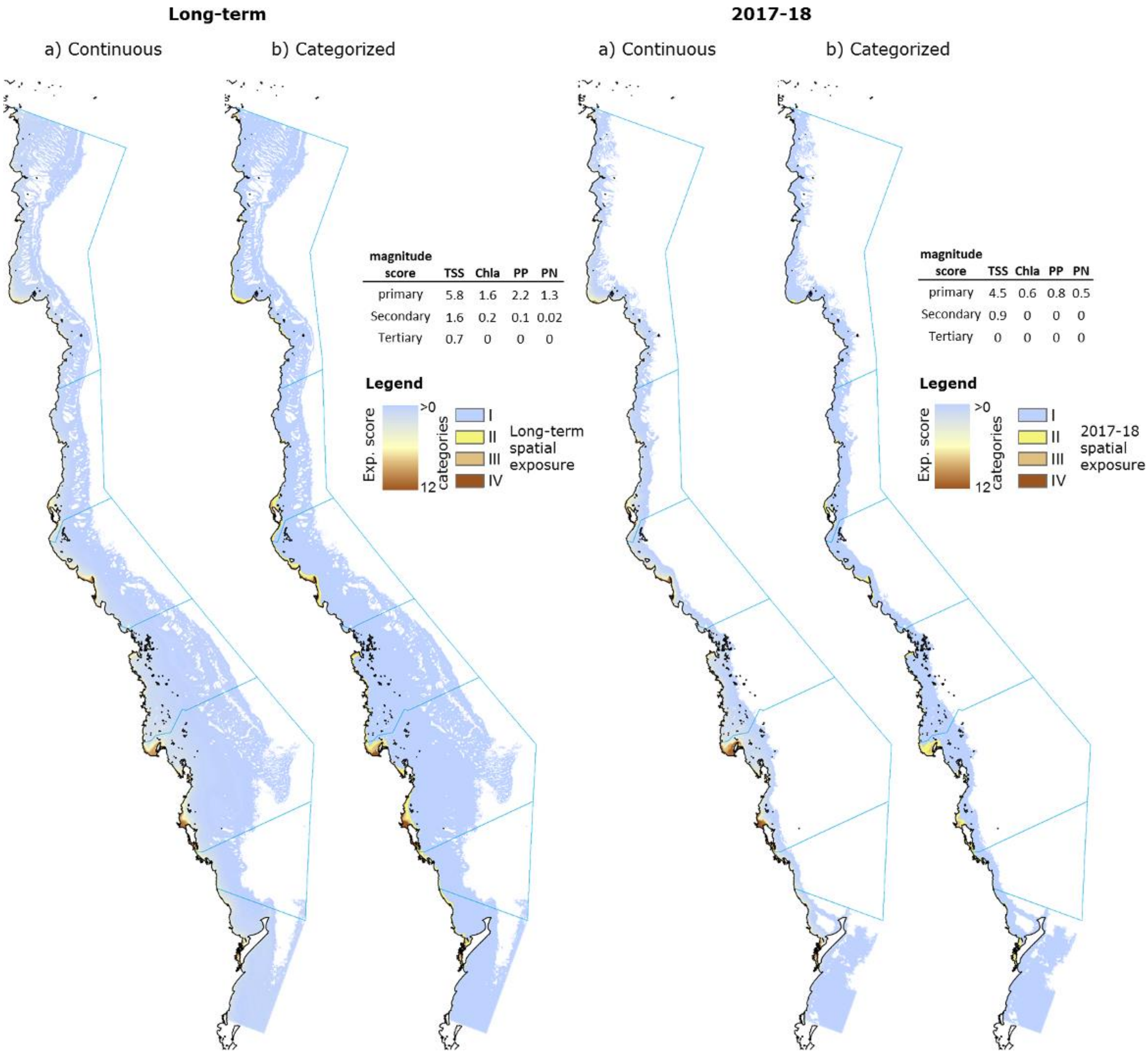

Figure 4. Long-term (2003-2018) and 2017-18 maps of potential risk exposure: a) continuous exposure scores and b) categorised exposure scores: [>0-3] = cat. I, [3-6] = cat. II, [6-9] = cat III and [> 9] = cat IV. Reproduced from (Gruber *et al.* 2019).

1.3. Inshore water quality from *in situ* monitoring

In situ monitoring of water quality has been conducted since 2005 in the Wet Tropics (Barron Daintree, Mulgrave-Russell and Tully focus areas), Burdekin and Mackay Whitsunday regions. The Fitzroy and the Burnett Mary regions are not routinely monitored, although historic data has been archived and is available in reports (Devlin et al. 2011, Devlin et al. 2015, Waterhouse et al. 2018, Da Silva et al. 2013).

Changes to the sampling design post-2015 (more sites, more sampling during the wet season, and additional sites further inshore) allow improved characterisation of wet season conditions and water quality in the inshore Reef. The sampling regime is not representative of the entire inshore Reef, and consequently is not summed to Reef level, or used to derive the water quality metric for the Reef Water Quality Report Card 2017 and 2018. The inclusion of water quality monitoring in Cape York will enable reporting of a condition and trend for that region in the future.

Observations from the inshore water quality monitoring demonstrate that long-term changes in water quality in many regions. In particular, concentrations of organic carbon and particulate nutrients have increased, while Secchi depth has decreased; i.e. water clarity has worsened in most regions since 2005 (Gruber et al. 2019).

Increases in dissolved organic carbon concentrations have occurred since 2005 in Great Barrier Reef waters (Waterhouse et al. 2018, Gruber et al. 2019). This suggests that either the inputs of dissolved organic carbon and/or the transformation rates of dissolved organic carbon have changed since 2005. Most of the dissolved organic carbon pool in the Great Barrier Reef is derived from phytoplankton production, and therefore increases in plankton community production would result in elevated dissolved organic carbon concentrations. In addition, plankton communities have been shown to increase their dissolved organic carbon production in response to environmental stress (for example, changing light, temperature, and nutrient conditions) and/or changes in the plankton community structure (Gruber et al. 2019). .

Although productivity experiments have been conducted periodically in the Reef lagoon, no long-term monitoring of productivity is available to test this hypothesis. Increases in the coastal dissolved organic carbon pool could be related to changes in catchment loads from changing land management use (Darnell et al. 2012), but again there is no monitoring data on dissolved organic carbon loads from Great Barrier Reef catchment rivers since 2005.

Measured increases in dissolved organic carbon are nonetheless concerning, as they could impact benthic ecological communities. Dissolved organic carbon constitutes the major carbon source for heterotrophic microbial growth in marine pelagic systems and increases in dissolved organic carbon have previously been shown to promote microbial activity and coral diseases (Kline et al. 2006, Kuntz et al. 2005).

Water quality results for parameters measured at individual sites, and comparison with water quality guidelines on a sample-by-sample basis, is provided in the annual technical reports (Waterhouse et al. 2018, Gruber et al. 2019).

An *in situ* water quality index based on monitoring data (oxidised nitrogen, particulate nitrogen, particulate phosphorus, chlorophyll *a*, total suspended solids, turbidity and Secchi depth) shows changes in water quality since 2005 (Figure 5). The *in situ* water quality index combines five indicators and scores them relative to water quality guidelines (Great Barrier Reef Marine Park Authority 2018, State of Queensland 2016a) – the index is used to communicate both the long-term trend in water quality (less sensitive to year-to-year variability such as river flow) and the annual condition (more sensitive to year-to-year variability).

Scores for the long-term trend (circles in Figure 5) are calculated based on the program design pre-2015, which had a limited number of sites visited three times per year. Scores are based on exceedance of annual water quality guidelines (Great Barrier Reef Marine Park Authority 2018) and a four-year running mean is applied to focus on the long-term trend and reduce the effect of sampling time.

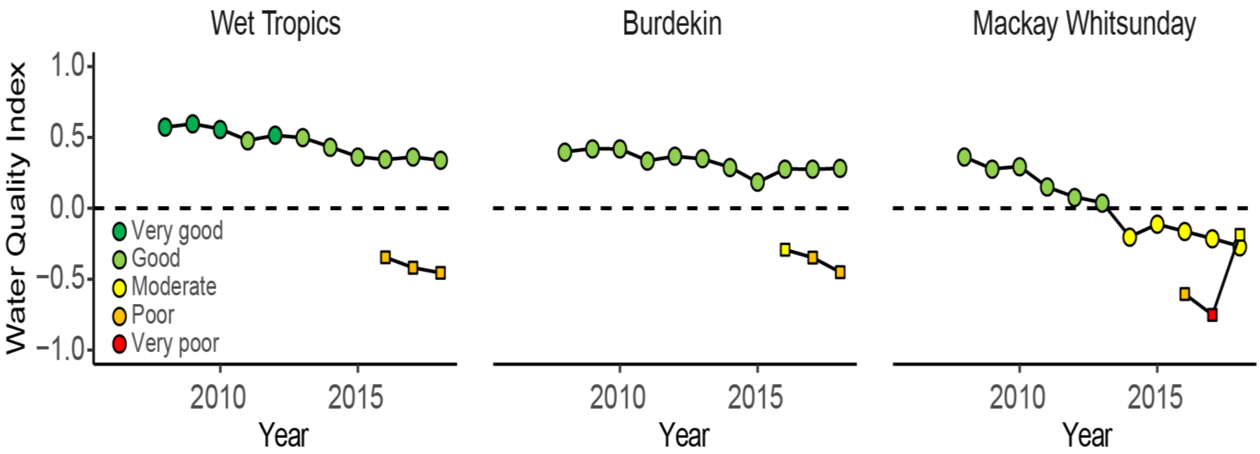

Figure 5. ***In situ*** **water quality index for the Wet Tropics, Burdekin and Mackay Whitsunday regions from 2007-2008 to 2017-2018 circle symbols indicate the 'long-term' trend since the start of monitoring based on an initial program design. From 2015 a revised program design was implemented that includes increased temporal and spatial sampling and compares water quality values to wet and dry season water quality guidelines where available (squares). Colour coding: ■ = very good (> 0.5 to 1), ■ = good (> 0 to 0.5), ■ = moderate (<0 to -0.33), ■ = poor (< -0.33 to -0.66), ■ = very poor (< -0.66 to -1). Data source: (Gruber et al. 2019).**

This version of the index (which is less sensitive to year-to-year environmental variation) shows inshore water quality has:

- declined gradually in the Wet Tropics region from very good to good
- remained stable in the Burdekin region in good condition
- declined in the Mackay Whitsunday region, with condition changing from good to moderate in 2013-2014 (Gruber et al. 2019).

From 2015-2016, scores for annual condition (squares in Figure 5) have been calculated based on a new program design that includes a larger number of sites visited five to ten times per year (with more sampling during the wet season to better represent dynamic wet season conditions). These sites are located along expected water quality gradients related to exposure to terrestrial run-off. Annual scores are calculated based on exceedance of wet and dry season water quality guidelines (i.e. samples collected during the wet season are scored against wet season water quality guidelines) and a running mean is not applied (Gruber et al. 2019). This version of the index (which is sensitive to year-to-year environmental variation) showed very poor scores in the Wet Tropics and Burdekin, and a moderate score in the Mackay Whitsunday region (squares in Figure 5).

1.4. What about pesticides?

A range of pesticides continues to be detected at 11 monitoring sites, although no data were collected from Normanby Island in 2016-2017 (Figure 6). In line with previous years, diuron, atrazine and hexazinone were the most frequently detected pesticides at high concentrations at most sites (Grant et al. 2018, Gallen et al. 2019).

Region-specific differences in pesticide profiles have emerged over time. Diuron typically dominates the pesticide profile at sites in the Wet Tropics and Mackay Whitsunday regions, atrazine and its metabolites have dominated the profile at Barratta Creek (Burdekin region) and tebuthiuron has dominated the profile at North Keppel Island (Fitzroy region), albeit at very low concentrations in the two reporting years (Figure 6) (Gallen et al. 2019).

Figure 6. Maximum concentrations of individual pesticides at all sites monitored in 2017-2018 compared to previous years (2009-2010 onwards) in the Wet Tropics (upper panel) and the Burdekin, Mackay Whitsunday and Fitzroy (lower panel). Note that the scale of the vertical axis differs between the panels. Several pesticides were recently added to the analysis suite and are only included in the relevant years (2014-2015 onwards). *Dates with an asterisk are not representative values due to incomplete wet season sampling and should be interpreted with caution. Source: (Gallen et al. 2019)

Pesticide concentration data are evaluated in two ways:

- **Exceedances:** time-averaged concentrations of individual pesticides are compared against their corresponding water quality guideline values that are set for the protection of high ecological value aquatic ecosystems; i.e. protection of at least 99% of marine species (Australian and New Zealand governments 2018). Note that the exceedance of a guideline value from passive samplers indicates that exceedances occurred, on average, for the whole deployment period (1-2 months). This has a much higher potential impact to the ecosystem than, for example, a single recorded exceedance from a grab sample. For time-averaged detections below guideline values, exceedances may have occurred on a shorter time-scale relative to the deployment period, e.g. from pulses of peak concentrations corresponding with flood events. This would be particularly true for time-averaged detections close to, but not exceeding, the guideline values.
- **Mixtures:** 2017-2018 is the first year for reporting using a new method – the multisubstance potentially affected fraction method (Traas et al. 2002; Warne et al. 2018). From the measured concentrations of 19 pesticides, the percent of species protected (and conversely that may be affected) from the combination of the pesticides detected were determined (Gallen et al. 2019). The remaining 11 pesticides detected do not have all the available information required to be able to include them in the assessment at this time.

The water quality guideline values for high ecological value aquatic ecosystems including the Marine Park and the Great Barrier Reef World Heritage Area are set to protect at least 99% of species (i.e. no more than 1% of species affected). No individual exceedances of the current marine guideline values (Australian and New Zealand governments 2018) were detected in either year (Grant et al. 2018; Gallen et al. 2019), although some of the guidelines values are undergoing review (King et al. 2017a; King et al. 2017b). Comparing against the proposed default guideline values (King et al. 2017a; King et al. 2017b) would result in a number of exceedances for diuron.

All of these exceedances were from passive samplers located at Round Top Island, in the Mackay Whitsunday region. Comparison to the proposed diuron guideline value of 430ng L^{-1} (King et al. 2017a), there was one exceedance (580ng L^{-1}) in 2016-2017, and two (778ng L^{-1} and 531ng L^{-1}) in 2017-2018. Using the multisubstance potentially affected fraction (ms-PAF) method of assessment, the extreme value corresponded to very high risk (protective of less than or equal to 80% of species, or greater than or equal to 20% of species potentially affected) and the others to high risk (protective of greater than 80% but less than 90% of species, or 10 to less than 20% of species affected). It should be noted that these high concentrations were recorded during the wet season deployments, dry season deployments demonstrate a very low risk of pesticides at this site.

In addition, Round Top Island had the highest concentrations for 17 of 26 pesticides (found above the limit of detection) across all sites sampled in 2016-2017. It is an anomalous hotspot among the 11 sampling locations and worthy of follow-up investigation. Other monitoring sites in the Mackay Whitsunday region recorded a lower risk (greater than or equal to 95% species protection) at Repulse Bay, Sandy Creek, and Sarina Inlet. However, due to a number of sampler losses during the wet season in this region, some pesticide exceedances may not have been recorded and/or pesticide risk may be underestimated. For example, at Repulse Bay (2016-2017) and Sandy Creek (2017-2018) only one and zero wet season samples were obtained, respectively, due to sampler losses and deployment issues.

Wet Tropics sites recorded a low to very low risk throughout the year, whereas the risk recorded in the end-of-catchment monitoring ranged from moderate to very low risk (depending on catchment land-use) (Ten Napel et al. 2019a, Ten Napel et al. 2019b). Grab sampling in this region showed that elevated concentrations were localised near river mouths and these concentrations decreased with increasing distance from the river mouth (Gallen et al. 2019).

Other sites, North Keppel Island (Fitzroy) and Barratta Creek mouth (Burdekin) indicated very low and low risks of pesticides at these sites, respectively.

1.5. How does water quality affect the Reef?

The premise underpinning the Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) is that pollutants delivered by rivers suppress ecological resilience. For example, a correlation between low rainfall, low river flows and coral recovery has been observed in the Burdekin region from 2013 to 2018, where coral condition improved from poor to moderate (Waterhouse et al. 2017b; Australian and Queensland government 2017, Thompson et al. 2019).

Local environmental conditions including water quality influence the benthic communities found on coastal and inshore reefs. Enhanced levels of suspended sediment and chlorophyll *a* (and thus reduced water clarity) affect coral and seagrass growth, health and survival both directly and indirectly (reviewed in (Gruber et al. 2019; Schaffelke et al. 2017; Waterhouse et al. 2017a)). Potential impacts include:

- sediment exposure can lead to impaired functional performance, burial of organisms, and increase susceptibility to disease (Fabricius et al. 2016, Brodie et al. 2017, Schaffelke et al. 2017, Pollock et al. 2014)
- nutrients discharged during flood events can increase the susceptibility of corals to disease and thermal stress (Haapkylä et al. 2011, Wiedenmann et al. 2013), and affect coral reproduction (Fabricius 2005). Nutrients can also reduce light for seagrass and coral (Fabricius 2005, McKenzie et al. 2018), and promote fleshy macroalgae growth in some areas (Thompson et al. 2017, Fabricius et al. 2005, Schaffelke et al. 2017). Nutrient enrichment has also been associated with the initiation of coral eating crown-of-thorns outbreaks (Pratchett et al. 2017)
- pesticides can harm coral, seagrass and other organisms; mostly through sub-lethal effects on physiological performance rather than acute toxicity. The cumulative effects of long-term exposure to multiple pesticides are not well understood, but there is potential for chronic exposure to reduce the resilience of Reef ecosystems (Grant et al. 2018, Smith et al. 2012).

The *2017 Scientific Consensus Statement: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef* (Waterhouse et al. 2017b) concluded that:

- "Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land run-off associated with past and ongoing catchment development, coastal development activities, extreme weather events and climate change impacts such as the 2016 and 2017 coral bleaching events..."
- "The decline of marine water quality associated with land-based run-off from the adjacent catchments is a major cause of the current poor state of many of the coastal and marine ecosystems of the Great Barrier Reef. Water quality improvement has an important role in ecosystem resilience."
- "Periods of reduced catchment run-off associated with low rainfall demonstrate the inherent ability of inshore reef communities to recover from acute disturbances. This provides a strong case for reducing the pollutant loads being delivered to the Great Barrier Reef."

2. What is the condition and trend of inshore coral?

2.1. Coral condition in the inshore Reef

Coral condition shown by the inshore Great Barrier Reef coral scores remained moderate in the Wet Tropics, Burdekin, Mackay Whitsunday regions and poor in the Fitzroy region in 2016-2017 and 2017-2018 (Table 2). In contrast to the stability of the overall score, the five indicators contributing to the coral index showed considerably more change between years and among regions.

2.2. Trends for coral in the inshore Reef

Coral scores for the inshore Great Barrier Reef declined slightly in 2016-2017 and 2017-2018 (Figure 7), attributable to Severe Tropical Cyclone Debbie and coral bleaching (Thompson et al. 2019). Nonetheless, overall condition remains moderate and is within the range of variation observed over the previous decade.

Trends in the five indicators that generate the coral condition for the inshore Great Barrier Reef are mixed. In brief:

- Mackay Whitsunday reefs showed the greatest change, declining while remaining in moderate condition (Table 2). The declining scores for all indicators except juvenile density can be attributed to Severe Tropical Cyclone Debbie and continued high water turbidity.
- Inshore reefs in the Fitzroy region showed modest improvements across all indicators except coral cover (Table 2). Overall, they remain in poor condition but have improved since 2012-2014. A combination of high water temperatures in 2016 and 2017 and flooding in 2017 may have stalled this recovery (Thompson et al. 2019).

Table 2. Coral scores for the inshore Great Barrier Reef and natural resource management regions in 2016-2017 and 2017-2018.

Region (inshore)	Year	Coral cover	Coral change	Macroalgal cover	Juvenile density	Community composition	Coral score
Great Barrier Reef	2016-2017	37	48	53	36	41	43
	2017-2018	36	47	41	39	43	41
Cape York	2016-2017						
	2017-2018						
Wet Tropics	2016-2017	47	75	59	50	46	55
	2017-2018	50	71	58	51	56	57
Burdekin	2016-2017	34	56	26	54	60	46
	2017-2018	37	57	26	50	57	45
Mackay Whitsunday	2016-2017	37	43	93	34	53	52
	2017-2018	32	37	60	32	47	42
Fitzroy	2016-2017	31	32	8	26	17	23
	2017-2018	30	41	13	34	25	29
Burnett Mary	2016-2017						
	2017-2018						

Note: The Great Barrier Reef inshore coral score is the average of scores for five indicators. Grey shading indicates that there is no coral monitoring occurring in the Cape York or Burnett Mary. 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. Data source: (Thompson et al. 2019)

2.3. What does this tell us about water quality and coral resilience?

Coral reef communities vary along water quality gradients. Communities found on coastal and inshore reefs differ markedly from those found in clearer, offshore waters (Done 1982, Wismer et al. 2009). Pressures imposed by high turbidity and nutrient availability variously support, or select against, different species of corals and their competitors, such as macroalgae. In the inshore areas of the Great Barrier Reef, high macroalgae cover persists where high chlorophyll *a* concentration exceeds water quality guidelines (Great Barrier Reef Marine Park Authority 2018). At reefs where high levels of macroalgae become established the recovery of coral communities can be curtailed. There is the potential for this to result in phase shifts at these reefs. Where turbidity is high, light-sensitive species don't occur, or are lost, affecting coral community composition (De'ath and Fabricius 2010).

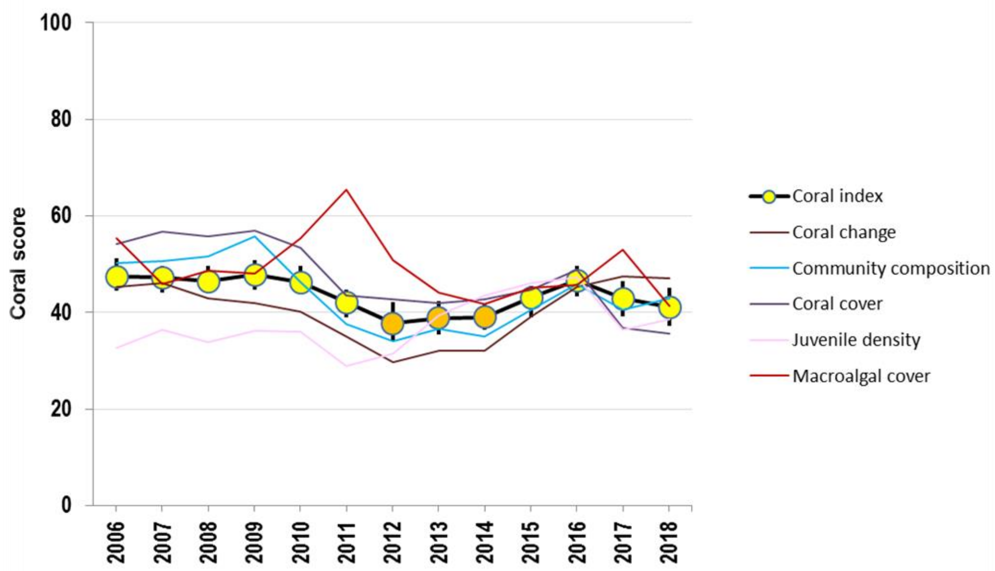

Figure 7. Trends in coral scores for the inshore Great Barrier Reef from 2006 to 2018. The score for the Reef is derived from the average of scores for the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent 95% confidence limits. Note: Scores are unitless. The overall coral score is the average of the component scores for combined hard and soft coral cover, coral change, proportional macroalgal cover, juvenile density and coral community composition. Data includes monitoring in the Marine monitoring program and the Australian Insitute of Marine Science Long-term Monitoring Program. Data source: (Thompson et al. 2019).

In addition to water quality effects, acute disturbances such as cyclones, bleaching, and coral eating crown-of-thorns starfish outbreaks significantly affect coral condition. The combined impact of these disturbances and a series of high discharge years (Figure 2) reduced coral condition to poor between 2012-2014 (Thompson et al. 2019). The trend after 2014 showed evidence of recovery (Thompson et *al.* 2019) until the impacts of Severe Tropical Cyclone Debbie in 2017 and coral bleaching (Great Barrier Reef Marine Park Authority 2017, Hughes et al. 2019).

Analysing periods free from acute disturbance events, when reefs do recover, showed that coral recovery has an inverse relationship to discharge from local catchments. In three of the four natural resource management regions (Wet Tropics, Burdekin, and Fitzroy), catchment loads of nitrogen and phosphorus correlated with temporal changes in scores (Thompson et al. 2019). While this does not provide clear guidance in terms of the load reductions required to improve inshore coral condition, the results are consistent with the central premise of the Reef 2050 WQIP that the loads entering the reef, during high rainfall periods, are reducing the resilience of these communities. The potential for phase shifts or delayed recovery in combination with expected increase in disturbance frequency reinforces the importance of reducing local pressures to support the long-term maintenance of these communities (Thompson et al. 2019).

3. What is the condition and trend of inshore seagrass?

3.1. Seagrass condition in the inshore Reef

Overall, inshore seagrass condition remained poor in 2017-2018, despite declining from the previous year (Table 3). This overall score reflects the moderate condition of seagrass in the Burdekin region, despite declining between the years; as did Cape York and Mackay Whitsunday. In contrast, seagrass scores improved in the Wet Tropics and remained stable in Fitzroy and Burnett Mary. A small decline in the latter region shifted the condition assessment across the boundary between poor and very poor.

Table 3. Seagrass scores for the inshore Great Barrier Reef and natural resource management regions in 20160-2017 and 2017-2018.

Region (inshore)	Year	Abundance	Reproduction	Nutrient status	Seagrass score
Great Barrier Reef	2016-2017	46	15	46	36
	2017-2018	42	12	32	29
Cape York	2016-2017	46	10	47	34
	2017-2018	40	6	30	25
Wet Tropics	2016-2017	28	2	35	22
	2017-2018	40	33	35	36
Burdekin	2016-2017	70	38	54	54
	2017-2018	62	33	45	47
Mackay Whitsunday	2016-2017	32	33	34	33
	2017-2018	29	9	25	21
Fitzroy	2016-2017	27	0	44	24
	2017-2018	35	0	30	22
Burnett Mary	2016-2017	29	0	33	21
	2017-2018	33	0	24	19

Note: The Great Barrier Reef inshore seagrass score is the average of scores for three 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. (McKenzie et al. 2019).

3.2. Trend for seagrass in the inshore Reef

While the average condition in 2017-2018 was less than the levels seen in the previous four years, it remains within the range of variation observed since the start of monitoring (Figure 8). As noted above, regional scores for inshore seagrass showed a complex pattern and mixed picture of change (Table 2). Briefly:

- Seagrass abundance declined in Cape York and Burdekin regions; increased in the Wet Tropics and Fitzroy regions; and showed little change in Mackay Whitsundays and

Burnett Mary regions, despite starting from different conditions (Cape York – moderate; Burdekin – good; elsewhere – poor).

- Reproductive scores increased in the Wet Tropics (very poor to poor) and decreased by a similar amount in Mackay Whitsunday (poor to very poor). There was little change in the other four regions despite Burdekin remaining poor and the others very poor. Scores of zero were recorded for the Fitzroy and Burnett Mary regions.
- Seagrass nutrient status declined in Cape York and Fitzroy regions (moderate to poor), Burdekin (remaining moderate), Mackay Whitsundays and Burnett Mary (both remaining poor). Against the trend, it remained stable in the Wet Tropics region (Table 3).

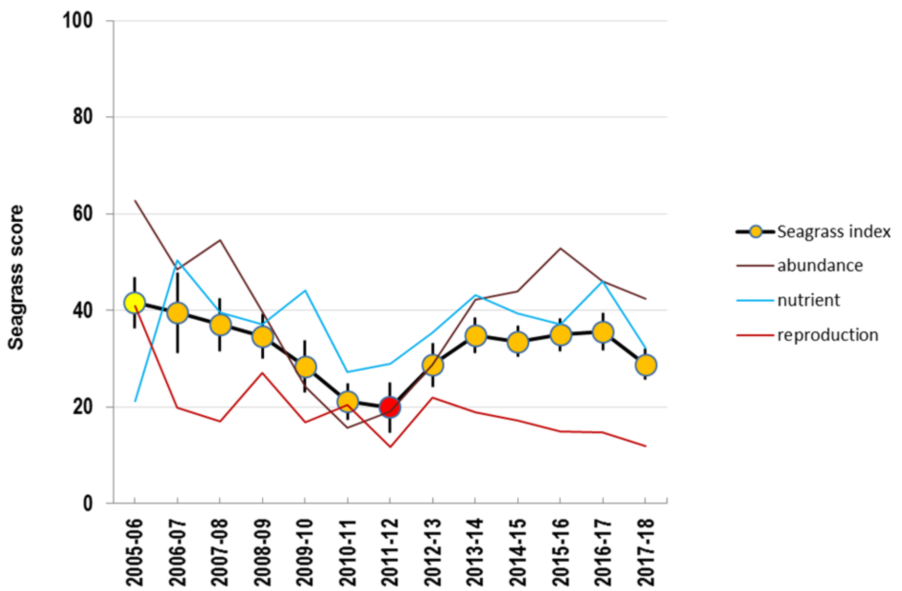

Figure 8. Trends in seagrass scores for the inshore Great Barrier Reef from 2006 to 2018. The score for the Reef is derived from the average of scores for the six natural resource management regions. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent standard error. Note: Scores are unitless. The overall seagrass score is the average of the component scores for abundance, nutrient status (C:N ratio) and reproduction. Data source: (McKenzie et al. 2019).

Of the three condition indicators, abundance has had the greatest leverage on the combined score (Figure 8). Over the 13 seasons of monitoring, abundance has rebounded significantly from a nadir in 2011-2012 that followed multiple disturbances. Despite the partial recovery of abundance, meadows are vulnerable to further disturbances because of their limited capacity to recover from seed (i.e. low resilience) (McKenzie et al. 2019).

3.3. What does this tell us about seagrass resilience?

Recovery of seagrass meadows is proceeding slower than expected (McKenzie et al. 2019). This is likely due to frequent disturbances during the past decade with Severe Tropical Cyclone Yasi reducing the average seagrass score to its lowest level (very poor) in 2011-2012 (Figure 8). While seagrass meadows are inherently dynamic, their poor recovery rates at many locations and poor resilience (e.g. reproductive effort and seed density) may also affect recovery from future disturbances. Reproductive scores have declined since the start of the Marine monitoring program (Figure 8). Low reproductive effort will hinder replenishment of seed banks, which are therefore likely to remain low in coming years.

Vigorous recovery of seagrass meadows requires optimum conditions of light and nutrient availability, and the absence of major physical disturbances such as cyclones or even excessive sediment resuspension (Van Katwijk et al. 2010). For example, the lower than average light (as measured on-site since monitoring began) and variable light availability in 2014-2015, 2016-2017 and 2017-2018 has probably slowed recent recovery. It may have affected the generation of seed banks in some locations as recovering meadows allocate resources to vegetative growth before reproduction. The seagrass leaf tissue nutrient indicator, while showing no clear trend over time, suggests that excess nitrogen exists at most locations, relative to the rate at which the leaves are growing and incorporating carbon.

The Wet Tropics and Fitzroy regions have shown the slowest recovery rates, although this is for different reasons. In the Fitzroy region, declines up to early 2011 were more moderate than elsewhere, but the estuarine intertidal and coastal intertidal habitats declined further in 2013–15, and recovery has since been slow except in coastal habitats. Abundance in the Wet Tropics declined in early 2011, and recovery has been delayed. In the southern Wet Tropics, it appears that sediment scouring caused by Severe Tropical Cyclone Yasi in 2011 altered bed elevation and substrate composition, however the growth substrate is not routinely measured. By contrast, slow recovery in the northern Wet Tropics reef sites (Low Isles intertidal and subtidal and Green Island subtidal) may be affected by water quality (McKenzie et al. 2019).

4. What does this tell us about the Reef's resilience?

Nutrients in catchment run-off have increased markedly since European settlement (Kroon et al. 2012; Waters et al. 2014). River discharge carrying pollutants in water from run-off (especially sediment, nutrient and pesticides) influences coral reef and seagrass condition. Responses depend on exposure, sensitivity and resilience of particular species. Monitoring shows that ecosystems can recover following disturbances when catchment loads are low (McKenzie et al. 2019; Thompson et al. 2019).

In addition to catchment run-off, there are a range of other confounding pressures affecting the health and resilience of the Reef at local and regional scales (Great Barrier Reef Marine Park Authority 2014) which are likely to impact on corals and seagrasses including:

- high physical damage and sedimentation caused by cyclones
- high sea temperatures
- coral eating crown-of-thorns starfish (for corals)
- reduced daily light.

While weather is a major driver of pressures from water quality, and can vary substantially between years, climate change is the primary threat to the Great Barrier Reef. Marine heatwaves and severe storms and cyclones have affected coral and seagrass in this reporting period. Severe Tropical Cyclone Debbie's impact followed the predicted pattern for cyclone wave damage on coral reefs. Since the Marine monitoring program began, ten cyclones of category 3-5 strength have crossed the Great Barrier Reef. The interval between severe disturbances is decreasing, which is limiting opportunities for recovery.

Seagrass meadows are less vulnerable to temperature than coral reefs, which bleach when exposed to sea temperatures just one degree Centigrade above the climatological average. However, 40°C is a critical canopy temperature threshold for photoinhibition and acute temperature stress for seagrass (Campbell et al. 2006). Growth reduction can occur in some species from prolonged warm water exposure (Collier et al. 2011, Collier et al. 2016).

Both the number of degrees above the monthly long-term average temperature and the duration of exposure to those temperatures is relevant to the responses of the corals. Exposures of 4 degree-heating-weeks, or greater, is commonly accepted as the threshold for significant bleaching to occur (i.e. two weeks at 2°C above, or four weeks at 1°C above, would both cross this threshold). Mortality can be expected above 8 degree-heating-weeks (Eakin et al. 2010, Liu et al. 2014, Kayanne 2017).

Consecutive thermal stress events in 2015-2016 (data not shown) and 2016-2017 (Figure 9) caused mass coral bleaching in the northern two thirds of the Reef. Aerial surveys indicated that the 2016-2017 mass coral bleaching event extended further south than the 2015-2016 event, with the most severe bleaching occurring from Cooktown south to Townsville (as well as some isolated instances in the Mackay region). Some reefs that were not heavily impacted in 2015-2016 were severely impacted in the 2016-2017 event (Great Barrier Reef Marine Park Authority 2017, Hughes et al. 2019).

Post-event analysis found that ecological memory modified the impact of the recurrent climate extremes (i.e. it took hotter temperatures to bleach corals in the second event) (Hughes et al. 2019). This meant that losses of shallow water coral cover were not as extreme as the 50% losses initially estimated from aerial survey bleaching assessment. The reduced effects of the second heatwave may be partially explained by the loss of heat-sensitive species (i.e. community shifts). Regardless, mortality levels were unprecedented (Great Barrier Reef Marine Park Authority 2017, Hughes et al. 2019) which is concerning given the predicted increase in marine heatwaves, and this continues to be a priority area for ongoing research.

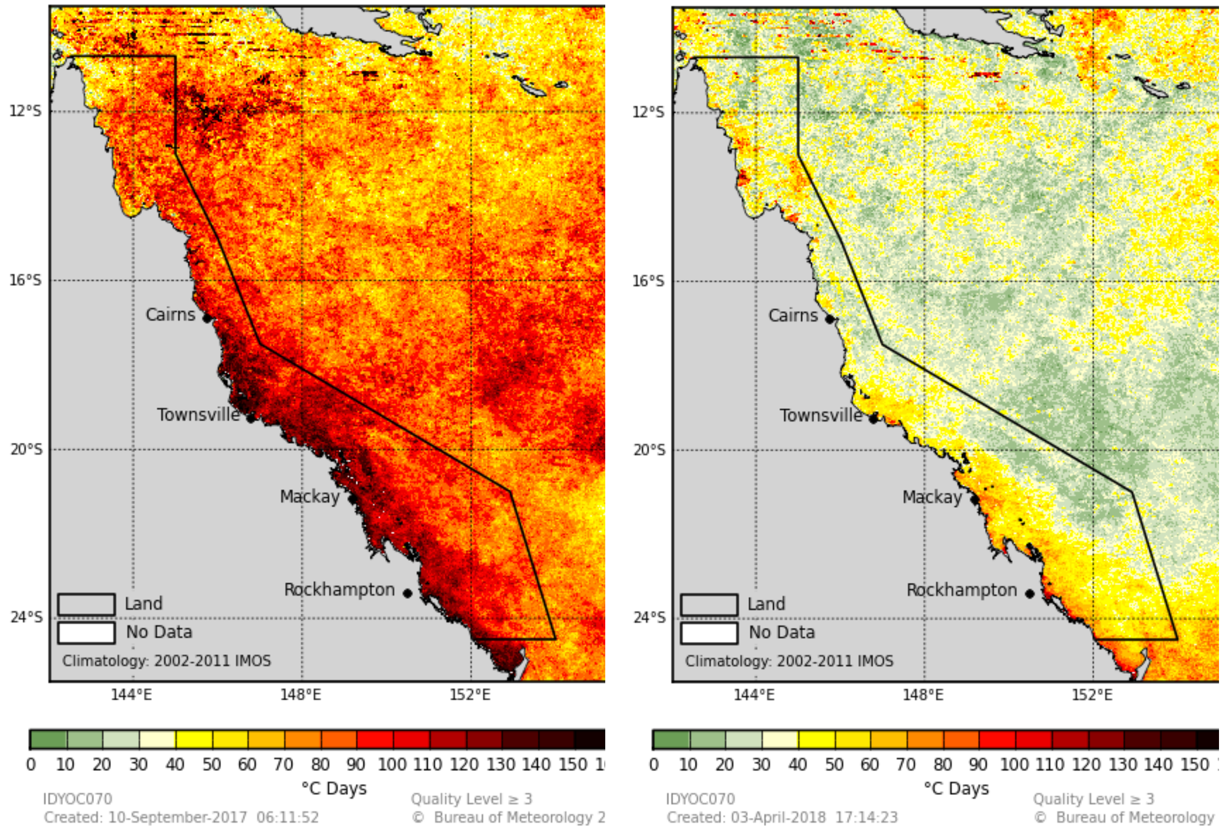

Figure 9. Accumulation of summer thermal stress (1 December until 31 March) in 2016-2017 (left) and 2017-2018 (right) based on degree heating days (14 day IMOS climatology). Data source: ReefTemp, Bureau of Meteorology.

The 2017-2018 sea surface temperatures were not as extreme, but some inshore areas experienced above average temperatures. Thermal stress accrued throughout the Great Barrier Reef, particularly in the far northern and southern management regions, as well as the inshore regions of the central management area (Figure 9). Projections for the future as the world continues to warm place coral reefs at high to very high risk (Frieler et al. 2013).

While the southern section was minimally affected by bleaching, an increase in coral eating crown-of-thorns starfish outbreaks in 2017 caused coral cover to decline there (Australian Institute of Marine Science 2018b). The spatial extent of known coral eating crown-of-thorns starfish outbreaks in the northern sections of the Great Barrier Reef Marine Park was already considered to be extensive prior to that date. In the Wet Tropics, there was ongoing pressure from coral eating crown-of-thorns starfish at High Island and in the Frankland Group observed from monitoring (Thompson et al. 2019). The current coral eating crown-of-thorns starfish outbreak started in 2010, but this was the fourth outbreak since the 1960s (Pratchett et al. 2014). Outbreaks have caused extensive coral decline, and are thought to pose a high risk to coral (De'ath et al. 2012). These waves of secondary outbreaks can spread 60km per year and can persist for more than 10 years (Vanhatalo et al. 2017). The recovery of coral reefs following coral eating crown-of-thorns starfish outbreaks can take up to a decade.

Land management and coastal development are still affecting water quality in the Great Barrier Reef (State of Queensland 2016b, Waterhouse et al. 2017b) through the ongoing modification of coastal ecosystems (clearing or modifying catchments, mangroves and other coastal habitats). The condition of the Great Barrier Reef into the future is reliant upon the healthy functioning of multiple chemical, physical and ecological processes and connection to functioning coastal ecosystems.

5. Regional results

5.1. Cape York

Pressures

During both 2016-2017 and 2017-2018 wet seasons, freshwater discharge from the rivers were either at, or slightly above, the long-term median levels (Figure 2). However regular rainfall and flooding influenced water quality at field sites close to the river mouths on many occasions in the wet season.

Most of the 2017-2018 Annan-Endeavour rivers flood plumes hugged the coast and flowed north. However, on at least one occasion, plume water reached mid-shelf reefs.

Cumulative exposure modelling and mapping from eReefs showed that the Normanby River discharge (in 2017-2018) heavily affected inshore waters in Princess Charlotte Bay, and reached mid-shelf, and even offshore waters in some areas (Gruber et al. 2019).

Maximum seagrass within-canopy temperatures exceeded 35°C in both years (McKenzie et al. 2018, McKenzie et al. 2019):

- For 58 days in 2016-2017, with high temperatures. Canopy temperatures exceeded 38°C for 11 days, but no temperatures over 40°C occurred. This is the longest sustained period of elevated canopy temperature recorded at the Cape York sites
- For 30 days in 2017-2018, with one day where 40°C was exceeded in the canopy. The low frequency at which these high temperatures occurred indicates burning or mortality was unlikely.

Water quality based on in situ monitoring

Monitoring occurs in marine waters adjacent to the Endeavour catchment, Normanby catchment, Stewart River and Pascoe River mouths. Sampling generally occurs between November and June as high winds restrict access at other times. Full implementation of this program in the Cape York focus area provides a baseline for the region. There is not enough data to assess long-term trends yet.

Monitoring at specific sites showed variability in meeting draft Eastern Cape York water quality objectives (Department of Environment and Heritage Protection 2017). Table 4 shows wet season comparisons for inshore waters and grey cells indicate where there has been an exceedance of a water quality objective value during any period within the wet season. Exceedances also occurred in mid-shelf waters (at times), while offshore waters met water quality objectives. Exceedances reported in Table 4 may be over-estimated, since wet season water quality objectives are not designed to be applied in flood events. It is difficult to differentiate ambient wet season conditions from events at some of the time in the wet season, due to regular freshwater inflow from rivers.

Table 4. Sites monitored in Cape York inshore waters where wet season mean or median concentrations of chlorophyll *a*, total suspended solids (TSS), particulate phosphorus (PP) and oxidised nitrogen (NO_x) did or did not meet inshore water quality objectives (Department of Environment and Heritage Protection 2017) at one or more times of sampling (grey shading indicates not met).

Cape York River	Chlorophyll *a*		TSS		PP		NO_x	
	2016-2017	2017-2018	2016-2017	2017-2018	2016-2017	2017-2018	2016-2017	2017-2018
Pascoe					NA	NA		
Stewart								
Normanby								
Annan-Endeavour								

Data source: (Waterhouse et al. 2018; Gruber et al. 2019). NA = not assessed

Flood plume sampling in both years (although limited in 2016-2017) showed exceedance of total suspended solids and chlorophyll *a* water quality objectives (Waterhouse et al. 2018, Gruber et al. 2019). In 2017-2018:

- chlorophyll *a* and particulate phosphorus concentrations in the primary water type were just above wet season water quality objectives
- nutrient concentrations in event samples were highly elevated above background concentrations.

During March 2018, a flood plume from the Annan-Endeavour rivers reached corals and seagrass at Draper Patch, 3km southeast of the Annan River mouth, with high total suspended solids concentrations (greater than 50 mg/L).

Potential exposure of pollutants to ecosystems

Figure 10 shows the frequency of exposure to plume and resuspension processes, and the potential exposure risk in 2017-2018, and the average over the long term.

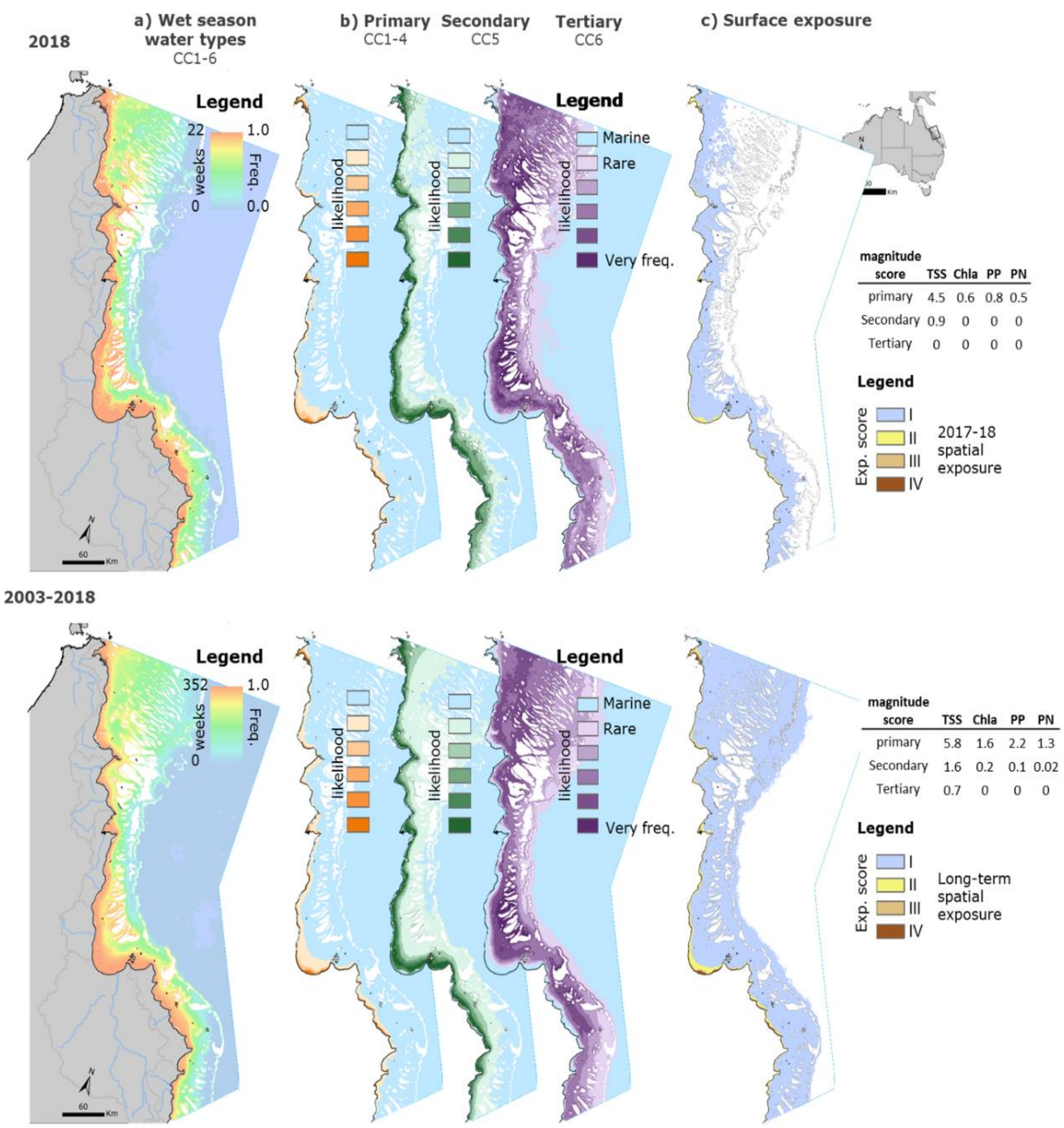

Figure 10. Maps showing the a) frequency of combined wet season water types (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary wet season water types and c) the exposure maps for the Cape York region in the long-term (bottom) and 2017-2018 (top). Reproduced from (Waterhouse et al. 2018, Gruber et al. 2019).

Approximately 56% of the total area of the Marine Park region was exposed to a potential risk from wet season plumes and resuspension processes in 2016-2017, which is larger than the area exposed in 2017-2018 (25%). Long-term average exposure is 55%. However, the area was mostly low potential exposure risk (categories I and II) (Figure 10) when constituent pollutant concentrations were taken into account, in agreement with long-term trends (Waterhouse et al. 2018, Gruber et al. 2019).

Additional analysis of potential exposure risk of pollutants to coral and seagrass ecosystems revealed that:

- 97% of coral reefs were exposed to potential risk in 2016-2017 and 40% in 2017-2018. However, almost all of the exposure was to the low potential risk (categories I and II).
- In both years, less than 0.05% of corals were in exposure category III. In 2016-2017, only 0.02% were in category IV and in 2017-2018 no reefs were in this category (Waterhouse et al. 2018, Gruber et al. 2019).

- Most of the seagrass was exposed to potential risk (94-99%). However, most exposure was in the low risk categories in both years, with 84-85%, 7% and 2-3% of seagrasses in exposure categories I, II and III respectively. In 2016-2017, only 4% of meadows were in category IV and in 2017-2018 no seagrass was in this category (Waterhouse et al. 2018, Gruber et al. 2019).

Pesticides

The Marine monitoring program does not monitor pesticides in Cape York.

Coral

The Marine monitoring program does not monitor coral in Cape York. However, the region was severely affected by the unprecedented back-to-back years of coral bleaching in the summers of 2016 and 2017 that particularly affected the northern two-thirds of the Great Barrier Reef Marine Park. Surveys in the Northern Great Barrier Reef by the Australian Institute of Marine Science showed reefs have lost about half of their coral cover by mid-2018, due to cumulative impacts of two severe cyclones and two episodes of severe coral bleaching from 2014 to 2017 (Australian Institute of Marine Science 2018b).

Seagrass

Seagrass meadow condition remained poor (Figure 11), declining overall in 2017-2018 from the previous year (McKenzie et al. 2018, McKenzie et al. 2019). All indicators declined in 2017-2018 (Figure 11) including:

- Abundance, which decreased marginally – predominately in coastal and intertidal reef meadows, and more in the south of the region
- Leaf tissue nutrient concentrations, which indicates that availability of nitrogen, particularly in coastal habitats, has increased relative to carbon demand for growth. However there was no significant influence on epiphytic and macroalgae abundance
- Reproductive effort, which declined at coastal habitats.

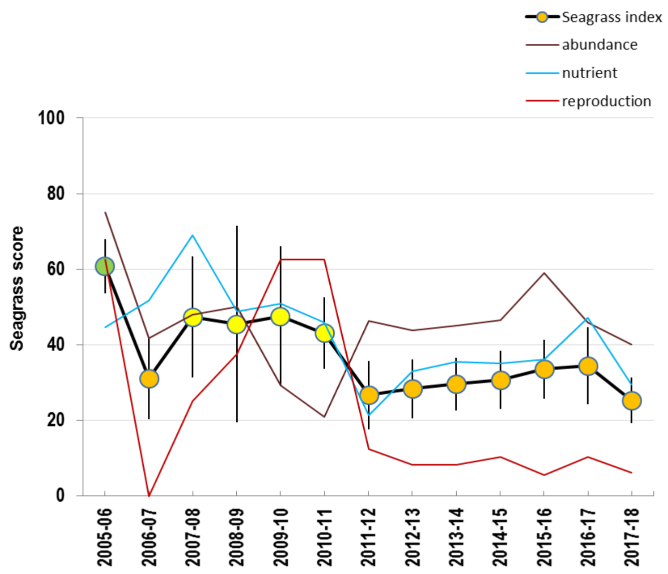

Figure 11. Seagrass scores for the Cape York region from 2006 to 2018. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent 95% confidence limits. Note: Scores are unitless. Data source: (McKenzie et al. 2019).

Declines were likely the result of a combination of light limitation and elevated water temperatures, and there are possibly residual effects of thermal stress from earlier years. Exposure of inshore seagrass to turbid waters during the wet season was at or about the long-term average in both years. Within-canopy light was lower than long-term averages (McKenzie et al. 2019), but the ecological significance of this is uncertain. Daily tidal exposure was below the long-term average for the second consecutive year, which may have provided some respite from elevated temperatures (McKenzie et al. 2019).

The capacity for meadow recovery is variable across the region and between habitats (McKenzie et al. 2019). Positive signs include:

- large seed banks which persist at intertidal coastal meadows (provided conditions support germination)
- increased reproductive effort at intertidal reef meadows.
- However, these positive trends are potentially negated by:
  - low reproductive effort at intertidal coastal meadows which may limit replenishment and maintenance of the bank in the near future
  - lack of seeds in most intertidal reef meadows limiting recovery.

5.2. Wet Tropics

Pressures

The Wet Tropics region river discharge was below average flow in the 2016-2017 year, followed by an above average flow in 2017-2018 (Figure 2). Major flooding occurring in many rivers including the Mulgrave-Russell, Herbert and Tully Rivers. Cumulative exposure modelling and mapping from eReefs showed that Tully and Mulgrave-Russell rivers discharges heavily affected enclosed coastal waters (Gruber et al. 2019). Plumes travelled primarily in a northerly direction along the coast, detectable more than 200km north from the Mulgrave-Russell River mouth. However, prevailing currents drove some plumes southward. Discharge reached inshore and mid-shelf waters. Barron River plumes were relatively small (Gruber et al. 2019).

Maximum seagrass within-canopy temperatures exceeded 35°C in both years (McKenzie et al. 2018, McKenzie et al. 2019):

- for 70 days in 2016-2017, with canopy temperatures exceeding 40°C for three days
- for 59 days in 2017-2018 (mostly in the north), with two days where 40°C was exceeded in the canopy. The low frequency at which these high temperatures occurred indicates burning or mortality was unlikely.

Water quality based on in situ monitoring

Monitoring occurs in marine waters adjacent to the Tully, Mulgrave-Russell and Barron river mouths.

Long-term trend analysis compared against water quality guidleines (Great Barrier Reef Marine Park Authority 2018), which accounts for effects of wind, waves, and tides (i.e. is independent of changes in local weather) shows that on average:

- concentrations of chlorophyll a, total suspended solids and oxidised nitrogen have been relatively stable over time and currently meet water quality guidelines
- concentrations of particulate nutrients have generally increased over time and are currently above water quality guidelines at some sites

- water clarity (measured by Secchi depth) has declined over time and is currently not meeting water quality guidelines
- consistent increases in dissolved organic carbon concentrations have occurred since 2005 (Waterhouse et al. 2018, Gruber et al. 2019). A possible explanation for the trend is provided in Section 1.3.

The Mulgrave-Russell region also shows increased particulate organic carbon concentrations.

Flood plume sampling in both years showed exceedance of total suspended solids and chlorophyll *a* water quality guidelines (Great Barrier Reef Marine Park Authority 2018) across the primary and secondary water types (Waterhouse et al. 2018, Gruber et al. 2019). In 2017-2018:

- chlorophyll *a* concentration also exceeded tertiary water water quality guidelines
- particulate phosphorus and particulate nitrogen concentrations exceeded wet season water quality guidelines in primary waters.

The dissolved inorganic nitrogen end-of-catchment pollutant load for the Great Barrier Reef is dominated by the Tully-Murray-Herbert catchments exports, along with Mackay Whitsunday region catchments (Waterhouse et al. 2018, Gruber et al. 2019).

In situ water quality index

The long-term *in situ* water quality index (which is not sensitive to year-to-year environmental variation) shows inshore water quality has declined in parts of the Wet Tropics region but remains good overall (Figure 5).

The annual *in situ* water quality index was poor in both years in the region (Figure 5), although river discharge was at or above the long-term median level (Gruber et al. 2019). Post-2015 changes to the Marine monitoring program design (more inshore stations and more sampling during the wet season) increase the program's power to detect changes in water quality, but mean that sampling pre-2015 and post-2015 comparisons must be interpreted carefully.

Potential exposure of pollutants to ecosystems

Figure 12 shows the frequency of exposure to plume and resuspension processes and the potential exposure risk in 2017-2018, and the average over the long term.

Approximately 72% of the total area of the region was exposed to a potential risk in 2016-2017, larger than the area exposed in 2017-2018 (37%). Long-term average exposure is 59% (Waterhouse et al. 2018, Gruber et al. 2019). However, the area was mostly exposed to lower risk categories (categories I and II) (Figure 12) when constituent pollutant concentrations were taken into account, in agreement with long-term trends (Waterhouse et al. 2018, Gruber et al. 2019).

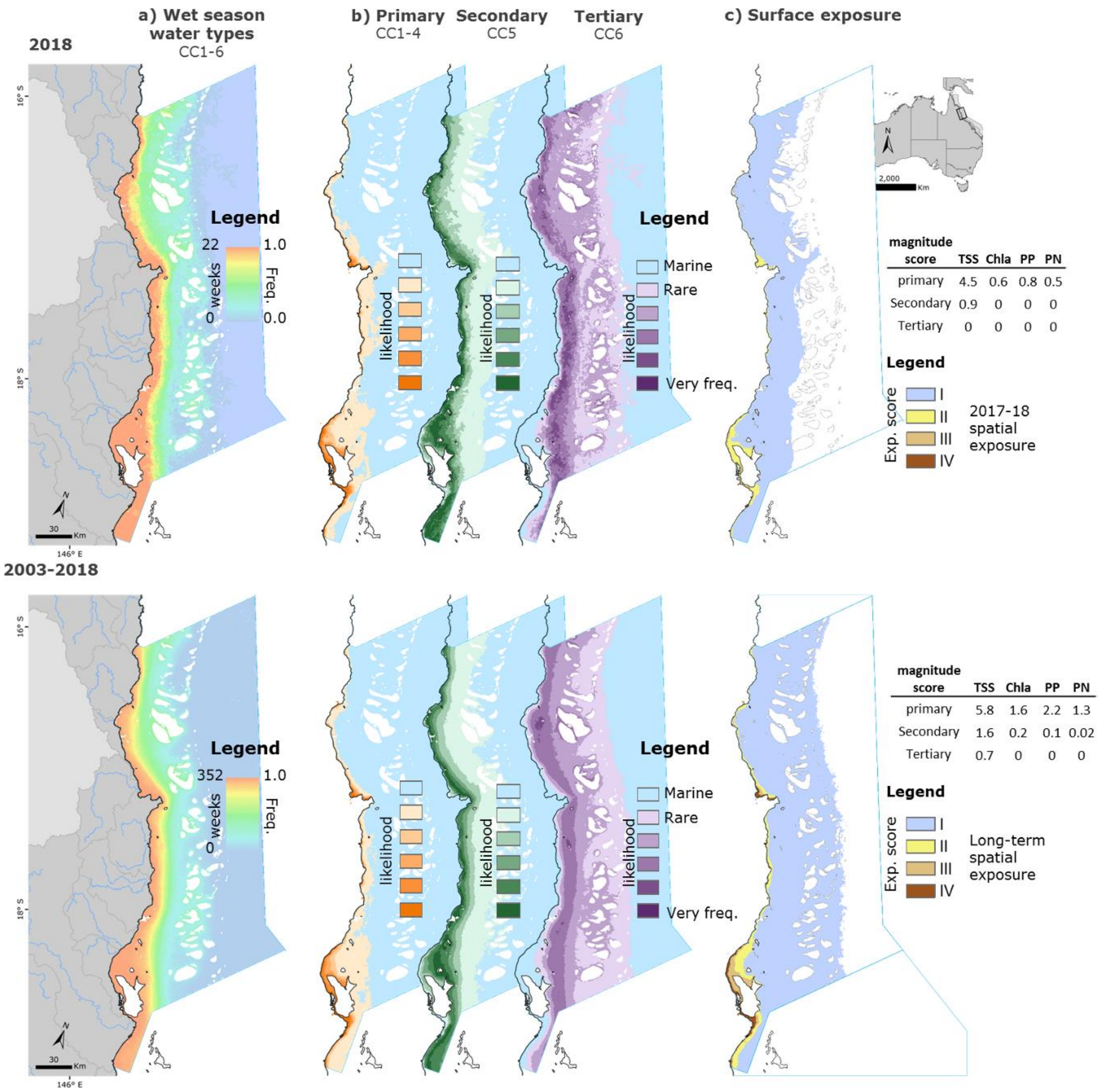

Figure 12. Maps showing the a) frequency of combined wet season water types (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary wet season water types and c) the exposure maps for the Mackay Whitsunday region in the long-term (bottom) and 2017–18 wet season (top).Reproduced from: (Gruber et al. In press).

Additional analysis of potential exposure risk of pollutants to coral and seagrass ecosystems revealed that:

- 99% of Wet Tropics coral reefs were exposed to potential risk in 2016-2017, and 43% in 2017-2018. However, almost all of the exposure was low potential risk (categories I and II). In 2016-2017, 0.1% of corals were exposed to category III, and 0.02% were exposed to the highest potential risk category IV. In 2017-2018 only 0.01% of corals were in exposure category III, and no reefs were in category IV.
- Most of the seagrass was exposed to potential risk (97-98%). However, most exposure was within the low risk category in both years, with 33-44%, 22-41% and 13-22% of seagrasses in exposure categories I, II and III respectively. However, 20% of seagrass was exposed to the highest potential risk category IV in the 2016-2017 year, while none was exposed in 2017-2018 (Waterhouse et al. 2018, Gruber et al. 2019).

Pesticides

Pesticides are monitored at Low Isles, High Island, Normanby Island, Dunk Island and Lucinda. There were no exceedances of marine water quality guidelines for time-averaged pesticide concentrations in either year, although a range of pesticides continue to be detected (Grant et al. 2018, Gallen et al. 2019). Atrazine, diuron and hexazinone continue to dominate the pesticide profile at these sites.

When the toxicity of mixtures of multiple pesticides are assessed, based on maximum time-integrated passive samples, all sites met the desired very low risk: protective of 99% of species (i.e. less than 1% of species are affected) (Gallen et al. 2019).

Coral

Inshore coral remains in moderate condition and has been stable for the last three years (Figure 13). Prior to that, there was a slow steady improvement from a low point in 2012-2013. A combination of high water temperatures in 2016-2017 and 2017-2018 and pressures associated with flooding have likely suppressed recovery (Thompson et al. 2019).

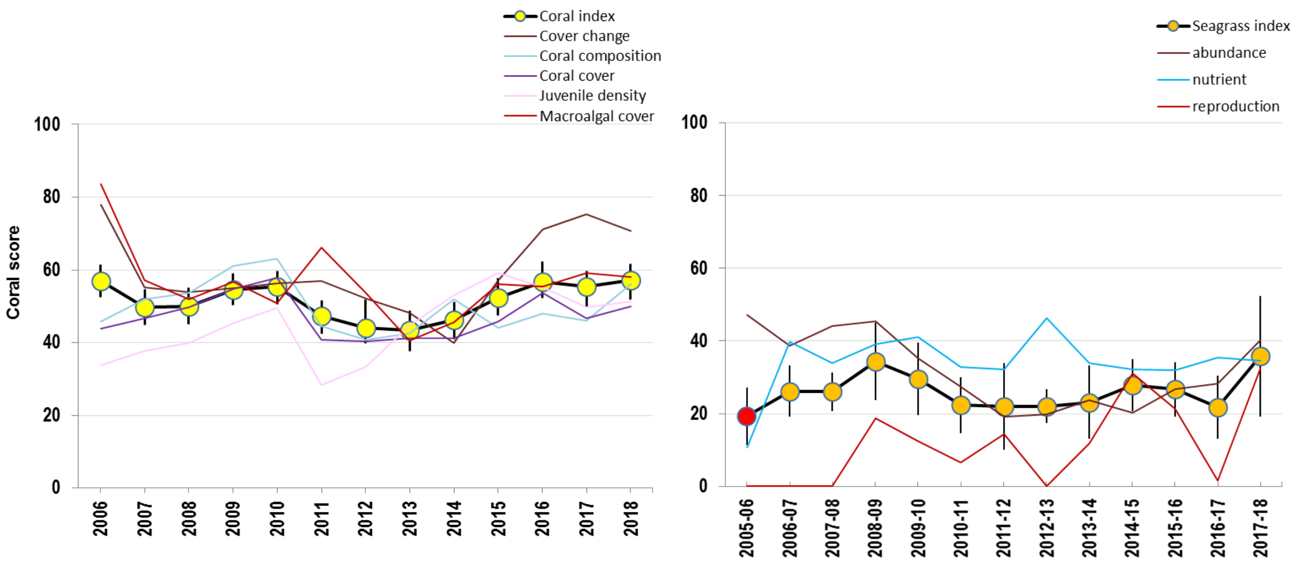

Figure 13. Coral scores (left) and seagrass scores (right) for the Wet Tropics region from 2006 to 2018. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent 95% confidence limits. Note: Scores are unitless. Data source: (Thompson et al. 2019) and (McKenzie et al. 2019).

In the Barron Daintree sub-region, coral condition remained moderate, which was mostly due to improved growth of corals in shallower water. Good scores in the cover change indicator, and a decline in the proportional cover of macroalgae at 5m are promising signs for recovery. Conversely, low scores for juvenile density around Snapper Island were the main factor limiting the sub-regional condition (Thompson et al. 2019).

In the Johnstone Mulgrave-Russell sub-region, coral condition improved slightly to return to a good score, recovering from the slight decline observed in 2017. The improvement was mostly due to increased coral cover and juvenile density at shallower depths. There was ongoing pressure from coral eating crown-of-thorns starfish at High Island and in the Frankland Islands Group. The long-term trend in the coral index here reflects the impact and subsequent recovery of coral communities following the severe impacts associated with Tropical Cyclones Tasha and Yasi in 2011 (Thompson et al. 2019).

In the Herbert Tully sub-region, coral condition declined slightly but remained moderate. The slight decline in the index in 2018 was due to ongoing effects of coral bleaching in 2017, and the likely influence of ongoing chronic pressures. The decline was primarily seen at shallower depths: a slower rate of improvement in coral cover, a decline in the density of juvenile corals, and an increase in macroalgal abundance. Low macroalgae scores and low coral cover at Bedarra Island and Dunk Island south continue to limit sub-regional coral condition (Thompson et al. 2019).

Seagrass

Seagrass meadow condition remained poor (Figure 13), although the score in 2017-2018 was the highest seen in 13 years of monitoring (McKenzie et al. 2018, McKenzie et al. 2019).

Seagrass meadows within the Wet Tropics were the only sites in the inshore Great Barrier Reef to show an overall improvement in seagrass condition in 2017-2018, but they remain in a vulnerable state, particularly in the southern Wet Tropics region. There was variation within the region – meadows in the northern sub-region were moderate, whereas meadows in the south were poor (McKenzie et al. 2019).

Seagrass abundance increased relative to the previous period (Figure 13), with increases in per cent cover at nearly 60% of sites, predominately in reef meadows (McKenzie et al. 2019). In the north, lower river discharge, adequate light and mild sea temperatures provided an environment conducive to improvements. In the south, improvement was not as great, possibly due to lower available light, above-average river discharge, and warmer temperatures (McKenzie et al. 2019).

The score for reproduction increased from very poor to poor in 2017-2018 (Figure 13). Meadows in the north have maintained a healthy seed bank and reproductive effort was high during 2017-2018. However, reproductive structures and seed banks remained absent in the south. Recovery is reliant on expansion of remnant plants or recruitment from elsewhere (e.g. vegetative fragments). As recovery potential remains extremely low without a seed bank, the absence of reproductive structures and seed banks may render the seagrass at risk from further disturbances, (McKenzie et al. 2019).

Nutrient status remained poor in 2017-2018 (Figure 13). Across the region, leaf tissue nutrients (carbon:nitrogen), have remained unchanged for a number of years. An excess of nitrogen relative to photosynthetic carbon uptake (carbon:nitrogen less than 20) is consistent with a high frequency of exposure to enriched water (McKenzie et al. 2019).

5.3. Burdekin

Pressures

The Burdekin region experienced an average wet season in both 2016-2017 and 2017-2018 (Figure 2), with flooding occurring from the Burdekin River in March-April. The 2017 river flow followed rainfall from Severe Tropical Cyclone Debbie.

The eReefs cumulative exposure model output showed that the Burdekin River discharge in 2017-2018 heavily affected enclosed coastal waters. Plumes were detectable more than 150km from the river mouth and also reached mid-shelf waters. River discharge travelled primarily in a northerly direction along the coast although plumes did travel east for a short period.

Maximum seagrass within-canopy temperatures exceeded 35°C in both years: for 45 days in 2016-2017 and for 42 days in 2017-2018. In addition, within-canopy temperatures exceeded 40°C for one day in 2016-2017, and no days in 2017-2018. The low frequency at which these high temperatures occurred indicates burning or mortality was unlikely (McKenzie et al. 2018, McKenzie et al. 2019).

Water quality based on in situ monitoring

Monitoring occurs in marine waters adjacent to the Burdekin River mouth. Monitoring ambient water quality at specific sites showed variability in meeting water quality guidelines (Waterhouse et al. 2018, Gruber et al. 2019).

Long-term trend analysis compared against water quality guidleines (Great Barrier Reef Marine Park Authority 2018), which accounts for effects of wind, waves, and tides (i.e. are independent of changes in local weather) show that:

- concentrations of total suspended solids and oxidised nitrogen have been relatively stable over time and meet water quality guidelines
- concentrations of particulate nitrogen meet water quality guidelines
- concentrations of particulate phosphorus are just above water quality guidelines
- water clarity (measured by Secchi depth) has remained fairly stable over time and is currently not meeting water quality guidelines
- consistent increases in dissolved organic carbon concentrations have occurred since 2005 in the region (Waterhouse et al. 2018, Gruber et al. 2019). A possible explanation for the trend is provided in Section 1.3

Flood plume sampling in both years showed exceedance of total suspended solids and chlorophyll *a* water quality guidelines (Great Barrier Reef Marine Park Authority 2018) across primary waters (Waterhouse et al. 2018, Gruber et al. 2019). In 2017-2018:

- total suspended solids also exceeded secondary water water quality guidelines, and was just above in tertiary waters
- chlorophyll *a* was at or near the water quality guidelines for secondary waters and met the water quality guideline for tertiary water
- particulate phosphorus and particulate nitrogen concentrations in the primary water type exceeded wet season water quality guidelines, were at or near the objectives for secondary water and met water quality guidelines for tertiary water.

The total suspended solids and particulate nitrogen loads to the Great Barrier Reef are dominated by the Burdekin-Haughton catchment exports (Waterhouse et al. 2018, Gruber et al. 2019).

In situ water quality index

The long-term *in situ* water quality index (which is not sensitive to year-to-year environmental variation) shows inshore water quality has remained good (Figure 5).

The annual *in situ* water quality index (sensitive to year-to-year environmental variation) shows inshore water quality was poor in both years in the region (Figure 5), although river discharge was just above or close to the long-term median. Post-2015 changes to the Marine monitoring program design (more inshore stations and more sampling during the wet season) increase the program’s power to detect changes in water quality, but mean that sampling pre-2015 and post-2015 must be interpreted carefully.

Potential exposure to ecosystems

Figure 14 shows the frequency of exposure to plume and resuspension processes and the potential exposure risk in 2017-2018, and the average over the long term.

Approximately 82% of the total area of the Burdekin region was exposed to a potential risk in 2016-2017, which was greater that the area exposed in 2017-2018 (16%). Long-term average exposure is 62% (Waterhouse et al. 2018, Gruber et al. 2019). However, the area was mostly exposed to lower risk categories (categories I and II) (Figure 14) when constituent pollutant concentrations were taken into account, in agreement with long-term trends (Waterhouse et al. 2018, Gruber et al. 2019).

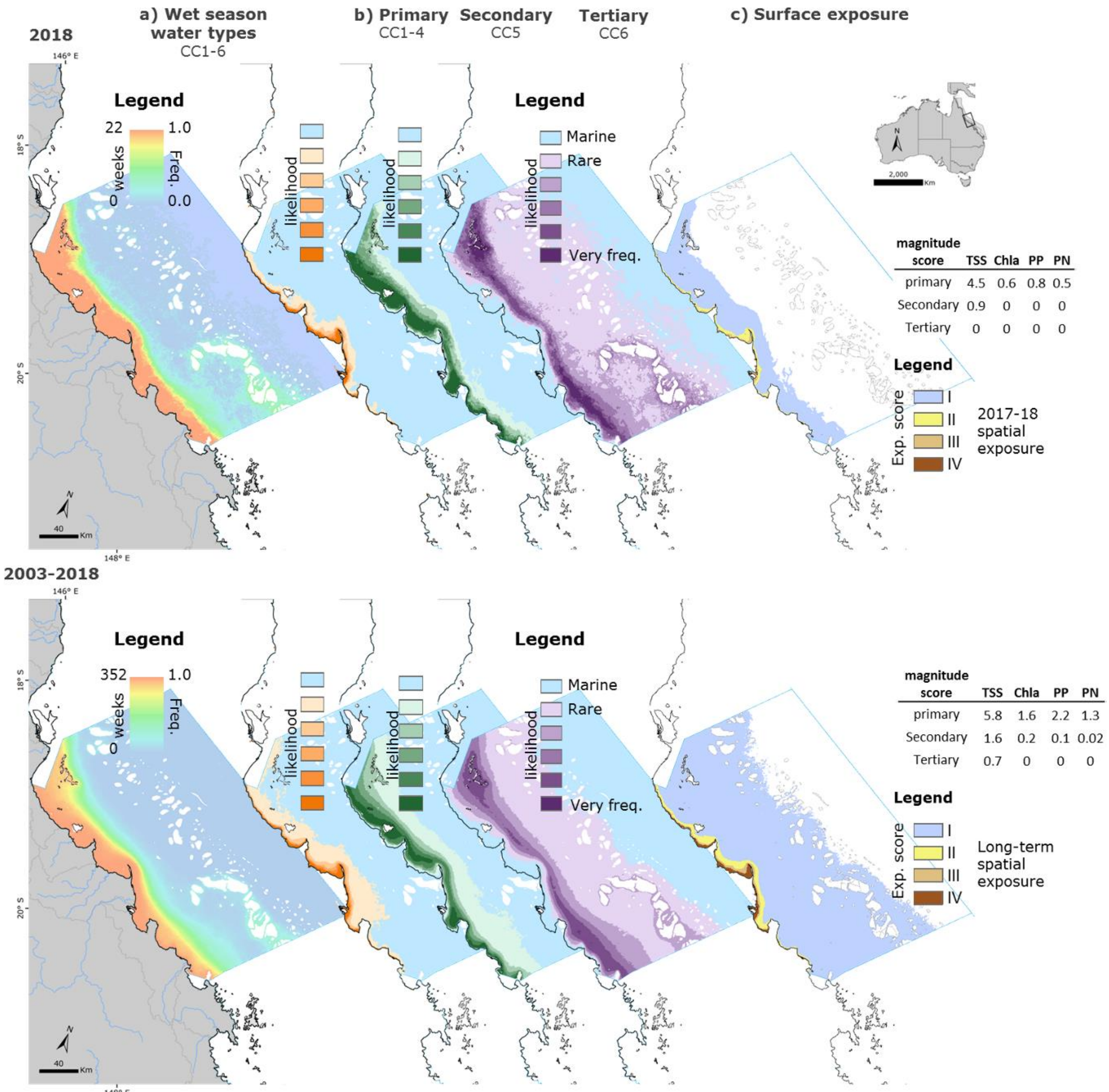

Figure 14. Maps showing the a) frequency of combined wet season water types waters (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary water types and c) the exposure maps for the Burdekin region in the long-term (bottom) and 2017-2018 wet season (top).Reproduced from (Waterhouse et al. 2018, Gruber et al. 2019).

Additional analysis of potential exposure risk of pollutants to coral and seagrass ecosystems revealed that:

- 99% of the Burdekin coral reefs were exposed to potential risk in 2016-2017, and only 2% in 2017-2018. However, almost all of the exposure was low potential risk (categories I and II). Less than 0.05% of corals were in exposure category III, and no reefs were in the highest exposure category IV in either year (Waterhouse et al. 2018, Gruber et al. 2019).
- Most of the seagrass was exposed to potential risk (98%). However, most exposure was to the low risk category in both years, with 63-76%, 12-16% and 5-10% of seagrasses in exposure categories I, II and III respectively. No seagrass was exposed to the highest potential risk category IV in 2017-2018, whilst 14% was exposed in the previous year (Waterhouse et al. 2018, Gruber et al. 2019).

Pesticides

Pesticides are monitored at only one site in the region: Barratta Creek. There were no exceedances of marine water quality guidelines for time-average pesticide concentrations in either year, although a range of pesticides continues to be detected (Grant et al. 2018, Gallen et al. 2019). Historically, atrazine and atrazine metabolites have dominated the pesticide profile at this site.

Assessment against the multisubstance-potentially affected fraction (ms-PAF) method for pesticide mixtures showed that all samples from 2016-2017 fell into the lowest risk category: protective of 99% of species (less than 1% of species affected). In 2017-2018, two of six samples fell into the next risk class: protective of greater than 95% of species (i.e. 1 to less than 5% of species affected) (Gallen et al. 2019).

Coral

Inshore coral has remained stable and in moderate condition since 2016 (Figure 15). It has returned to the same condition observed during the first five years of monitoring before declining to poor for five years after the crossing of Severe Tropical Cyclone Yasi in 2011. Since 2012, scores for most coral indicators have improved (Figure 15). Macroalgal scores are the exception, and they remain low due to high cover of macroalgae at most reefs inshore of the Palm Island group (Thompson et al. 2019).

Coral bleaching in 2017 halted the trajectory of recovery that was observed between 2012 to 2016, following Severe Tropical Cyclone Yasi (2011) and pressures associated with large discharges from the region’s rivers (Thompson et al. 2018, Thompson et al. 2019).

Since 2012, scores for most coral indicators have improved (Figure 15) (Thompson et al. 2019). Macroalgal scores are the exception, and they remain low due to high cover of macroalgae at most reefs inshore of the Palm Island group (Thompson et al. 2019).

The improvement in the coral index after 2012-2013 coincided with a period free from acute disturbances and below median river discharge (Figure 2). Despite widespread coral bleaching over the 2016-2017 summer, which accounted for 18% of the coral cover lost since 2005, the index score remained relatively stable (Thompson et al. 2019).

The influence of the recent bleaching event on the index was limited by the rapid increase in the coral cover indicator since 2011-2012 and the rebound in cover at several reefs (particularly at Palm Island group east) since 2017. This demonstrates strong recovery capacity of these coral communities following the severe impact of Severe Tropical Cyclone Yasi in 2011.

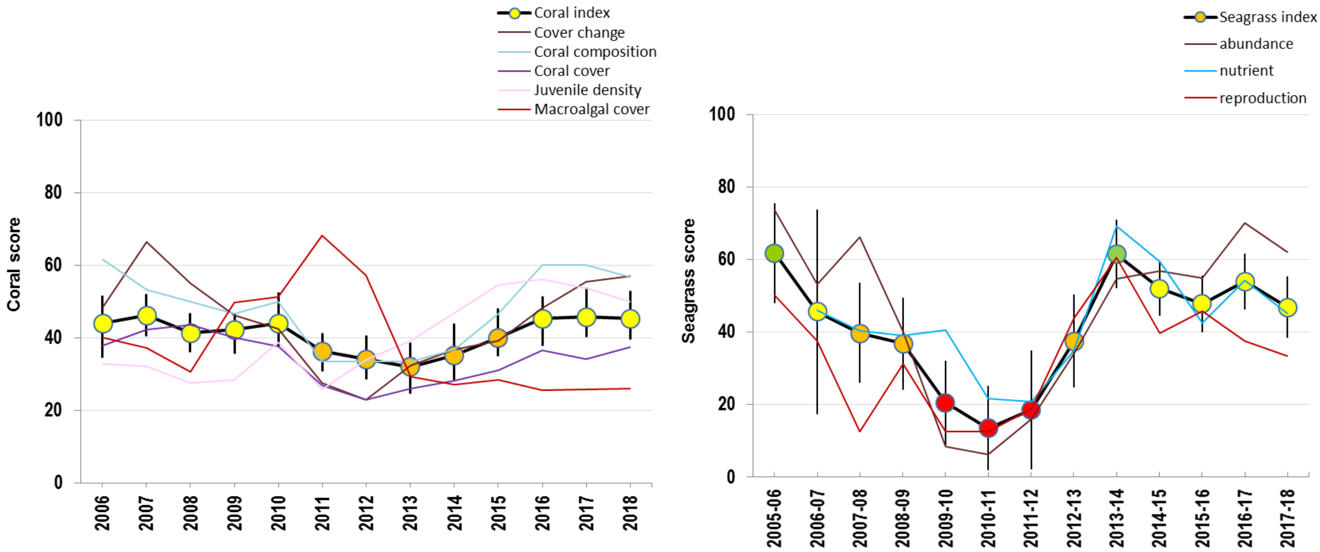

Figure 15. Coral scores (left) and seagrass scores (right) for the Burdekin region from 2006 to 2018. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent 95% confidence limits. Note: Scores are unitless. Data source: (Thompson et al. 2019) and (McKenzie et al. 2019).

The ten reefs monitored in the Burdekin span a distinct gradient in water quality. The reefs closer to the coast (i.e. Middle, Magnetic, Lady Elliot and Pandora islands) are more frequently exposed to high wet season chlorophyll *a* concentration than those further offshore, and the composition of these coral communities varies along these environmental gradients (Thompson et al. 2018; Thompson et al. 2019).

Seagrass

Seagrass meadow condition has remained in moderate condition across the Burdekin region for the last four years (Figure 15). Prior to this, a six-year decline from good (2005-2006) to very poor condition (2010-2011) was followed by a rapid rebound to good in just three years. This suggests that seagrasses in the Burdekin region are very dynamic.

All seagrass indicators have tracked the average score over time but reproductive effort was also variable across habitats. It has remained moderately high at coastal sites, where the seed banks have had the highest densities among all sites monitored by the Marine monitoring program. The decline in this indicator since 2013-2014 has been driven by weak reproductive effort at the reef intertidal and subtidal sites. Despite this, seed densities in the seed bank of the reef subtidal habitat remain high (McKenzie et al. 2019).

The decline in tissue nutrient score after 2013-2014, was primarily due to declining carbon:nitrogen ratios at reef habitats. The change may not indicate elevated anthropogenic nitrogen levels, irrespective of the maintenance of epiphyte abundance above the long-term average for the Reef for the last few years, and is more likely a response to recently elevated temperatures (McKenzie et al. 2019).

Over the past decade, seagrass meadows of the Burdekin region have demonstrated high resilience, particularly through their capacity for recovery. This may reflect adaptation to disturbance (high seed bank, high species diversity), but also reflects the nature of the disturbances, which are episodic and dominated by wind events and Burdekin River flows (McKenzie et al. 2019).

5.4. Mackay Whitsunday

Pressures

The 2016-2017 year had two to three times the long-term median combined river discharge. Severe Tropical Cyclone Debbie, a category 4 system, passed through the Whitsunday Islands and crossed the mainland at Airlie Beach in the Mackay Whitsunday region on 28 March 2017 (Bureau of Meteorology 2018a).

In contrast, 2017-2018 had below average rainfall, and consequently low river discharge (Figure 2).

Maximum seagrass within-canopy temperatures exceeded 35°C in both years (McKenzie et al. 2018, McKenzie et al. 2019): for 56 days in 2016-2017 and 66 days in 2017-2018. Canopy temperatures exceeded 40°C for four days in 2016-2017 and one day in 2017-2018. The low frequency at which these high temperatures occurred indicates burning or mortality was unlikely (McKenzie et al. 2018, McKenzie et al. 2019).

Water quality based on in situ monitoring

Monitoring in marine waters occurs adjacent to the Proserpine, O'Connell, Pioneer and Plane river mouths. Monitoring ambient water quality at specific sites in these areas showed variability in meeting water quality guidelines (Waterhouse et al. 2018, Gruber et al. 2019).

Long-term trend analysis compared against water quality guidleines (Great Barrier Reef Marine Park Authority 2018), which accounts for effects of wind, waves, and tides, i.e. are independent of changes in local weather, show that:

- concentrations of total suspended solids and oxidised nitrogen have been relatively stable since 2010 and mean values currently meet water quality guidelines for the region
- concentrations of particulate nitrogen and particulate phosphorus have risen and currently do not meet water quality guidelines
- water clarity (measured by Secchi depth) dropped in 2008 and, while stable since then, does not meet water quality guidelines
- consistent increases in dissolved organic carbon concentrations have occurred since 2005 in the region (Waterhouse et al. 2018, Gruber et al. 2019). A possible explanation for the trend is at Section 1.3.

No data were available for the primary water type in the 2017-2018 year. Event sampling in other water types showed:

- total suspended solids concentrations across the secondary water type met the water quality guidelines
- chlorophyll *a* concentrations exceeded the water quality guideline in both secondary and tertiary water types (Gruber et al. 2019).

The previous year rough weather and logistical issues associated with Severe Tropical Cyclone Debbie prevented flood plume sampling in the Proserpine-O'Connell and Pioneer rivers until approximately 10 days after peak stream flows occurred (i.e. road closures, cyclone damage and boat access). However, flood plumes were still evident in the region and were sampled for both the Proserpine-O'Connell and the Pioneer regions.

Highly elevated total suspended solids and chlorophyll *a* concentrations exceeding water quality guidelines (Great Barrier Reef Marine Park Authority 2018) were found across the plumes (Waterhouse et al. 2018). Initially, relatively rough sea conditions associated with Severe Tropical Cyclone Debbie were proposed to explain the high total suspended solids concentrations. In addition, the Australian Instituted of Marine Science long-term monitoring program found very low Secchi depth (less than 2m) at sites throughout the Whitsunday Islands at the end of May, inferring very low light levels occurred for an extended period (Australian Institute of Marine Science 2018a).

***In situ* water quality index**

The long-term *in situ* water quality index (which is not sensitive to year-to-year environmental variation) shows inshore water quality has declined since 2007-2008, and is currently in moderate condition (Figure 5).

The annual *in situ* water quality index returned to moderate in 2017-2018 following a very poor score in the previous year (Figure 5). The trend is probably a result of a much drier-than-average year in 2017-2018, following a 'large' wet season in 2016-2017. Post-2015 changes to the Marine monitoring program design (more inshore stations and more sampling during the wet season) increase the program's power to detect changes in water quality, but mean that sampling pre-2015 and post-2015 comparisons must be interpreted carefully.

Potential exposure to ecosystem

Figure 16 show the frequency of exposure to plume and resuspension processes and the potential exposure risk in 2017-2018, and the average over the long term. Approximately 93% of the total area of the region was exposed to a potential risk in 2016-2017, larger than the area exposed in 2017-2018 (24%). Long-term average exposure is 85%. However, the area was mostly exposed to lower risk categories (categories I and II) (Figure 16) when constituent pollutant concentrations were taken into account, in agreement with long-term trends (Waterhouse et al. 2018, Gruber et al. 2019).

Pesticides

Pesticides are monitored at four sites in the Mackay Whitsunday region: Repulse Bay, Round Top Island, Sandy Creek and Sarina Inlet. A range of pesticides was detected at all monitoring sites in both years although Repulse Bay, Sandy Creek and Round Top Island had missing wet season samples (Grant et al. 2018, Gallen et al. 2019). In line with previous years, diuron, atrazine and hexazinone were the most frequently detected pesticides at high concentrations at most sites.

There were no exceedances of marine water quality guidelines (Australian and New Zealand governments 2018) for individual pesticides in either year (Grant et al. 2018, Gallen et al. 2019), although these values are undergoing a review. Assessment against the proposed aquatic ecosystem protection guideline values (levels determined to be protective of 99% of marine species) would result in two instances of exceedance in the 2017-2018 year, both from passive samplers located at Round Top Island, and one in the 2016-2017 year, all of which were for diuron (Grant et al. 2018, Gallen et al. 2019).

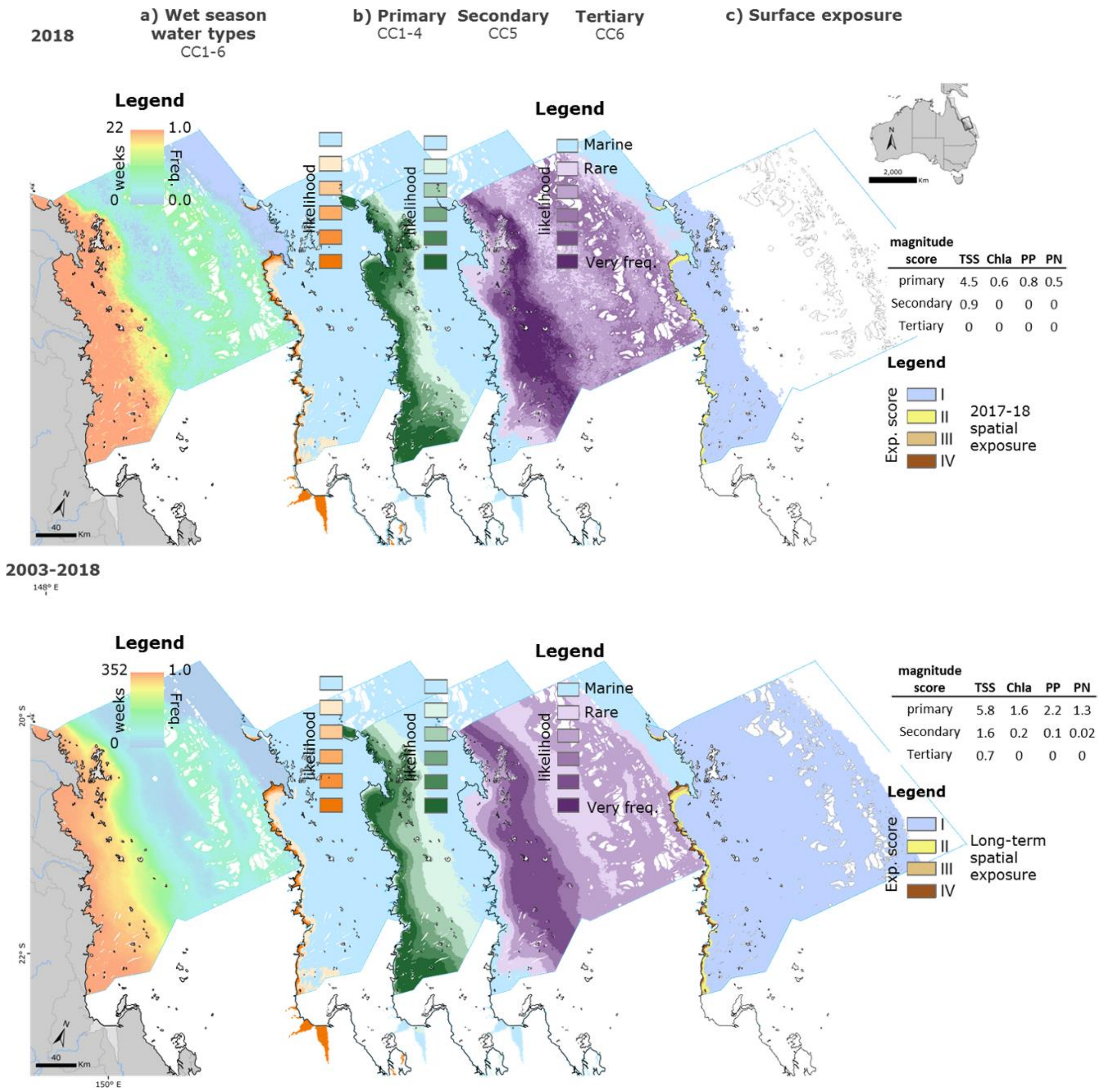

Figure 16. Maps showing the a) frequency of combined wet season water types (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary wet season water types and c) the exposure maps for the Mackay Whitsunday region in the long-term (bottom) and 2017-2018 wet season (top).Reproduced from: (Gruber et al. In press)

Consistent with historical data from the Mackay Whitsunday region, the Round Top Island site deployments recorded the greatest risk of toxic effects due to detected pesticide mixtures (Grant et al. 2018, Gallen et al. 2019). Due to sampler losses and deployment issues, in particular at Repulse Bay (2016-2017) and Sandy Creek (2017-2018), incomplete wet season sampling means that concentration peaks may have been missed. In other years, however, the maximum concentrations recorded from these sites have been among the lowest recorded from the region (Figure 6).

Round Top Island also had some samplers lost or not deployed during the wet season, but still returned the highest concentrations of pesticides. When the mixture of pesticides was evaluated by the multisubstance-potentially affected fraction (ms-PAF) method, one sample fell into the very high risk category: protective of less than or equal to 80% of species (or greater than or equal to 20% of species potentially affected). In addition, only four of 10 samples met the desired state of very low risk: protective of 99% of species (i.e. less than 1% of species affected). Round Top Island lies approximately 7km from the coast and almost equidistant from the mouths of three rivers draining extensive cane lands. The high but variable levels of pesticides detected at Round Top Island are consistent with a site affected by river plumes

(Waterhouse et al. 2018, Gruber et al. 2019), although the source(s) remains to be identified and should be a priority.

Coral

Inshore coral has declined from good condition in 2015-2016 in both reporting years, while remaining in moderate condition (Figure 17). The inshore coral score in 2017-2018 is the lowest observed since monitoring began. This is likely due to the regional impacts for Severe Tropical Cyclone Debbie, which passed directly over the Whitsunday Islands in March 2017. In 2016-2017, there was a spike in macroalgal abundance along with declines in coral cover and juvenile density indicators. Prior to this event, there was evidence of slow recovery from Tropical Cyclone Ului in 2010 (Thompson et al. 2018) with average condition increasing from moderate to good over a period of five years.(Thompson et al. 2018, Thompson et al. 2019).

The magnitude of the decline in coral cover following Severe Tropical Cyclone Debbie is unprecedented in the region since monitoring began in 2005. Ongoing monitoring will observe how these communities recover. Low juvenile densities and low rates of cover increase may limit the recovery of these communities.

Among the six reefs surveyed in 2017 soon after Severe Tropical Cyclone Debbie, the average loss of coral cover was 70% at 2m, and 64% at 5m (range 45-98% and 26-90% respectively (Thompson et al. 2018, Thompson et al. 2019). Reefs at Daydream, Double Cone and Pine islands were surveyed in both 2017 and 2018, where coral cover showed continued decline. The reef at Shute Harbour, the least impacted reef, showed signs of recovery.

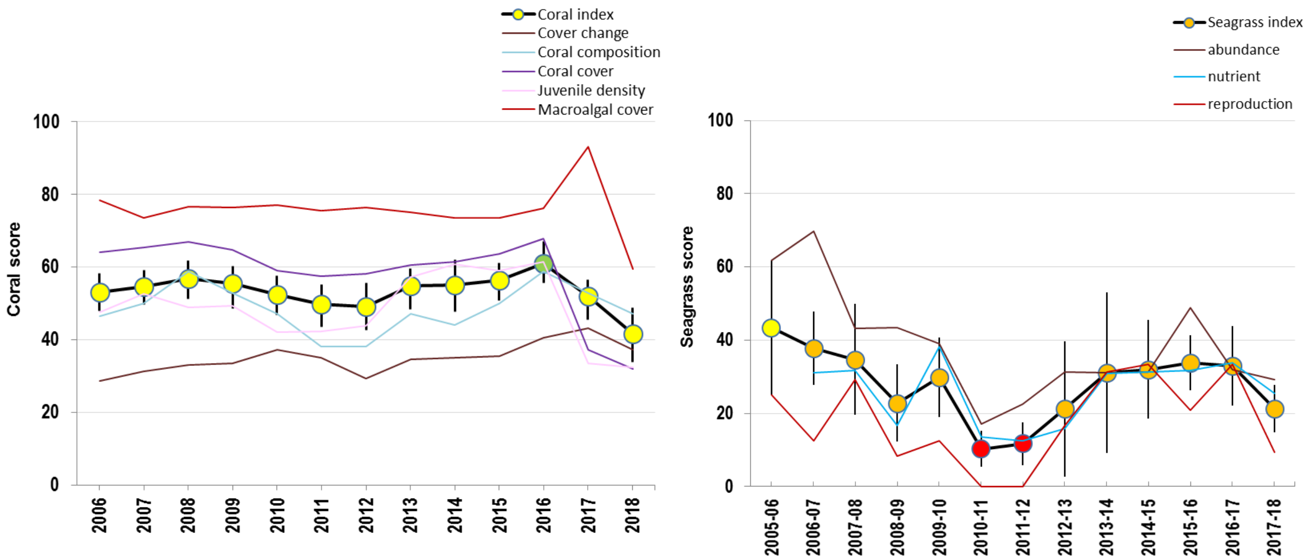

Figure 17. Coral scores (left) and seagrass scores (right) for the Mackay Whitsunday region from 2006 to 2018. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent 95% confidence limits. Note: Scores are unitless. Data source: (Thompson *et al.* 2019) and (McKenzie et al. 2019)

The influence of chronic environmental pressures in the region is demonstrated by the marked differences in the composition of coral communities between 2 m and 5 m depths. High turbidity at most of the reef sites, in combination with limited exposure to wave energy among the Whitsunday Islands, results in reduced availability of light and accumulation of fine sediments at 5m depths and the selection for corals tolerant to low light.

Seagrass

Seagrass meadow condition remains poor across the Mackay Whitsunday region with a decline in overall condition in 2017-2018 (Figure 17) due to the impacts of Severe Tropical Cyclone Debbie. From an historical low point in 2010-2011, seagrass improved from very poor to moderate over three years followed by a plateau over the following four years until the most recent decline. As in the Burdekin region, all three indicators of seagrass condition followed the average trend.

Recovery potential varies across the region and between habitats. Seagrass reproductive effort has remained high at coastal habitats, but declined due to very low or absent reproductive effort in reef and estuarine habitats. In addition, declining and low seed banks at coastal habitats and reef habitats may limit recovery. Although a greater seed bank was present in the estuarine meadows, they lack replenishment capability due to deficient reproductive effort (i.e. limited recovery capacity), which coupled with low seagrass abundance (i.e. low resistance) may render the meadows vulnerable to large disturbances in the near future (McKenzie et al. 2019).

While tracking the average seagrass score, the nutrient indicator has shown the smallest range of variation over the 13 years of monitoring and mostly remained in poor condition. This is consistent with a local surplus of nitrogen relative to photosynthetic carbon incorporation (McKenzie et al. 2019).

Exposure to turbid waters during the wet season was at the long-term average, and within-canopy light was at or slightly lower than long-term average. The slightly reduced light may have also been exacerbated by higher than average number of days in which wind speeds exceeded 25km hr^{-1}, which would have resuspended fine sediment. Daytime tides were generally higher throughout 2017-2018, which would have reduced light reaching meadows. However, this impact would be counterbalanced by potentially decreased intertidal exposure (McKenzie et al. 2019).

This region is of greatest concern regarding its ability to withstand or recover from future disturbances. In 2017-2018, it had the greatest percentage of sites with:

- decreased abundance
- below-average reproductive effort
- decreased seed density and seeds banks lost from half of the sites
- increased nitrogen in the leaf tissues.

Encouragingly, in the previous two years there has been a dramatic reduction in colonising species in estuarine and coastal intertidal habitats (McKenzie et al. 2018, McKenzie et al. 2019). In all habitats except the reef intertidal habitats, opportunistic foundational species (*H. uninervis* and *Z. muelleri*) now dominate; which is a first sign of recovery.

5.5. Fitzroy

Pressures

The Fitzroy region experienced above average freshwater discharge (2-3 times long-term median) rainfall in the 2016-2017 year due to Severe Tropical Cyclone Debbie, and below average in the 2017-2018 year (Figure 2). The flooding in the Fitzroy River in 2017 only lasted approximately 10-14 days, which is a shorter period compared to the 1991 and 2011 floods where elevated river flows lasted several weeks (40-50 days).

Maximum seagrass within-canopy temperatures exceeded 35°C in both years (McKenzie et al. 2018, McKenzie et al. 2019): for 70 days in 2016-2017 and 45 days in 2017-2018. Canopy temperatures exceeded 40°C for two days in 2016-2017 but no days in 2017-2018. The low frequency at which these high temperatures occurred indicates burning or mortality was unlikely.

Water quality based on in situ monitoring

Following a program redesign in 2015, field monitoring is not undertaken in the Fitzroy region by the Marine monitoring program except for periodic wet season sampling in response to high flow from the Fitzroy River. Monitoring results collected prior to 2015 can be sourced from reports (Devlin et al. 2011, Devlin et al. 2015, Waterhouse et al. 2018, Da Silva et al. 2013).

Flood plume sampling in 2016-2017 showed freshwater impacts and total suspended solids concentrations were lower than expected from the Fitzroy River. Salinity values were mostly greater than 27 practical salinity units, and total suspended solids concentrations mostly less than 4mg L^{-1} (Waterhouse et al. 2018). Total suspended solids was still above mean wet season water quality guidelines (Great Barrier Reef Marine Park Authority 2018) at this concentration, although the water quality guidelines are not derived to assess flood conditions. Chlorophyll *a* also exceeded mean seasonal water quality guidelines (Waterhouse et al. 2018). Monitoring of previous large Fitzroy River floods showed that salinity levels can reach below 10 practical salinity units for an extended period in Keppel Bay (Jones and Berkelmans 2014). Such low salinity results in freshwater mortality of corals, oysters and barnacles (summarised in Lewis et al. 2015).

Potential exposure to ecosystems

As *in situ* monitoring results are required to characterise and validate the potential exposure products, and as field monitoring is not conducted in this region, risk maps of potential exposure of different water types to benthic ecosystems are not produced.

Pesticides

Pesticides are monitored at one site in the region: North Keppel Island. There were no exceedances of marine water quality guidelines for individual pesticides in either year, although a range of pesticides continues to be detected (Grant et al. 2018, Gallen et al. 2019). The site is a relatively distant location (50km) from the Fitzroy River mouth.

Historically, tebuthiuron dominates the pesticide profile at this site, although concentrations are typically low.

When the toxicity of mixtures of multiple pesticides are assessed, all samples met the desired level: protective of 99% of species (i.e. less than 1% of species are affected) (Gallen et al. 2019).

Coral

Inshore coral remains poor, but has continued to improve from the very poor condition observed in 2013-2014 (Figure 18). The trend in the average score has been driven by improvements over the same period in coral change, coral composition, and juvenile density, which are indicators of recovery. However, there has been little change in coral cover, which may be resisted by persistent high levels of macroalgae. As reefs living in turbid waters, there are more positive scores from indicators measured at 2m rather than at 5m depths (Thompson et al. 2019).

The current condition of reefs in the Fitzroy region is still influenced by:

- the cumulative impacts of thermal stress in 2006
- a series of cyclones and storms
- flooding of the Fitzroy River that exposed corals to lethal levels of low salinity (Jones and Berkelmans 2014), and introduced high loads of nutrients and suspended sediments into Keppel Bay.

These pressures substantially reduced coral cover across the region after 2009-2010, which led to a four-year decline in the average score and other indicators (Figure 18). A combination of high water temperature in 2016 and 2017, and floods in 2017, have likely suppressed recent recovery (Thompson et al. 2019). While not resulting in substantial loss of cover, high temperatures did result in coral bleaching (Kennedy et al. 2018) and this stress is likely to have reduced the rate of coral cover increase.

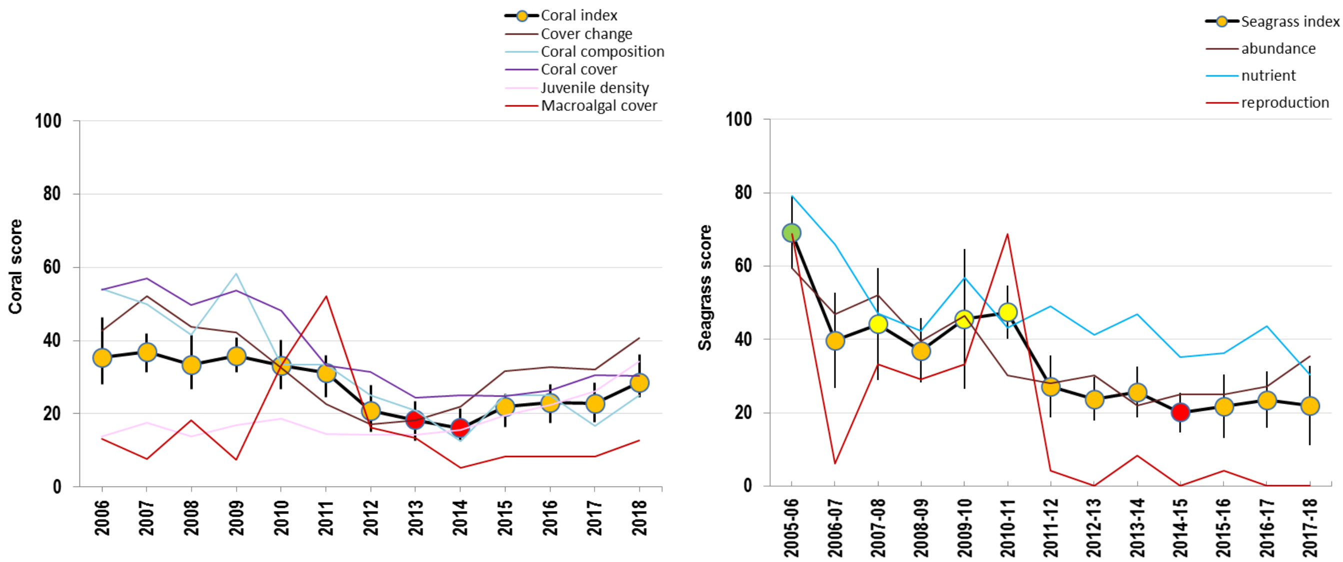

Figure 18. Coral scores (left) and seagrass scores (right) for the Fitzroy region from 2006 to 2018. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent 95% confidence limits. Note: Scores are unitless. Data source: (Thompson et al. 2019) and (McKenzie et al. 2019).

Seagrass

Seagrass meadow condition remains poor but has been stable for the last three years in the Fitzroy region (Figure 18). Slight improvements in the abundance have been offset by declines in nutrient status and very poor reproductive effort since 2011-2012 (McKenzie et al. 2018; McKenzie et al. 2019).

Improvements in abundance were variable between sites. The extent of the coastal meadows in Shoalwater Bay has remained stable and at the maximum since monitoring commenced in 2005. Conversely, meadows on the reef flat at Great Keppel Island remained highly fragmented after losses in 2016 and show little sign of recovery because of unstable sediments. Approximately 67% of sites in the Fitzroy region improved in abundance in the 2017-2018 year, but half of the estuary and reef sites decreased relative to the previous period (McKenzie et al. 2019). The improved abundances at many sites reflected a period of below average river discharge, improved benthic light, together with improved reproductive effort and a persistent seed bank. These improvements were observed despite elevated temperatures for the fifth consecutive year.

The long-term trend in seagrass abundance across the region is one of decline, primarily influenced by significant decreases in estuary and reef habitats. The low abundance in estuary meadows appears to be due to extensive scarring and sediment deposition in 2016-2017. These meadows should recover because the scarring has abated and the meadow is showing signs of recovery such as shoot extension and improved meadow integrity (McKenzie et al. 2019). The deteriorating condition of the reef habitats after losses in 2016 remains a concern. The reef meadows remain highly fragmented, dominated by colonising species and show little sign of recovery. Reproductive effort remains very low and seed banks are absent (McKenzie et *al.* 2019).

Seagrass leaf nutrients (carbon:nitrogen ratios) continue to indicate a surplus of nitrogen relative to the need for photosynthetic carbon assimilation. However, there is no indication of elevated nitrogen across the region. This is indicated by low epiphyte loads and macroalgae cover (McKenzie et al. 2019).

Annual within-canopy light was lower than average in 2016-2017 following Severe Tropical Cyclone Debbie, but in contrast was the highest in seven years across all habitats in 2017-2018. Lower than average number of days in which wind speeds exceeded 25km hr^{-1} occurred, reducing suspension of fine sediments in the water column, and lowering tide heights. This would have facilitated light reaching the meadows. However, this impact could be counterbalanced by potentially increased intertidal exposure (McKenzie et al. 2019).

In summary, inshore seagrass meadows across the region remain in the early stages of recovering from multiple recent years of climate related impacts. The coastal habitats have been improving, while other habitats demonstrate a legacy of reduced resilience (McKenzie et al. 2019).

5.6. Burnett-Mary

Pressures

The Burnett Mary region received near-average river discharge in 2016-2017 and 2-3 times above the long-term river discharge in 2017-2018 year (Figure 2).

Maximum seagrass within-canopy temperatures exceeded 35°C in both years (McKenzie et al. 2018, McKenzie et al. 2019): for 10 days in 2017-2018 and for 21 days in 2016-2017. Canopy temperatures over 40°C did not occur in either year. The low frequency at which these high temperatures occurred indicates burning or mortality was unlikely.

Water quality based on in situ monitoring

In situ monitoring of water quality is not undertaken in the Burnett Mary region.

Potential exposure of pollutants to ecosystems

As *in situ* monitoring results are required to characterise and validate the potential exposure products, and as field monitoring is not conducted in this region, risk maps of potential exposure of different water types to benthic ecosystems are not produced

Pesticides

Pesticides monitoring is not undertaken in the Burnett Mary region.

Seagrass

Seagrass meadows across the Burnett Mary region were in poor condition in 2015-2016 and very poor condition in 2017-2018, despite a very small change in the average score (Figure 19). While this is the lowest grade for seagrass in the last five years, it returns meadows to the same state observed for three years (2010-2011 to 2012-2013). This other period of very poor condition was preceded by five years of declining abundance from the moderate state observed at the start of the monitoring (McKenzie et al. 2018; McKenzie et al. 2019). The two reporting years have revealed a complete collapse in reproductive effort, but the long-term record reveals two periods of resurgent abundance that was followed by a rapid improvement in the reproductive indicator over the one to two years (Figure 19). It may be that these meadows are more ephemeral than most.

Only intertidal estuarine and coastal seagrass meadows located in bays protected from south-easterly winds and wave action have been monitored by the Marine monitoring program. The choice of sites may be partly responsible for the observed dynamics. While seagrass meadow distribution remained stable in 2017-2018, seagrass abundance varied between habitats across the region. Percent cover was lower than the previous year at two-thirds of sites, but this trend was countered by high and/or improved abundance at the remaining sites. Annual within-canopy light was slightly lower than average in both 2017-2018 and 2016-2017. Above-average river discharge resulted in slightly lower benthic light during the peak seagrass growing period, which may also have contributed to the poor current state of the monitored meadows (McKenzie et al. 2019).

Nutrient status remained poor in 2017-2018 (Figure 19) and continues to indicate surplus (elevated) availability of nitrogen relative to that required photosynthetic carbon uptake (McKenzie et al. 2019). Although macroalgae abundance remained low across the region, epiphyte loads on the blades of seagrass in estuarine habitats remained above the long-term average. These burdens may limit the light available for photosynthesis and tissue growth (McKenzie et al. 2019). High water temperatures, coupled with lower benthic light, may have imposed chronic stress conditions on the seagrass, further constraining their growth.

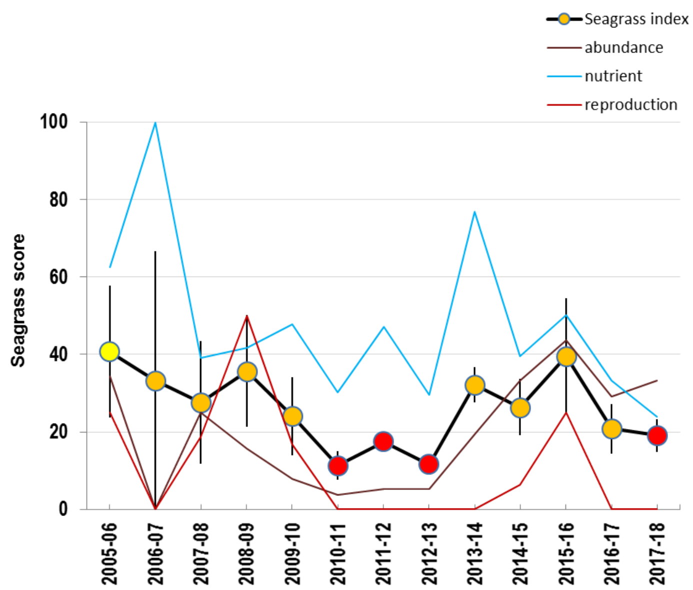

Figure 19. Seagrass scores for the Burnett-Mary region from 2006 to 2018. Values are indexed scores scaled from 0-100; ■ = very good (81-100). ■ = good (61-80), ■ = moderate (41-60), ■ = poor (21-40), ■ = very poor (0-20). Vertical bars represent 95% confidence limits. Note: Scores are unitless. Data source: (McKenzie et al. 2019).

Between 2012-2013 and 2015-2016, meadows were on a recovery path (Figure 19). The proportion of seagrass species displaying colonising traits declined in meadows in both reporting years. Hence the potential for recovery remains but the very poor condition of the reproductive indicator and local seed banks poses a challenging obstacle (McKenzie et al. 2019).

Glossary

Ecosystem: dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit

Ecosystem health: ecological processes, biodiversity and function of biological communities is maintained.

eReefs: coupled hydrodynamic and biogeochemical models of water quality and ecosystem condition for the Marine Park <https://research.csiro.au/ereefs/models/>

Exposure categories: the proportional exceedance of the water quality guidelines (Great Barrier Reef Marine Park Authority 2018) (of sediment and nutrient parameters during the wet season and focuses on total suspended solids, Chlorophyll *a*, particulate phosphorus and particulate nitrogen concentrations) multiplied by the likelihood of exposure in each of the water types. Overall exposure scores are categorised into four equally-distributed potential risk categories (I to IV). Exposures risk is termed 'potential' because the risk from surface plumes is not proven in ecosystem response data to confirm the ecological consequences.

Guideline value: a measurable quantity (e.g. concentration) or condition of an indicator for a specific community value below which (or above which, in the case of stressors) there is considered to be a low risk of unacceptable effects occurring to that community value

Inshore: the enclosed coastal and open coastal water bodies combined. These terms are defined and mapped under schedules in the *Environmental Protection (Water) Policy.*

ms-PAF: multisubstance-potentially affected fraction

Pollutant: a substance that is present in concentrations that may harm organisms or exceed an environmental quality standard. In this program the term refers primarily to nutrients, sediment and pesticides

Practical salinity units: a measure of conductivity at a constant pressure and temperature that is about equivalent to parts per thousand

Great Barrier Reef: Great Barrier Reef and all its constituent parts

Reef 2050 WQIP: *Reef 2050 Water Quality Improvement Plan*

Reef Plan: Reef Water Quality Protection Plan

Reef 2050 Plan: *Reef 2050 Long-Term Sustainability Plan*

Secchi depth: a measure of the clarity of water based on the Secchi disk.

Water quality index: metric based on five indicators measured *in situ*

Water quality objective: are long-term goals for water quality management. They are numerical concentration levels or narrative statements of indicators established for receiving waters to support and protect the designated environmental values for those waters. Water quality objectives are not individual point source emission objectives, but the receiving water quality objectives. They are based on scientific criteria or water quality guidelines but may be modified by other inputs (e.g. social, cultural, economic).

Wet season water types: there are three water types: primary, secondary, and tertiary referred to in this report. The term refers to waters that are distinguishable from true colour satellite imagery interpretation, and grouped into colour classes according to their optical properties. Primary, secondary and tertiary water types equate to the brownish, greenish and paler greenish-blue waters from the imagery, respectively.

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