Centre for Tropical Water and Aquatic Ecosystem Research

JAMES COOK UNIVERSITY
AUSTRALIA

ANNUAL SEAGRASS MONITORING IN THE MACKAY-HAY POINT REGION – 2017

York PH and Rasheed MA

Report No. 18/13

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Information should be cited as:
York PH and Rasheed MA 2018, 'Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2017', JCU Centre for Tropical Water & Aquatic Ecosystem Research Publication, 38pp.

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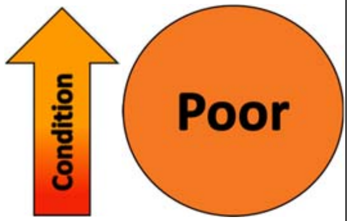
This publication has been compiled by the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.

Acknowledgments:

This project was funded by North Queensland Bulk Ports and TropWATER. We wish to thank the many TropWATER staff that helped put this project and report together. We also acknowledge Jacobs as contributors of some of the data between 2010 and 2012.

KEY FINDINGS

Offshore Seagrass Interim Condition



Likely causes of seagrass condition:

Linked to Climate

TC Debbie in March 2017

Inshore Seagrass Condition 2016

?

An interim condition score for inshore seagrasses will be available following the 2018 annual surveys after 5 years of data have been collected

- 2017 is the first year that a full condition score has been applied to the Hay Point offshore monitoring meadow incorporating area into the indices as well as biomass and species composition.

- The overall condition of offshore seagrasses in Hay Point was graded as poor, an improvement in grade from 2016 when the condition was considered very poor.

- Overall poor condition was likely influenced by disturbance from TC Debbie in March 2017, however favourable climate conditions (rainfall, river flow, light) were observed during the seagrass growing season in the months prior to the annual survey in October.

- Inshore meadows have now been monitored for seagrass condition on four occasions with an interim condition index to be available following a 5 year baseline established following the 2018 survey. Results from the 2017 survey show:

    - Inshore meadows in the Hay Point area remained in similar locations to the previous year with the return of the meadow inshore of Dudgeon Point that was absent in 2016.

    - Meadows adjacent to Keswick and St Bees Islands had increased slightly in area however biomass has declined since 2016.

IN BRIEF

A long-term seagrass monitoring program and strategy was developed for the Mackay-Hay Point region following a broad-scale baseline survey in 2014. The program built on seagrass monitoring that had been conducted at offshore areas around the Port of Hay Point since 2005, as well as numerous broad scale surveys that have been conducted since 2004. The annual monitoring program was revised in 2017 to include a broader survey and mapping of the Hay Point and Mackay offshore seagrass communities allowing for the adoption of a full seagrass condition reporting index developed by the TropWater seagrass group for ports throughout north Qld. In addition to the annual monitoring areas, a broader-scale survey of all seagrasses in the Hay Point region was also conducted in 2017.

The annual monitoring strategy assesses two offshore monitoring areas at Mackay and Hay Point, an inshore region between Dudgeon Point and Hay Point, and two inshore subtidal meadows at the Keswick Island group. Seagrass meadows in these areas represent the range of different seagrass community types found in the Mackay-Hay Point region. The offshore monitoring meadow in the Port of Hay Point has a long history of monitoring while monitoring in the other meadows only began in 2014 and natural ranges of change are still being established.

The 2017 broad-scale survey of seagrass in the Hay Point, Mackay and Keswick Island regions found seagrass present in much the same areas with roughly the same species present as seen in historical surveys since 2004, however, generally the meadows were of lower biomass. Offshore seagrasses in the monitoring area near Hay Point were in a poor condition in 2017, with biomass well below the long-term average which was driven by a year of high abundance in 2004. (Figure 1 & 3). The wider survey also showed that the offshore seagrasses were present in patchy low-biomass meadows in the greater Hay Point-Mackay area dominated by *Halophila decipiens* with *H. spinulosa* present in the northern region closer to Mackay.

The seagrass meadows around Keswick and St Bees Island increased their footprint compared to surveys conducted over the previous three years (Figure 3), however, their biomass was also lower than historical levels for the area. The inshore monitoring area around Dudgeon Point saw the return of a meadow dominated by *Halophila ovalis* which was absent in the 2016 survey. Other coastal meadows between Hay Point and the Pioneer River consisting of *Halodule uninervis* species were similar to the previous broad-scale survey in 2016, with the exception of the absence of a small meadow south of the Pioneer River in 2017.

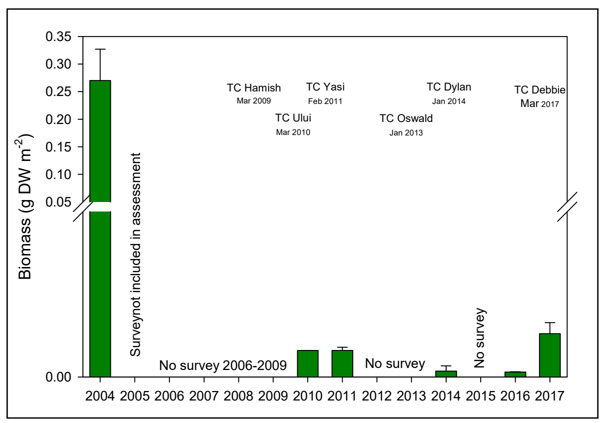


Figure 1. Mean seagrass biomass of Hay Point offshore monitoring site

Tropical cyclone Debbie, which impacted the Mackay area for several days in late March of 2017 was the major event likely to have influenced the condition of seagrass communities in the 12 months since the previous survey. The inshore meadows around Dudgeon Point would have sustained a combination of high rainfall, flood plumes and increased wave/wind activity that can severely impact seagrass either physically (e.g. burial, scouring, direct removal of plants and seed-banks) or physiologically (light limitation, excess nutrients and herbicides, and changes in salinity). As these meadows are dominated by *Halodule uninervis* which is a much more resistant species than the deeper water seagrasses it seems they were able to withstand the disturbance from the cyclone in most meadows with reductions in biomass.

Seagrasses around Keswick and St Bees Islands are considerably further offshore and less susceptible to turbid plumes from coastal flooding therefore water quality would have returned to favourable conditions soon after the cyclone and rainfall events passed. This shorter period of disturbance may have allowed the *Halophila* at these sites to resist the poor conditions during the cyclone suffering loss of biomass but with the remaining seagrass and/or seed bank allowing the meadows to persist or re-establish.

The cyclone occurred during the senescent season for seagrass in the deep-water *Halophila* meadows off Hay Point when above ground seagrass was absent. Therefore associated rainfall and flood plumes would have been negligible to the health of these meadows. The high energy environment and large waves associated with the passing of the cyclone, however, may have disturbed bottom sediments and relocated, buried or removed many of the seeds from the seedbank potentially resulting in decreased germination and recruitment during the seagrass growing season.

More generally, climate conditions for seagrass growth were favourable for much of the year. Although rainfall and river flows were above average (Figure 2), this was mainly driven by two extreme rainfall events. Low rainfall in the three month period leading into the survey in October 2017 would have allowed for the recovery of meadows following the impacts of TC Debbie.

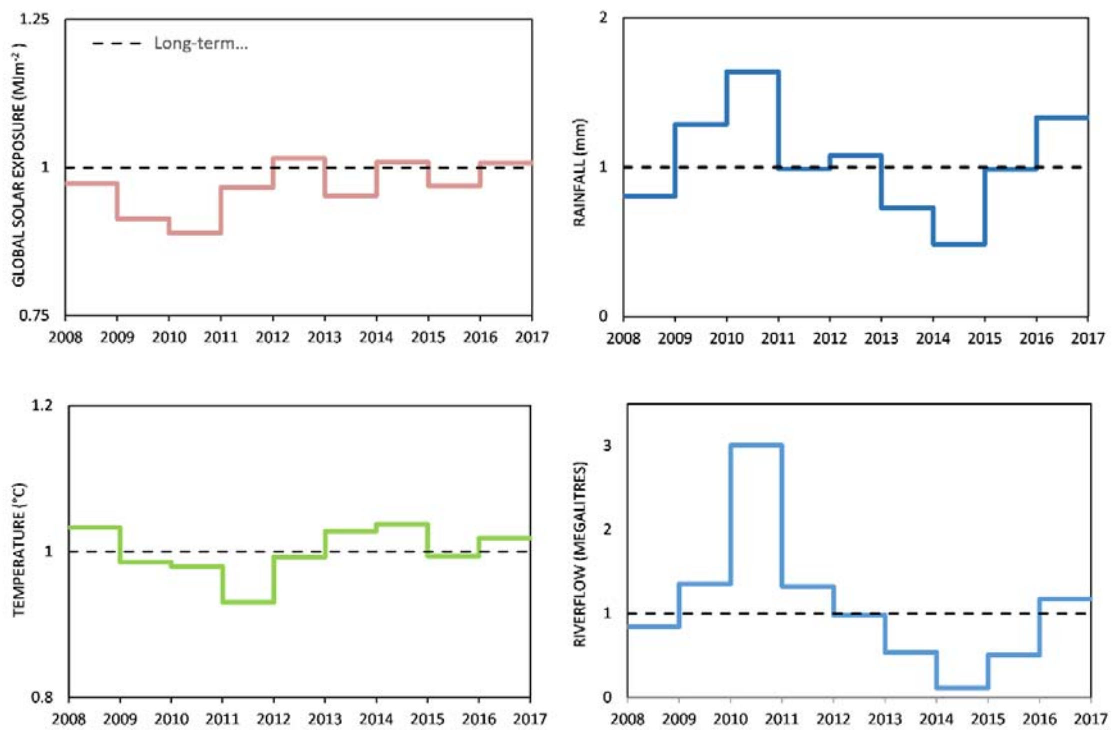


Figure 2. Recent climate trends in the Hay Point Area: change in climate variables as a proportion of the long-term average. (See section 3.5 for detailed climate data).

The deep-water seagrass meadows offshore from the ports of Hay Point and Mackay consist of colonising *Halophila* species with annual occurrence from July to December. The meadows show naturally high inter-annual variability in biomass and meadow area indicating they are living at the margins of their environmental tolerances. This makes them highly susceptible to collapse with disturbance, although they also have the ability to rapidly recover by relying on a seed bank to regenerate. Management programs that consider the timing, and where possible limit the duration and/or intensity of anthropogenic disturbances can improve outcomes for seagrass meadows and maintain and enhance their resilience.

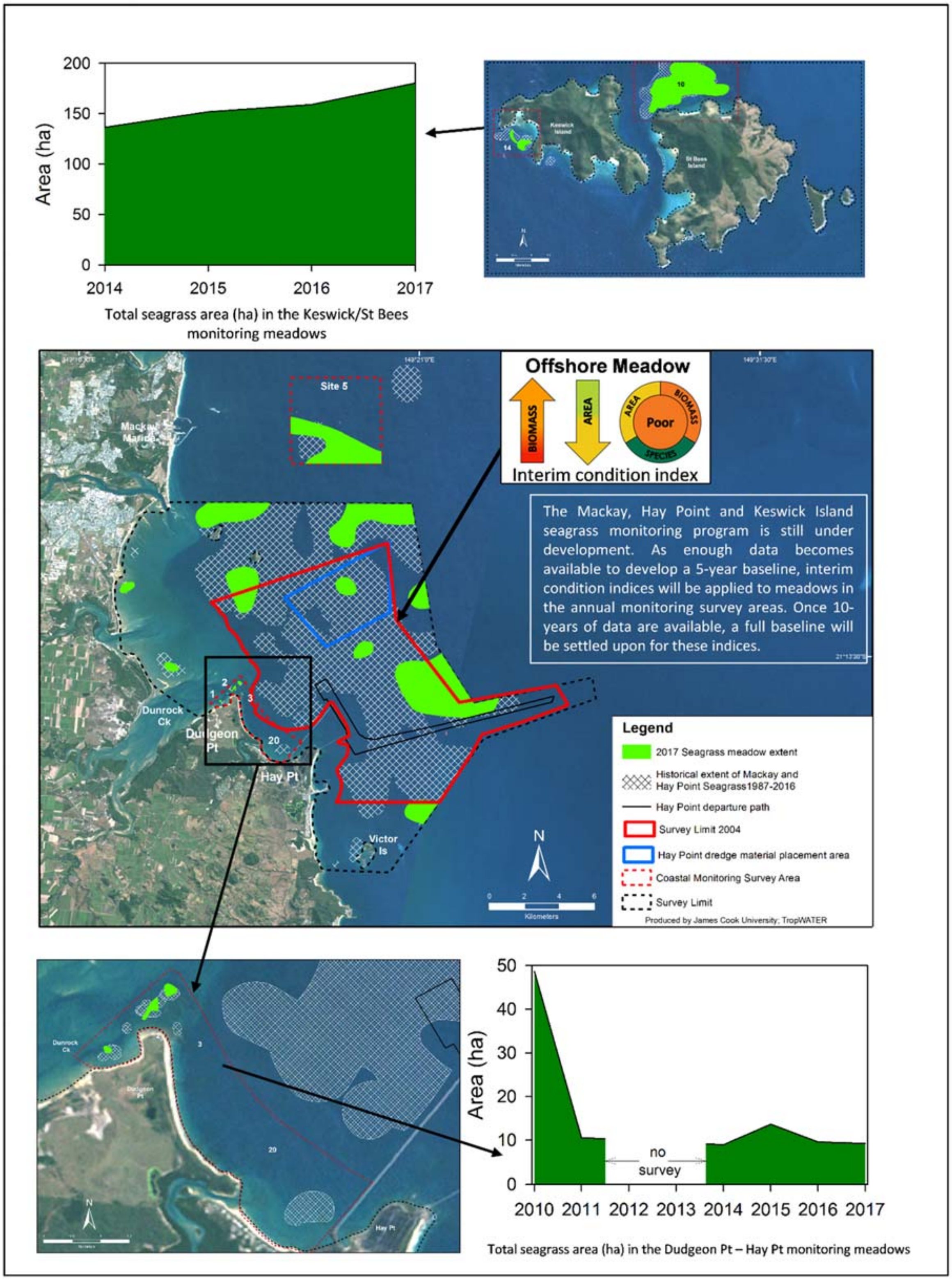


Figure 3. Seagrass meadow condition for the ports of Mackay and Hay Point, and Keswick/St Bees Island 2017

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1 INTRODUCTION

Seagrasses are one of the most productive marine habitats on earth and provide a variety of important ecosystem services worth substantial economic value (Costanza et al. 2014). These services include the provision of nursery habitat for economically-important fish and crustaceans (Coles et al. 1993; Heck et al. 2003), and food for grazing mega herbivores like dugongs and sea turtles (Heck et al. 2008; Scott et al. 2018). Further, seagrasses play a major role in the cycling of nutrients (McMahon and Walker 1998), stabilisation of sediments (Madsen et al. 2001), improving of water quality (McGlathery et al. 2007) and recent studies suggest they are one of the most efficient and powerful carbon sinks in the marine realm (Fourqurean et al. 2012; Lavery et al. 2013; Pendleton et al. 2012).

Globally, seagrasses have been declining at increasing rates due to both natural and anthropogenic causes (Waycott et al. 2009). Explanations for seagrass decline include natural disturbances such as storms, disease and overgrazing by herbivores, as well as anthropogenic stresses including direct disturbance from coastal development, dredging and trawling, coupled with indirect effects through changes in water quality due to sedimentation, pollution and eutrophication (Short and Wyllie-Echeverria 1996; York et al. 2015). Locally, in the Great Barrier Reef (GBR) coastal region, the hot spots with highest threat exposure for seagrasses all occur in the southern two thirds of the GBR, in areas where multiple threats accumulate including urban, port, industrial and agricultural runoff (Grech et al. 2011). These hot-spots arise as seagrasses preferentially occur in the same sheltered coastal locations that ports and urban centres are established (Coles et al. 2015). In Queensland this has been recognised and a strategic monitoring program of these high risk areas has been established to aid in their management and ensure impacts are minimised (Coles et al. 2015).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in the majority of Queensland commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with the various Queensland port authorities. While each location is funded separately and they have a range of requirements for use of the information, a common methodology and rationale is utilised to provide a network of seagrass monitoring locations throughout the state (Figure 4).

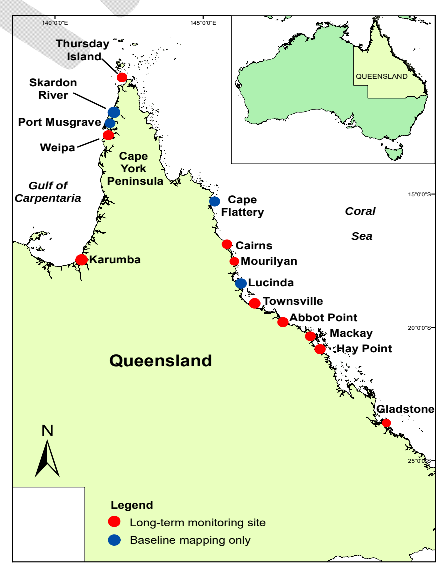

Figure 4. Location of Queensland Port Seagrass assessment sites

A strategic long-term assessment and monitoring program for seagrasses provides port managers and regulators with the key information to ensure effective management of seagrass resources. It is useful information for planning and implementing port development and maintenance programs so they have a minimal impact on seagrasses. The program also provides an ongoing assessment of many of the most threatened seagrass communities in the state.

The program not only delivers key information for the management of port activities to minimise impacts on seagrass habitat but has also resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses, and an understanding of the drivers of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses.

For more information on the program and reports from the other monitoring locations see www.jcu.edu.au/portseagrassqld

1.2 Mackay and Hay Point Seagrass Monitoring Program

The Port of Hay Point (approximately 38 km south of Mackay) is one of the world's largest coal exporting ports and comprises two coal export terminals; Dalrymple Bay Coal Terminal (DBCT) leased from the State Government by DBCT Management Pty Ltd and the Hay Point Coal Terminal (HPCT) owned by BHP Billiton Mitsubishi Alliance (BMA). The Port of Mackay is a multi-commodity port mainly exporting sugar and grain, and located 5km from the city of Mackay. The Port comprises four wharves and a harbour formed by rock breakwaters. North Queensland Bulk Ports (NQBP) is the port authority for the Port of Hay Point and the Port of Mackay.

TropWATER's Seagrass Ecology Group first mapped significant areas of seagrass within the Port of Hay Point in a benthic survey conducted in July 2004 (Rasheed et al. 2004) and in Mackay in 2001 (Rasheed et al. 2001). The broad scale habitat surveys that have since occurred at Hay Point (2005, 2010, 2011, 2014, 2016 and 2017), as well as the seagrass monitoring program that ran between 2005 and 2012 has established that the majority of seagrass in the area is of low density and cover (< 1 gdw m^{-2} and < 5% cover) and the spatial extent of deep water seagrasses around Hay Point is naturally extremely variable with an annual cycle of occurrence; deep water seagrass being present within the period from July to December each year (York et al. 2015). The broad scale surveys and current monitoring program similarly show that inshore seagrass meadows at Hay Point tend to be highly variable both in distribution and species composition. The small Dudgeon Point meadows while consistently present have experienced changes in species composition from being dominated by the colonising *H. decipiens* species to the more persistent *Z. muelleri* and *H. uninervis*.

The monitoring program between 2005 and 2012 found that Hay Point deep water seagrass meadows were susceptible to impacts associated with large-scale capital dredging operations, but recovered quickly once dredging was completed (York et al. 2015). York et al. (2015) found that deep water seagrasses at Hay Point, despite considerable inter annual variability, had a regular annual pattern of occurrence, low resistance to reduced water quality but a capacity for rapid colonisation on the cessation of impacts. Extensive and persistent turbid plumes from a large scale and extended dredging program (in 2006) over an eight month period resulted in a failure of the seagrasses to establish in 2006, however recruitment occurred the following year and the regular annual cycle was re-established (York et al. 2015).

NQBP recognise that seagrasses form a key ecological habitat in the Mackay-Hay Point region and commissioned TropWATER to re-establish and expand on the long-term seagrass monitoring program that was conducted between 2005 and 2012. The broad-scale survey conducted in 2014 was used as a platform to re-establish the program, and additional monitoring in the Keswick Island (southern Whitsunday Islands) and Mackay areas were also added (Figure 5). The long-term monitoring program coupled with regular broad scale surveys and other research programs being conducted in the Hay Point region by TropWATER enhance our understanding of water quality, seagrass and benthic habitat community dynamics, and enable more effective management of valuable marine habitats and marine port environments. Information collected in these programs aims to assist in planning and managing future developments in coastal areas. The monitoring program also forms part of Queensland's network of long-term monitoring sites of important fish habitats in high risk areas. It also provides a key input into the condition and trend of seagrasses in the Mackay-Whitsundays NRM region, an area which otherwise has a poor spatial coverage for seagrass assessment and condition.

From the 2017 there has been a change in approach to annual monitoring and reporting of the highly variable offshore seagrasses at Hay Point, from focusing on the fixed blocks originally established to detect changes from the 2006 capital dredging program, to a more expansive meadow scale assessment with an increased sampling effort. This change has been implemented due to the extreme spatial variability in the footprint of these seagrasses limiting the effectiveness of the fixed design. The new level of sampling is achieved by spreading sampling during annual monitoring to cover the same spatial footprint as the original 2004 baseline survey. Historically, this was already done in baseline surveys at intervals covering several years beginning in 2004. This historical sampling covering the 2004 survey limit allows for the calculation of an interim seagrass condition score for reporting to continue with the additional advantage of incorporating change in seagrass area to the assessment. When a 10-year baseline has been established over the broader spatial footprint of the 2004 survey limit this condition index will become permanent. Surveys of the annual inshore monitoring areas offshore from Mackay, inshore at Dudgeon-Hay Point and at Keswick/St Bees Island will also be used to calculate seagrass condition scores for these areas which will be reported on once 5-years of baseline of survey data has been established. The change brings the assessment in line with seagrass monitoring programs in other ports and significantly improves the monitoring program's power to understand seagrass changes.

This report presents the findings of the annual seagrass habitat monitoring survey conducted in October 2017 including a survey of a broader baseline area covering the 2014 survey limits and the broader sampling of inshore meadows within this region. The objectives of these studies were to:

- Map seagrass distribution and determine seagrass density and community type at the identified monitoring areas including the broader seagrass area of Hay Point outside of annual monitoring meadows;
- Compare results of monitoring surveys and assess any changes in seagrass distribution and abundance in relation to natural events or human induced port and catchment activities;
- Incorporate the results into the Geographic Information System (GIS) database for the Mackay-Hay Point region;
- Provide an interim seagrass condition score for the first time that incorporates the 2004 survey limits for offshore meadows;
- Build on historical data sets to establish a baseline of temporal change for annual monitoring areas with the goal of incorporating findings for the Mackay/Hay Point region into a report card system for seagrass condition developed across ports inshore of the GBR.
- Discuss the implications of monitoring results for overall health of the Mackay-Hay Point marine environment and provide advice to relevant management agencies.

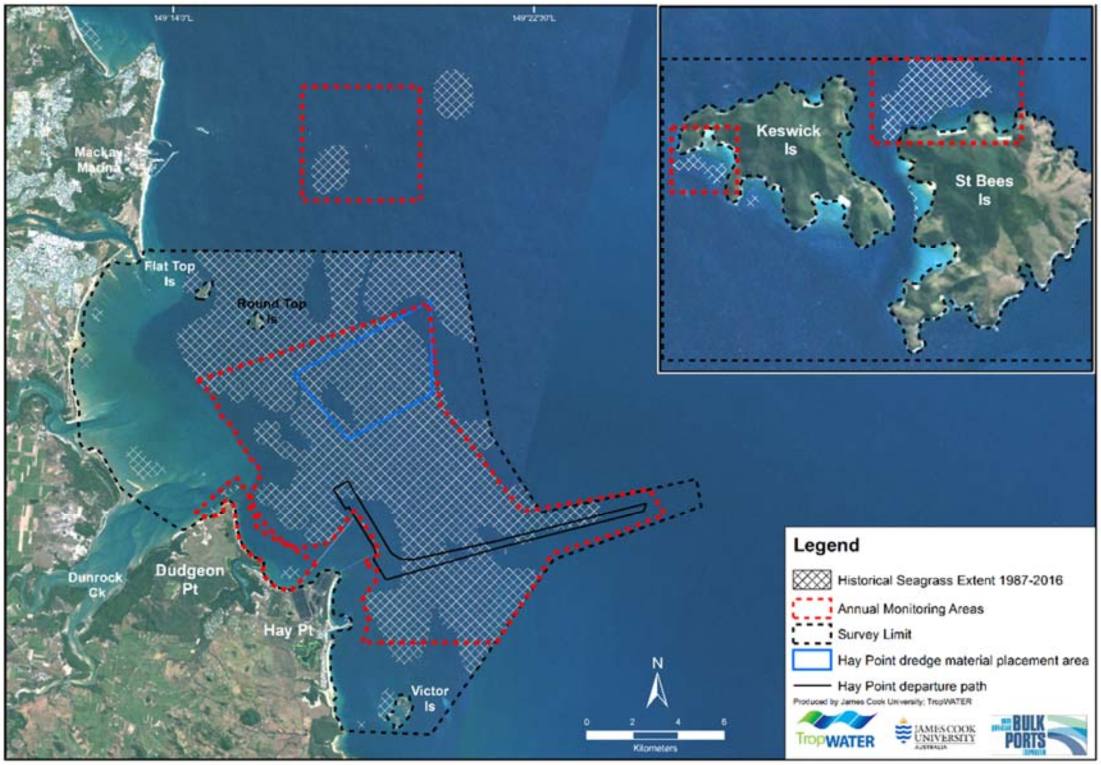

Figure 5. Location of survey limits and annual seagrass monitoring areas around Mackay, Hay Point and the Keswick Island group.

2 METHODS

2.1 Survey Approach

A broad-scale survey of the greater Hay Point area seagrass communities was conducted in 2017 along with annual monitoring of offshore seagrass off Mackay and the two annual monitoring areas at Keswick and St Bees Islands in the Southern Whitsunday region (Figure 5). The broad-scale mapping of Hay Point meadows was also undertaken in 2014 and 2016 and is scheduled to occur again in 2020. This same approach of annual monitoring of representative meadows with a broader survey every three years has now also been adopted as part of NQBP's long-term seagrass programs in the Ports of Weipa and Abbot Point, and elsewhere in other Queensland ports.

Annual surveys are conducted between September and December to capture seagrasses at their likely seasonal peak in distribution and abundance, and to facilitate comparisons with the previous surveys conducted in the area.

Methods implemented followed previous surveys, and employed standard and extensively reviewed techniques applied for baseline assessments and monitoring of seagrasses and other benthic communities in Queensland including; Gladstone, Cairns, Mourilyan, Karumba, Abbot Point, Weipa, Torres Straits and Townsville. Techniques in offshore areas ensure that a large area of seafloor is integrated at each site to take into account the low density, spatial variability and patchiness common for many tropical benthic habitats, as well as logistical issues associated with naturally high water turbidity and the presence of dangerous marine animals. These standardised methods were used to ensure that new information collected would be directly comparable with existing and past programs.

2.2 Survey Methods

Sampling methods applied were based on existing knowledge of benthic habitats and physical characteristics of the area such as depth, visibility and logistical and safety constraints. Three sampling techniques were used:

1. Shallow subtidal areas <8m below MSL: Free diving;
2. Subtidal inshore areas >8m below MSL: Boat based underwater digital camera mounted on a drop frame;
3. Offshore subtidal areas >8m below MSL: Boat based digital camera sled tows with sled net attached.

At each survey site, seagrass habitat observations included seagrass species composition, above-ground biomass, percent algal cover, depth below mean sea level (MSL), sediment type, time and position (GPS). The percent cover of other major benthos at each site was also recorded.

At sites where seagrass presence was noted seagrass above-ground biomass was determined. Above-ground seagrass biomass was determined using a "visual estimates of biomass" technique (Kirkman 1978; Mellors 1991). At free diving and camera drop sites this technique involved an observer ranking seagrass biomass within three randomly placed 0.25m^2 quadrats at each site (Figure 6A-C). At digital camera sled tow sites this technique involved an observer ranking seagrass at 10 random time frames allocated within the 100m of footage for each site (Figure 6D-F). The video was paused at each of the ten time frames then advanced to the nearest point on the tape where the bottom was visible and sled was stable on the bottom. From this frame an observer ranked seagrass biomass and species composition. A 0.25m^2 quadrat, scaled to the video camera lens used in the field, was superimposed on the screen to standardise biomass estimates.

Biomass ranks at all sites are made in reference to a series of quadrat photographs of similar seagrass habitats for which above-ground biomass has previously been measured. The relative proportion of the above-ground biomass (percentage) of each seagrass species within each survey quadrat was also recorded. Field biomass ranks were then converted into above-ground biomass estimates in grams dry weight per square metre (g dw m^2). At the completion of sampling, each observer ranked a series of calibration quadrats that represented the range of seagrass biomass in the survey. After ranking, seagrass in these quadrats were harvested and the actual biomass (separated by species) determined in the laboratory. A separate regression of ranks and biomass from these calibration quadrats was generated for each observer and applied to the field survey data to standardise the above-ground biomass estimates.

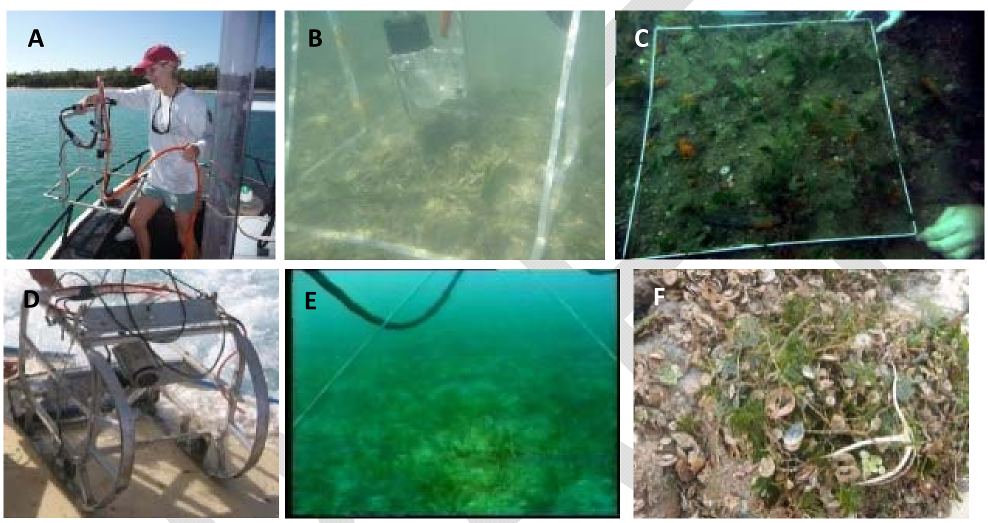

Figure 6. (A – B) Shallow subtidal mapping of seagrass meadows using digital camera mounted on a $0.25m^2$ drop frame, (C) freediving and (D-F) offshore underwater sled tows with digital camera.

All survey data was entered into a Geographic Information System (GIS) database for presentation of seagrass species distribution and density. Three GIS layers were created in ArcGIS to describe the seagrass habitat in the survey areas:

- **Habitat characterisation survey sites** - site data containing above-ground biomass (total and for each species), depth below mean sea level (MSL), sediment type (based on visual estimates), latitude and longitude from GPS fixes, sampling method and comments.

- **Seagrass meadow biomass and community types** - Area data for seagrass meadows with summary information on meadow characteristics. Seagrass community types were determined according to overall species composition from nomenclature developed for seagrass meadows of Queensland (Table 1). This system was based on the percent composition of biomass contributed by each species within the meadow. This layer also included a measure of meadow density that was determined by the mean above-ground biomass of the dominant species within the community (Table 2).

- **Seagrass landscape category** - Area data for seagrass meadows showing the seagrass landscape category according to the below descriptions:

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

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

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

Table 1. Nomenclature for seagrass community types in Queensland.

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

Table 2. Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density in Queensland.

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

The boundary of seagrass meadows was mapped by free diving, underwater camera techniques and the distance between sites, and then assigned a mapping precision estimate (±ha) (Table 3). The precision of the boundary was determined using an estimate of mapping reliability (R) based on the distance between sampling sites. This resulted in a range of meadow sizes which is expressed as an error (±ha) around the total meadow area (ha).

Table 3. Mapping precision and methodology for boundary mapping in the Port of Hay Point and Keswick Island group.

Mapping precision	Mapping methodology
20-30 m	Subtidal meadow boundaries determined from free diving surveys; Relatively high density of survey sites; Recent aerial photography aided in mapping.
30-100 m	Subtidal meadow boundaries determined from free diving and underwater CCTV camera drops; Moderate to high density of survey sites; Recent aerial photography aided in mapping.
300 m	Larger subtidal meadows with boundaries determined from underwater CCTV and sled tows; All meadows subtidal; Relatively low density of survey sites.

2.3 Seagrass meadow condition index

A condition index was developed for the Hay Point seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator in Hay Point was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). The flow chart in Figure 7 summarises the methods used to calculate seagrass condition. See Appendix 1 for full details of score calculation.

At this stage, the condition index is only be applied to the offshore monitoring sites at Hay Point, the dominant seagrass habitat in the area. This condition is currently based on a 6-year baseline of data (2004, 2010, 2011, 2014, 2016 & 2017) which will vary until 10 years of data become available to establish a permanent baseline. The survey conducted in 2005 in the monitoring area was excluded from the baseline calculation as it was conducted late in the year (December) a time period when the dominant species for the meadow (*Halophila decipiens*) was likely to have already died off for the season leaving only a small patch of much higher biomass *H. spinulosa* remaining. Including this small patch as representing the entire offshore seagrass meadow would result in significantly skewing the biomass data in the baseline. Currently, there is insufficient data at the other annual monitoring areas to establish an interim baseline for the condition index, however this will be able to occur in the Dudgeon-Hay Point inshore and at the Keswick and St Bees monitoring meadows following the 2018 survey.

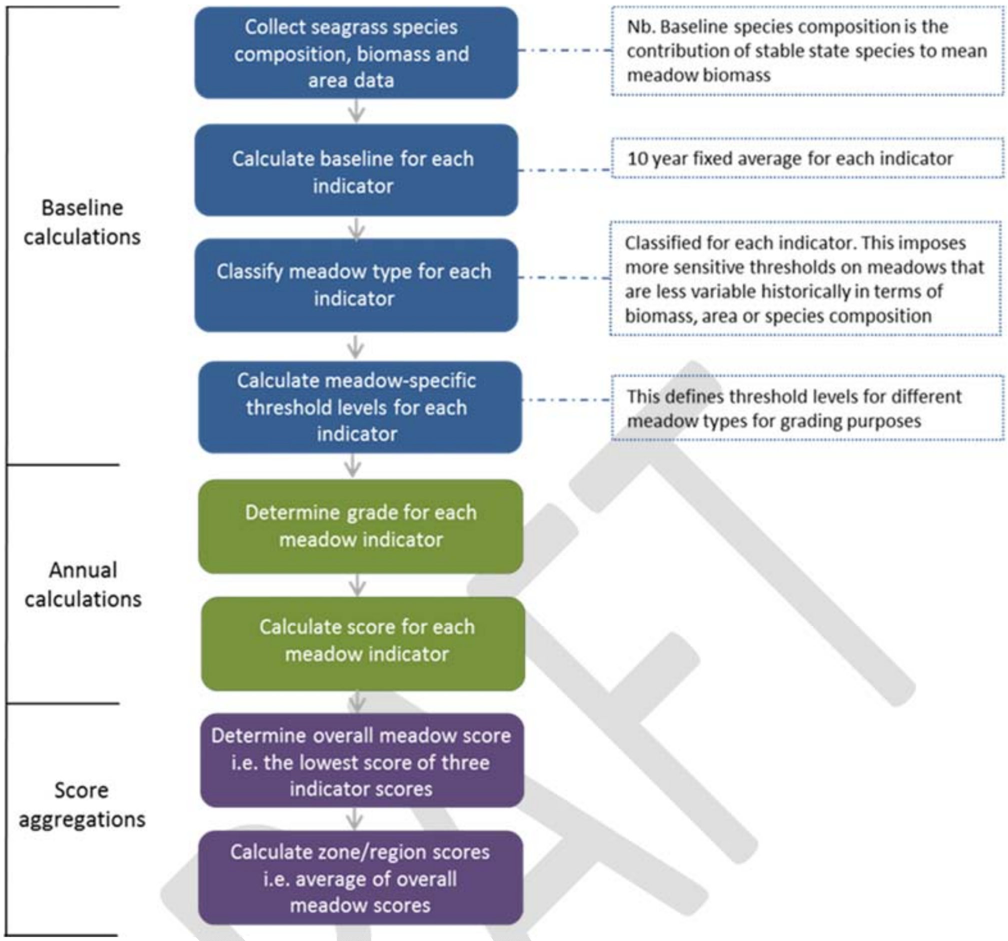

Figure 7. Flow chart to develop Hay Point grades and scores.

3 RESULTS

3.1 Seagrass in the Hay Point, Mackay and Keswick Island areas

A total of 367 sites were surveyed as part of the annual monitoring and broader scale survey in the Hay Point, Mackay and Keswick Island area in October 2017 (Figure 9). Seagrass was present at 18.2% of the inshore sites (Dudgeon/Hay Point & Keswick/St Bees Islands) and at 21.4% of the offshore sites within the broader study boundary (Hay Point & Mackay; Figure 9). Deep-water seagrass communities offshore from Hay Point and Mackay covered and area of 3555.6 ± 2524.7 ha in the broad-scale survey while inshore on the coast and adjacent to Keswick and St Bees Islands seagrass covered 256.9 ± 129.9 ha (Tables 5-8).

Five seagrass species were observed in 2017 (including the broad scale survey sites) (Figure 8). Deepwater assemblages were dominated by *Halophila decipiens* with *H. spinulosa* also occurring in two sites in the Mackay Offshore monitoring area and also at one site in the broader Hay Point survey north of the annual monitoring area (Figure 10, Appendix 2). *Halophila tricostata* dominated the two meadows in the Keswick Island region with small amounts of *H. decipiens* also occurring in both meadows and *Halodule uninervis* (narrow) being detected in the meadow north of St Bees Island for the first time since 2015 (Figure 10, Appendix 2). *Halophila tricostata* had been found in the offshore sites within the broad-scale survey in 2016 for the first time in 2016 but it was not detected in the 2017 survey. *Halodule uninervis* (both wide and narrow forms) dominated the inshore meadows of the coastline between Hay Point and Mackay with *H. ovalis* returning to Meadow 1 at Dudgeon Point in the annual monitoring area for the first time since 2014. Z*ostera muelleri* has also been found in this meadow, however this was only once during past monitoring events in 2014. The seagrass species found in the survey area were typical of those found for coastal and offshore seagrasses both in Hay Point and more broadly in central Queensland (Table 8, Figure 10, Appendix 2).

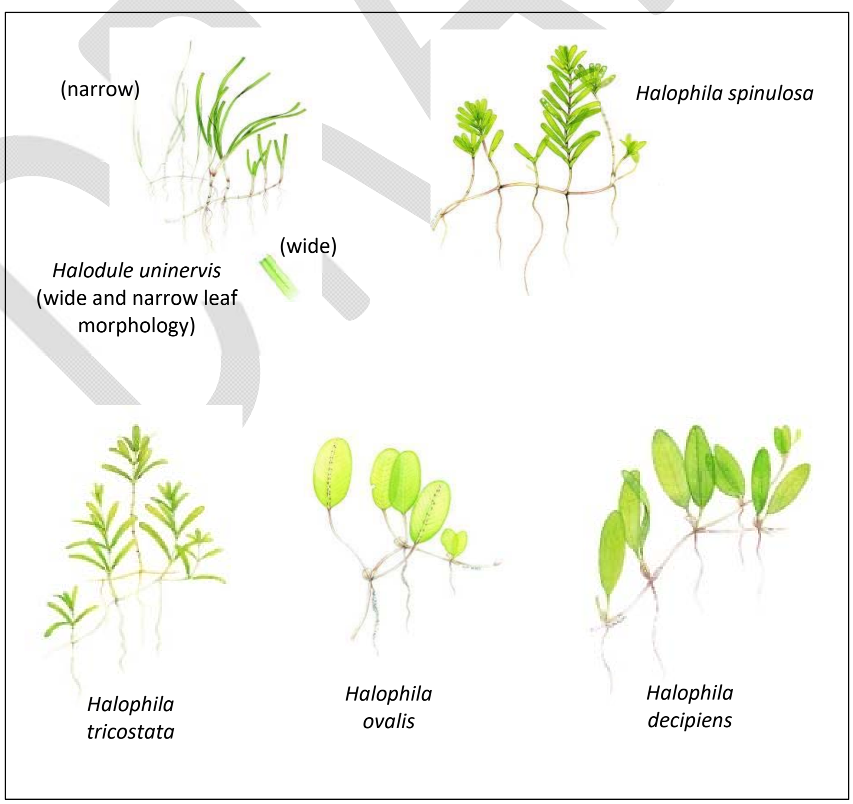

Figure 8. Seagrass species identified in the Hay point annual monitoring program in 2017.

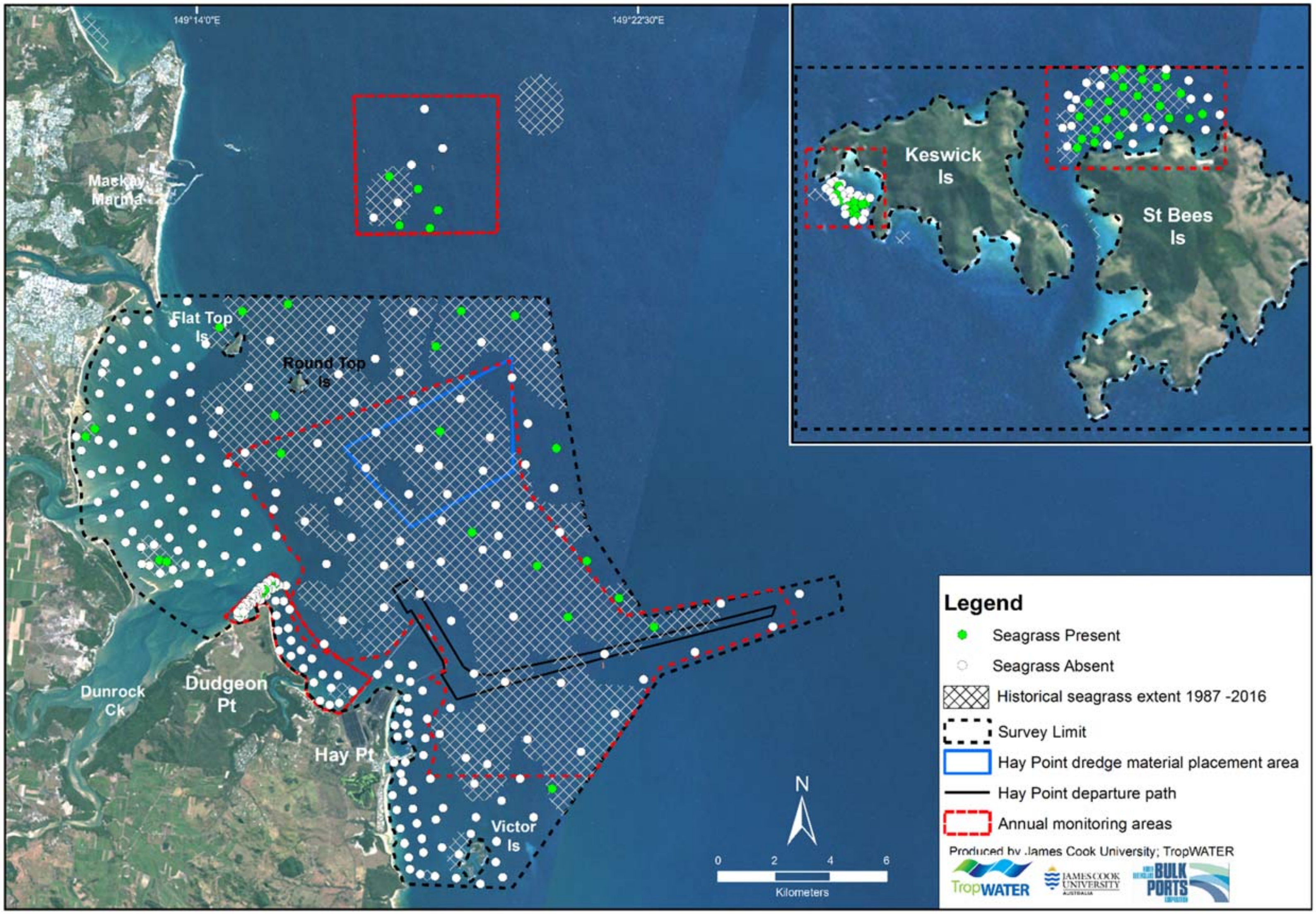

Figure 9. Location of 2017 annual seagrass monitoring survey sites in the Hay Point region.

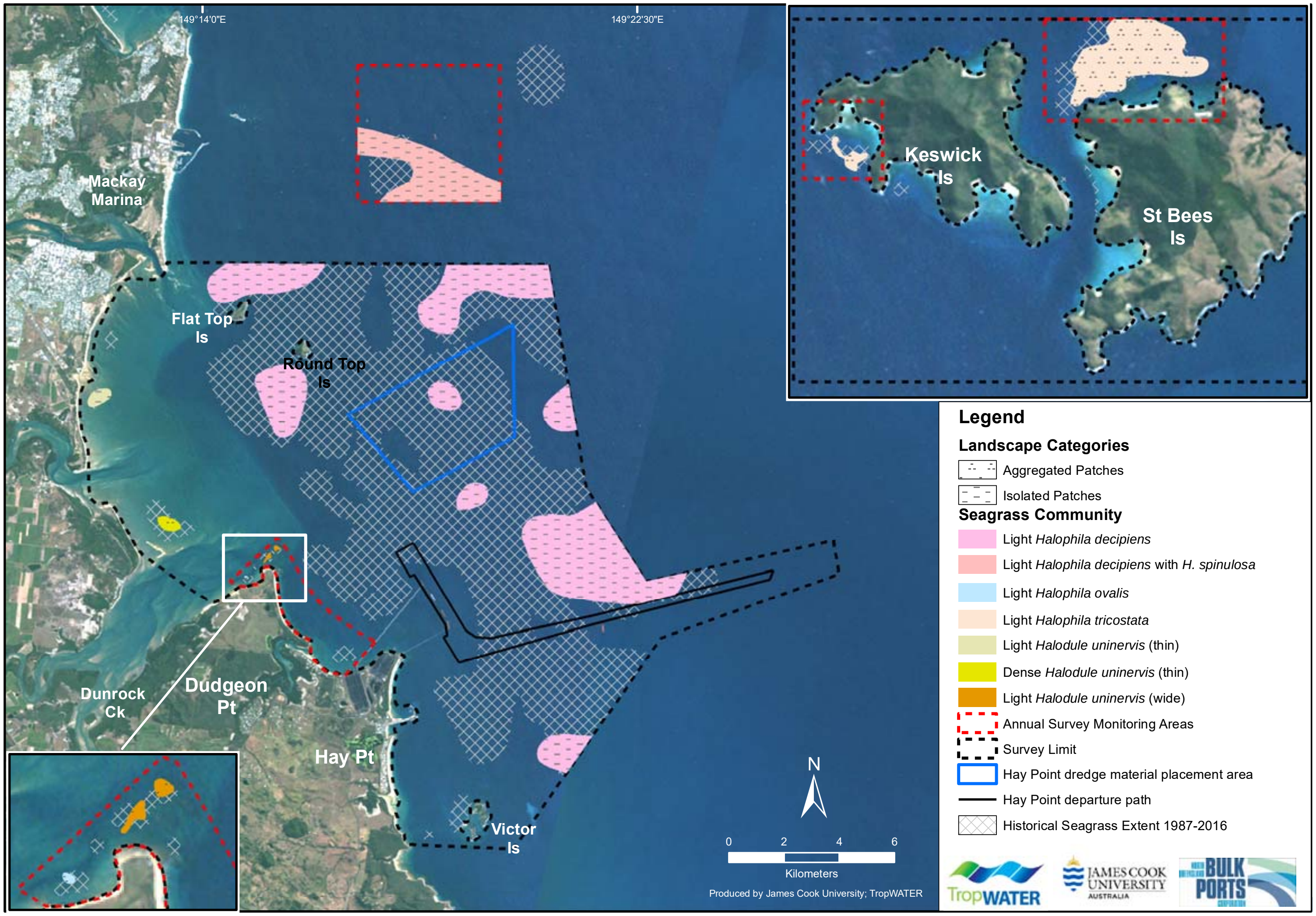

Figure 10. Location of 2017 seagrass meadows in the Hay Point region showing seagrass communities and landscape categories.

3.2 Seagrass condition in the Hay Point and Keswick Island monitoring areas

Offshore seagrass at Hay Point and Mackay

The 2017 survey is the first year that a full condition score has been applied to the Hay Point offshore monitoring meadow (set at the 2004 survey limit: Figure 9). An interim six-year average baseline from surveys completed in 2004, 2010, 2011, 2014, 2016 and 2017 was established to compare to the current survey. The baseline will remain an interim measure until 10 years of data have been collected, so the current baseline will shift over the next four survey years. The overall condition of offshore seagrasses in the Hay Point monitoring sites was classed as poor in 2017, a nominal improvement in grade compared to the previous 2016 survey where the condition was graded as very poor (Table 4; Figure 11). The seagrass condition is a combination of scores for seagrass biomass, area and species composition. While the area of the seagrass meadow declined from the previous year, it remained in satisfactory condition, whereas an increase in biomass from 2016 drove the overall score upwards from the very poor grading of last year. As the meadow classification for species is based on the pioneering *H. decipiens,* which was again the major seagrass found in 2017, the offshore seagrass area was graded very good for species composition.

The broader survey of the offshore meadows found a seagrass footprint covering 3555.6 ± 2524.7 Ha, which consisted of 2209.8 ± 2050.2 Ha in the Hay Point offshore meadows and 652.8 ± 474.5 Ha in the Mackay offshore survey area (Tables 5 & 8, Figure 10). Of the 103 offshore sampling sites, seagrass was found in 22 locations with the southern area around Hay Point consisting entirely of *H. decipiens,* while three sites at the north of the Hay Point broad-scale survey and in the Mackay monitoring area also contained *H. spinulosa.* Biomass ranged between 0.007 and 0.304 g DW m^2 across all offshore meadows with an average biomass of 0.046 ± 0.032 g DW m^2 in the broader Hay Point offshore area and 0.011 ± 0.003 g DW m^2 in the Mackay Monitoring area (Tables 5 & 8). Seagrass was recorded to a depth of 21.0 metres in the Hay Point survey area and 19.8 metres in the Mackay monitoring area. Seagrass was found across a broad but patchy distribution in 2017 including within the dredge material placement area (DMPA).

Compared to previous broad-scale surveys of the Hay Point offshore seagrass meadows, coverage was at an intermediate level and substantially smaller than the overall meadow footprint in both 2004 and 2014 (Figure 12). The seagrass coverage, however, was considerably greater than in surveys from 2005 and 2011. The trend in area over the last three surveys from 2014 is of decline with a loss of area in 2016 and a further decrease in 2017 (Figure 12). As this is the first year that the Mackay offshore meadow has been mapped (in 2015 and 2016 sites were sampled for biomass and species composition alone) it is not yet possible to ascertain any trends in area. This monitoring area, however has seen a shift in species composition from *H. spinulosa* to *H. decipiens* (Appendix 2) and a decline in biomass from 0.24 ± 0.12 g DW m^2 in 2015 to 0.12 ± 0.08 g DW m^2 in 2016 and 0.011 ± 0.003 g DW m^2 in 2017 (McKenna and Rasheed 2017a & b).

Table 4. Grades and scores for seagrass indicators (biomass, area and species composition) for the Hay Point offshore meadow.

Meadow	Biomass	Area	Species Composition	Overall meadow score
Offshore monitoring areas	0.045	0.565	1.0	0.045
Overall score for the Port of Hay Point				0.045

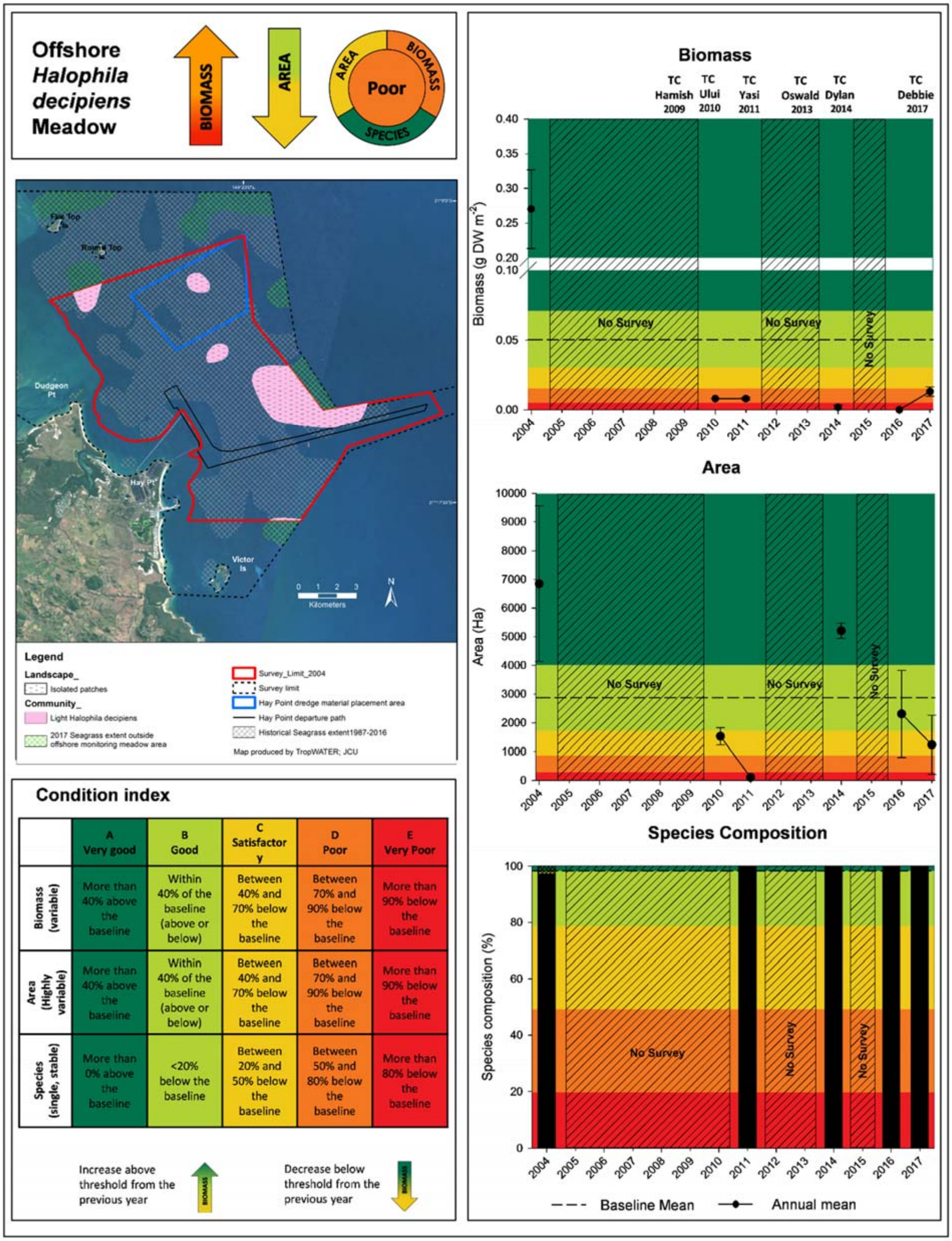

Figure 11. Changes in meadow biomass, area and species composition for seagrass in the offshore area around Hay Point, 4005 – 2017 (biomass error bars = SE).

Table 5. Seagrass community types, mean above-ground biomass and meadow area in the Hay Point offshore area 2004, 2005, 2010, 2011, 2014, 2016 & 2017
(note: survey extent modified to 2004 survey limit see Figure 5).

Meadow ID	Meadow location	Community type	Mean meadow biomass (gDWm^{-2} ± SE)	Area ± R (ha)
July 2004				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. decipiens*	0.270 ± 0.057	6851.9 ± 2715.6
Total				**6851.9 ± 2715.6**
December 2005				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. spinulosa*	2.186 ± 0.764	332.9 ± 152.9
Total				**332.9 ± 152.9**
October 2010				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. decipiens*	0.008 ± 0.003	1528.6 ± 302.5
Total				**1528.6 ± 302.5**
November 2011				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. decipiens*	0.008	105.1 ± 19.1
Total				**105.1 ± 1901**
October/November 2014				
5	Offshore	Light *H. spinulosa* with *H. decipiens*	0.244 ± 0.108	Not mapped
8	Offshore	Light *H. decipiens*	0.002 ± 0.001	5206.0 ± 276.2
Total				**5206.0 ± 267.2**
October/November 2016				
5	Offshore	Light *H. spinulosa*	0.108 ± 0.078	Not mapped
8	Offshore	Light *H. decipiens*	0.002 ± 0.0001	2311.0 ± 1515.9
Total				**2311.0 ± 1515.9**
October 2017				
5	Offshore	Light *H. decipiens* with *H. spinulosa*	0.011 ± 0.003	652.8 ± 474.5
8	Offshore	Light *H. decipiens*	0.046 ± 0.032	1234.1 ± 1023.1
Total				**1886.9 ± 1497.6**

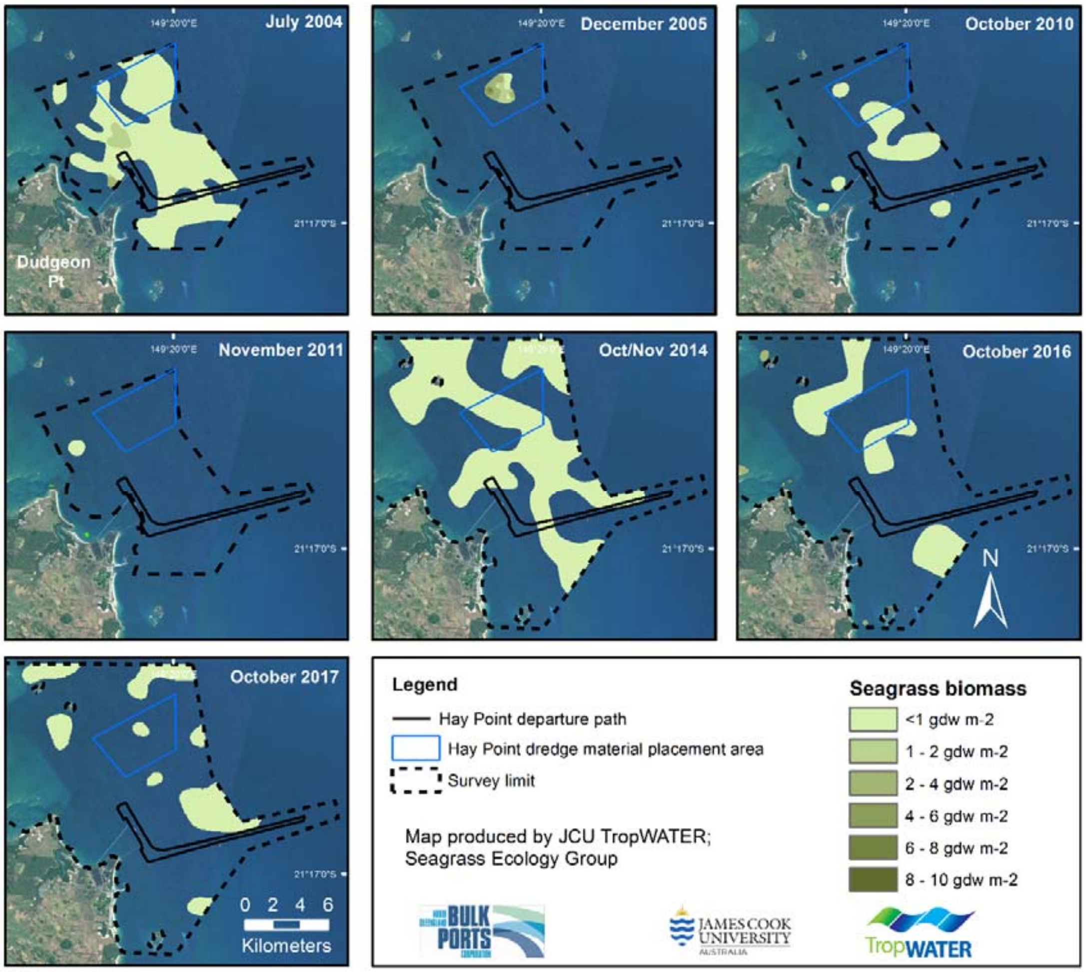

Figure 12. Seagrass landscape type and biomass distribution in the Hay Point offshore monitoring area when surveys were conducted between 2004-2017.

Inshore seagrass at Dudgeon Point - Hay Point & Keswick Island group

Surveys of inshore seagrass communities in the coastal region from Hay Point to the Pioneer River and in the annual monitoring areas around Keswick and St Bees Islands mapped six meadows in 2017. Two meadows were present in the annual monitoring area between Dudgeon Point and Hay Point (Figure 10). Meadow 2, which has been present every year that a survey has been conducted since 2010 remained composed of light *Halodule uninervis* (wide) and was slightly smaller (7.94 ± 5.78 Ha) with a lower biomass (7.94 ± 5.78 g DW m^2) than in the 2016 survey (Table 6). The 2017 survey also saw the return of light *H. ovalis* meadow (meadow 1) at Dudgeon Point where no seagrass was present in 2016 (Table 6). The inshore meadows around Dudgeon Point and Hay Point have been quite variable in their location, biomass and species composition since first surveyed in 2010 (Table 6, Figure 13, Appendix 2). Outside the annual monitoring survey areas in the broader port limits, a further two inshore meadows were present, containing *H. uninervis* (narrow) (Figure 10). Both of these meadows were also present in 2016, however a third small meadow found in 2016 was not present in 2017 (Table 8, Figure 10).

Seagrasses meadows in the Keswick and St Bees Islands annual monitoring areas covered 180.42 ± 72.79 ha and were dominated by *Halophila tricostata* with *H. decipiens* and *H. spinulosa* also observed (Table 7, Appendix 2). The meadow north of St Bees Island (meadow 10) covered the largest footprint for area (169.6 ± 66.5 Ha) since surveys began in 2014, however the overall biomass averaged across the meadow was at its lowest (1.09 ± 0.23 DW m^2) (Table 7, Figure 14). The meadow in Singapore Bay, Keswick Island is historically more spatially variable, and in 2017, was at its smallest area and lowest average biomass over the four year survey history (Table 7, Figure 14). The lower biomass is likely driven by the shift in species composition from being dominated by *H. spinulosa* to the morphologically smaller *H. tricostata* (Appendix 2).

Table 6. Inshore seagrass community type, mean above-ground biomass and meadow area in the Dudgeon Point - Hay Point annual survey areas, 2010 – 2017.

Hay Point – Dudgeon Point inshore survey area				
Meadow ID	**Meadow location**	**Seagrass meadow community type**	**Meadow biomass (g dw m^2 ± SE)**	**Area ± R (ha)**
October 2010				
1	Inshore	Light *Halophila ovalis*	na	4.5 ± 1.6
2	Inshore	Light *Halophila ovalis/Halodule uninervis* (wide & narrow)	na	5.1 ± 2.0
3	Inshore	Light *Halodule uninervis* (wide)	na	2.6 ± 1.3
20	Inshore	Light *Halodule uninervis* (narrow)	na	36.5 ± 12.2
			Total	**48.7 ± 17.1**
November 2011				
1	Inshore	Not present	np	np
2	Inshore	Light *Halodule uninervis* (wide)	na	4.3 ± 1.9
3	Inshore	Not present	np	np
20	Inshore	Light *Halodule uninervis* (narrow)	na	6.3 ± 1.9
			Total	**10.6 ± 3.8**
October/November 2014				
1	Inshore	Light *Zostera muelleri/Halophila ovalis*	1.18 ± 0	4.3 ± 1.8
2	Inshore	Light *Halodule uninervis* (wide)	2.74 ± 0	4.7 ± 1.8
3	Inshore	Not present	np	np
20	Inshore	Not present	np	np
			Total	**9.0 ± 3.6**
October 2015				
1	Inshore	Moderate *Halophila decipiens*	1.42 ± 0	1.8 ± 0.3
2	Inshore	Light *Halodule uninervis* (wide)	1.79 ± 0.23	11.9 ± 1.1
3	Inshore	Not present	np	np
20	Inshore	Not present	np	np
			Total	**13.7 ± 1.4**
October/November 2016				
1	Inshore	Not present	np	np
2	Inshore	Light *Halodule uninervis* (wide)	5.6 ± 0.76	9.62 ± 4.16
3	Inshore	Not present	np	np
20	Inshore	Not present	np	np
			Total	**9.62 ± 4.16**
October 2017				
1	Inshore	Light *Halophila ovalis*	0.34 ± 0.25	1.35 ± 0.97
2	Inshore	Light *Halodule uninervis* (wide)	3.32 ± 1.63	7.94 ± 5.78
3	Inshore	Not present	np	np
20	Inshore	Not present	np	np
			Total	**9.29 ± 6.75**

* na - biomass measure not available due to poor visibility; np – seagrass/meadow not present

Table 7. Inshore seagrass community type, mean above-ground biomass and meadow area in the Keswick Island annual survey areas, 2014 – 2017.

Keswick/St Bees Islands inshore survey areas				
Meadow ID	**Meadow location**	**Seagrass meadow community type**	**Mean meadow biomass (g dw m^{-2} ± SE)**	**Area ± R (ha)**
October/November 2014				
10	Inshore	Light *Halophila tricostata* with *Halophila decipiens*	2.34 ± 0.38	118.6 ± 60.0
14	Inshore	Moderate *Halophila decipiens* with mixed species	2.6 ± 0.71	17.9 ± 13.3
			Total	**136.5 ± 73.3**
October 2015				
10	Inshore	Light *Halophila tricostata*	1.23 ± 0.19	137.2 ± 30.5
14	Inshore	Light *Halophila spinulosa* with mixed species	1.13 ± 0.35	14.7 ± 11.3
			Total	**151.9 ± 41.8**
October/November 2016				
10	Inshore	Light *Halophila tricostata*	1.69 ± 0.33	147.59 ± 53.42
14	Inshore	Light *Halophila spinulosa* with mixed species	2.94 ± 0.54	11.5 ± 6.66
			Total	**159.09 ± 60.08**
October 2017				
10	Inshore	*Light Halophila tricostata*	1.09 ± 0.23	169.60 ± 66.49
14	Inshore	*Light Halophila tricostata*	0.54 ± 0.23	10.82 ± 6.30
			Total	**180.42 ± 72.79**

Table 8. Seagrass community types, mean above-ground biomass and meadow area outside of annual monitoring areas in the Hay Point survey area, October 2017

Meadow ID	**Meadow location**	**Community type**	**Mean meadow biomass (gDWm^{-2} ± SE)**	**Area ± R (ha)**	**No. of sites**
9	Inshore	Dense *Halodule uninervis* (narrow)	8.53 ± 3.01	30.91 ± 24.24	2
15	Inshore	Light *Halodule uninervis* (narrow)	0.19 ± 0.10	36.31 ± 26.08	2
8	Offshore (broader survey)	Light *Halophila decipiens*	0.046 ± 0.032	2902.80 ± 2050.19	17

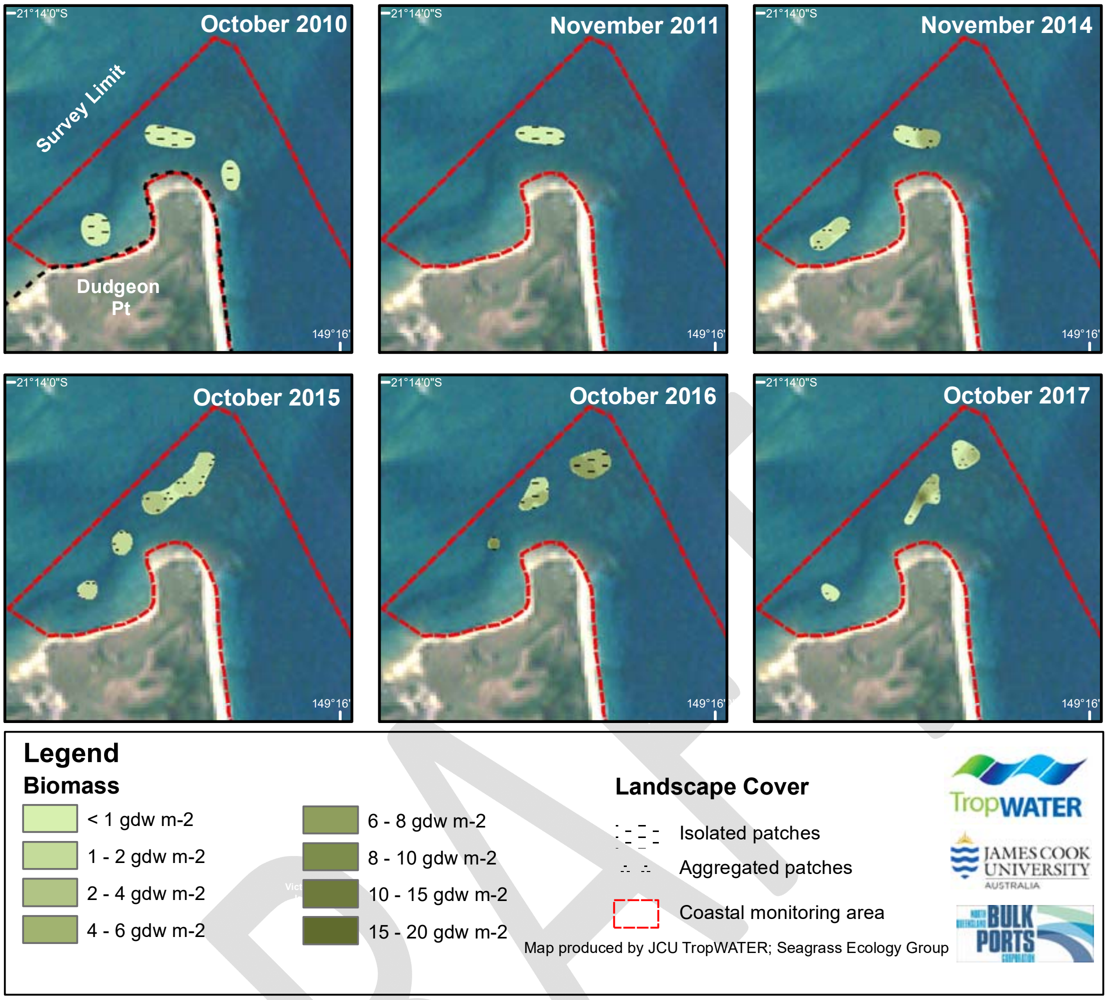

Figure 13. Seagrass landscape type and biomass distribution in the Dudgeon Point to Hay Point annual monitoring area; 2010, 2011, 2014 -2017.

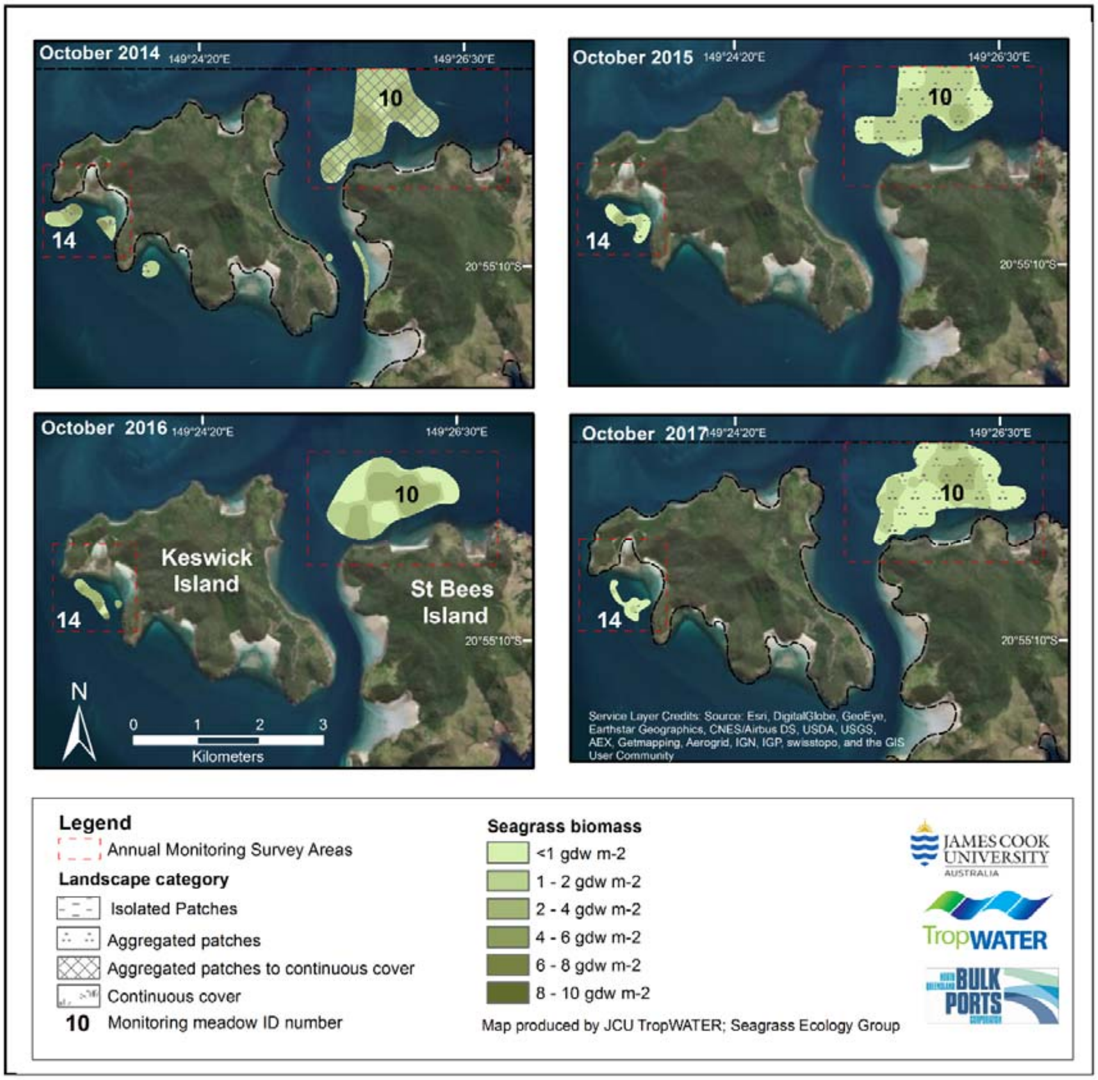

Figure 14. Seagrass landscape type and biomass distribution in the annual monitoring meadows at Keswick and St Bees Islands 2014 – 2017.

3.3 Hay Point Environmental Parameters

Rainfall

Annual rainfall was approximately 500 mm above the long term average in 2016/17 (Figure 15a). The majority of this rainfall occurred at the beginning of 2017 with January and March receiving approximately 600mm and 800mm respectively (Figure 15b). The heavy rainfall in March corresponded to Tropical Cyclone Debbie which crossed the coast in the Whitsunday region to the north of Mackay as a category 4 cyclone in late March. Following the cyclone Mackay remained relatively dry from June to September in the months preceding the survey.

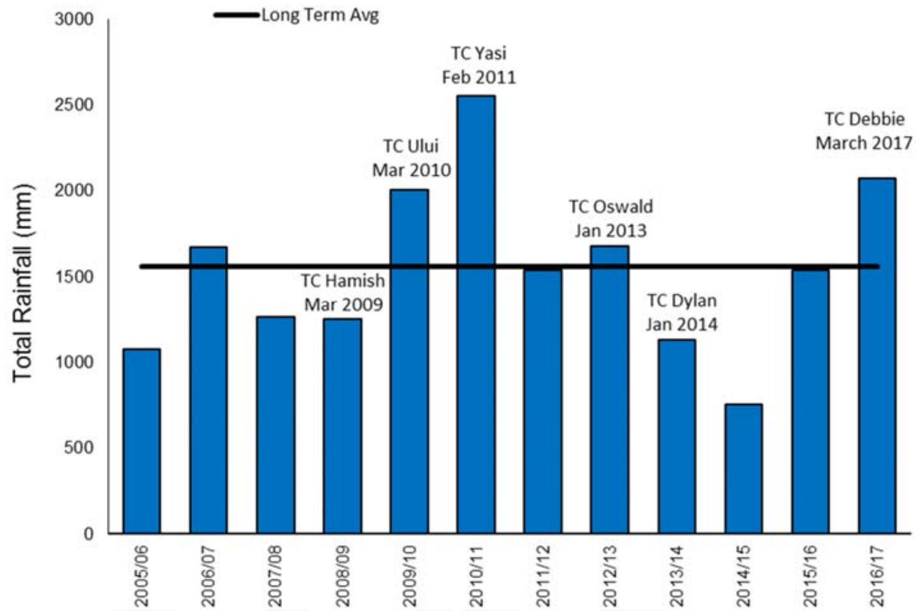

Figure 15a. Total annual rainfall (mm) recorded at Mackay Aero, 2005/06-2016/17. Twelve month year is twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033045.

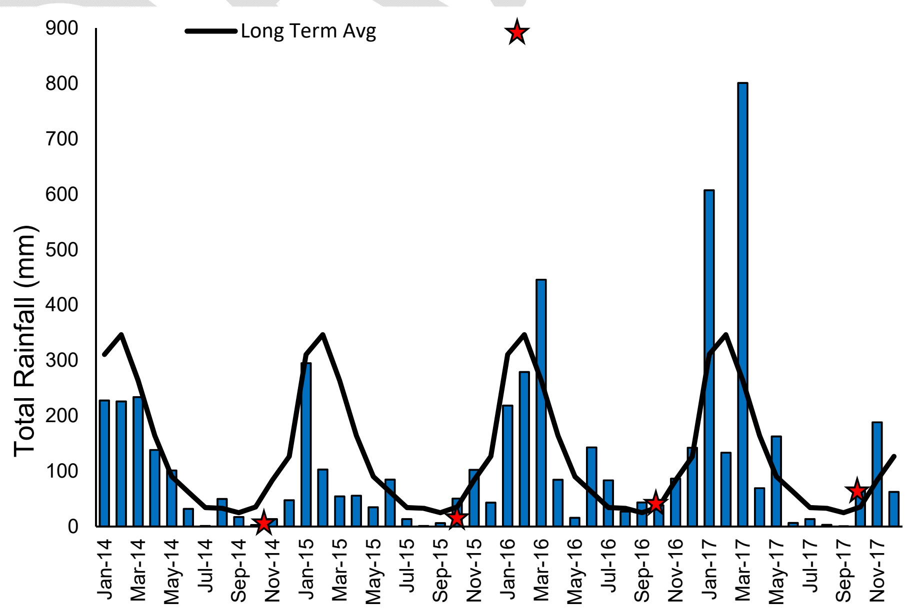

Figure 15b. Total monthly rainfall (mm) recorded at Mackay Aero, January 2014 - December 2017. Source: BOM, Station number 033045.

River flow

Annual river flow of the Pioneer River has was above the long-term average for the first time in four years, with 2013-16 experiencing very low river flows (Figure 16a). The majority of this above average flow was experienced in March 2017 with heavy rains and floods associated with Tropical Cyclone Debbie. The period from June to October prior to the survey was characterised by very low river flows (Figure 16b).

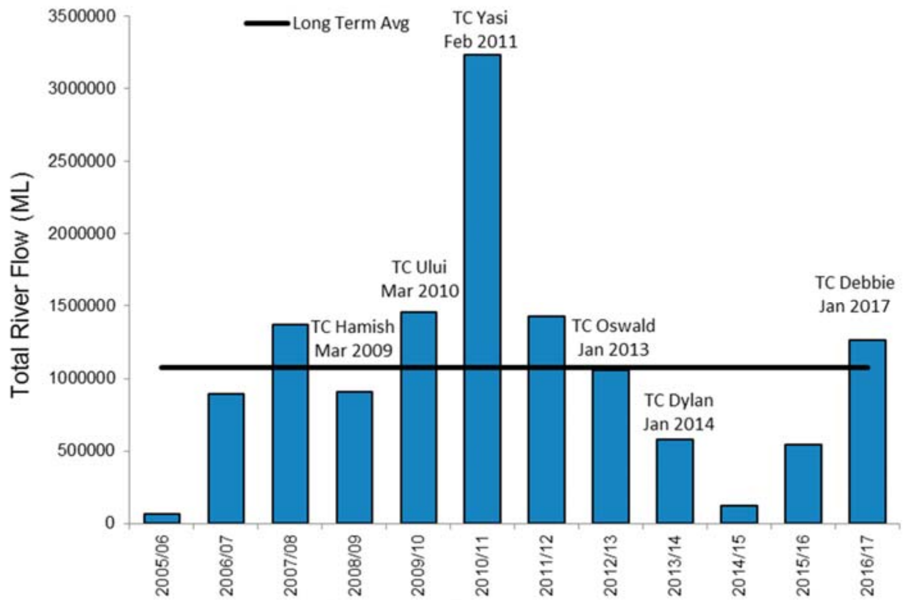

Figure 16a. Annual river flow (Mega litres) for the Pioneer River, 2004/05-2016/17. Twelve month year is twelve months prior to the survey. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

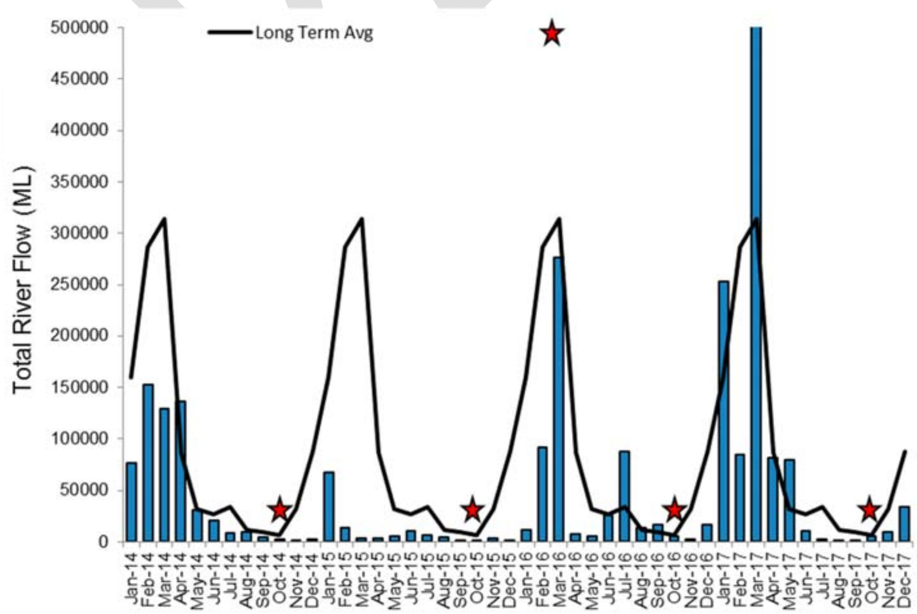

Figure 16b. Monthly river flow (Mega litres) for the Pioneer River January 2014-December 2017. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

Sea Surface Temperature

Sea surface temperature has been collected half hourly at Hay Point since 2008 (QLD Department of Science, Information Technology and Innovation 2017). Mean annual maximum daily sea surface temperature was approximately 0.5° C above the long-term average (8 years) in 2015-16 (Figure 17a). Monthly data shows that sea surface temperature was generally above the long-term monthly average in the first half of 2017, while for the second half year and leading up to the 2016 annual survey, temperatures were around monthly averages.

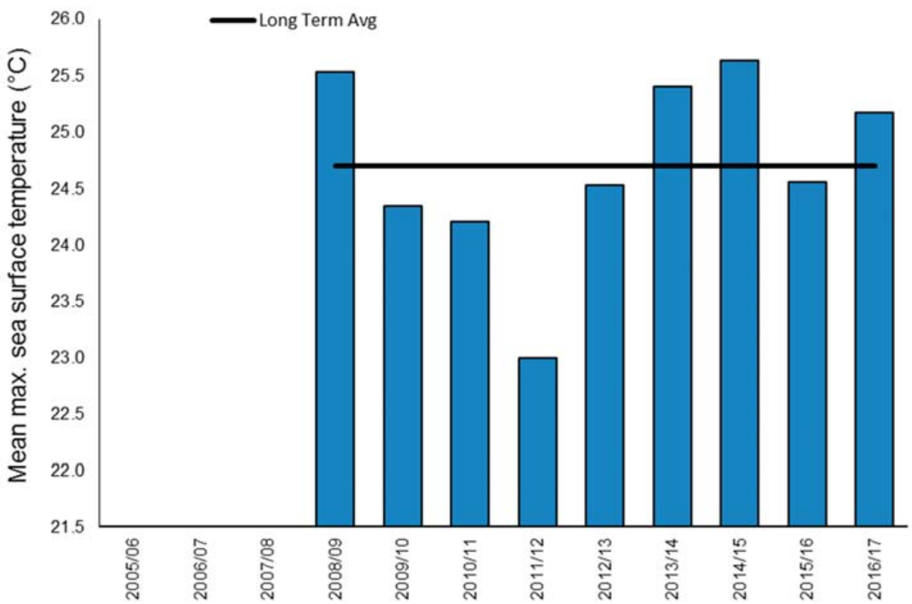

Figure 17a. Mean annual maximum sea surface temperature (°C) recorded at Hay Point 2008/09-2016/17. Twelve month year is twelve month prior to the survey. Source: QLD Department of Science, Information technology and Innovation

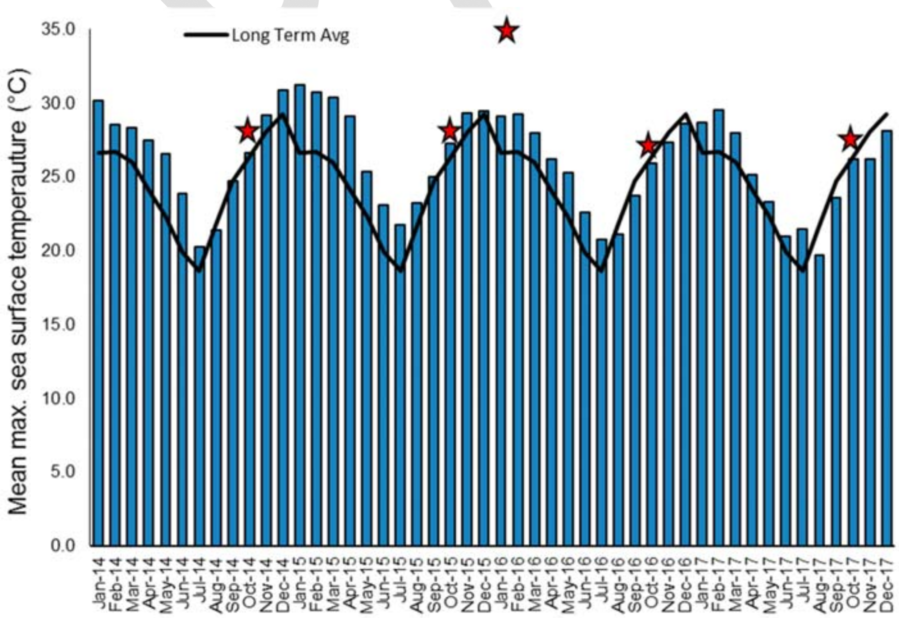

Figure 17b. Monthly maximum sea surface temperature (°C) recorded at Hay Point; January 2014 to December 2017. Source: QLD Department of Science, Information technology and Innovation

Daily Global Solar Radiation

Daily global exposure is a measure of the amount of the total solar energy falling on a horizontal surface in one day. Values are generally highest in clear sun conditions during spring/summer and lowest during winter. Solar exposure in the Hay Point area was slightly above the long term average in 2016/17 with a measure of 20.85 MJ m^{-2} (Figure 18a). Exposure was generally around the below average for each month in 2017 (Figure 18b).

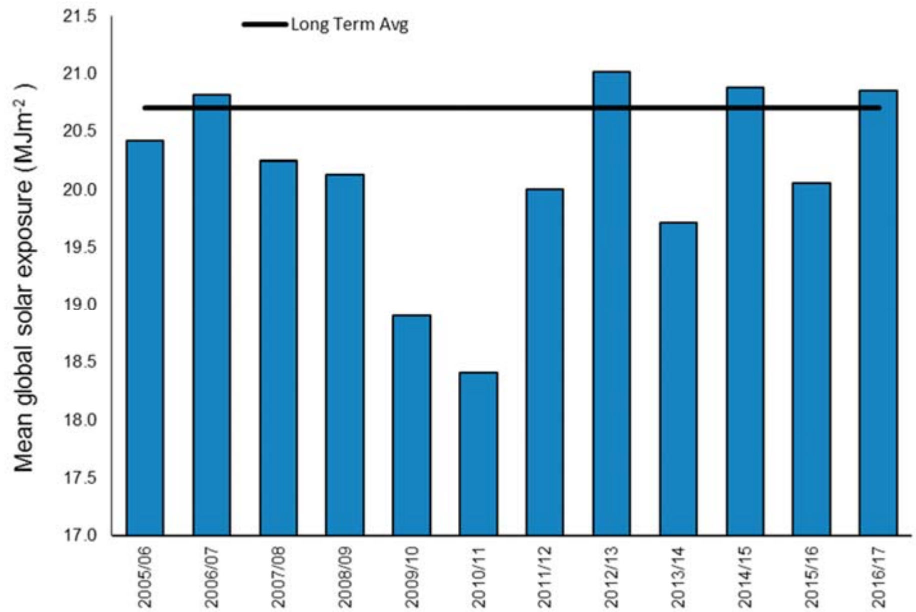

Figure 18a. Mean annual solar radiation (MJm^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) 2005/06 -2015/16. Twelve month year is twelve months prior to the survey. Source: BOM.

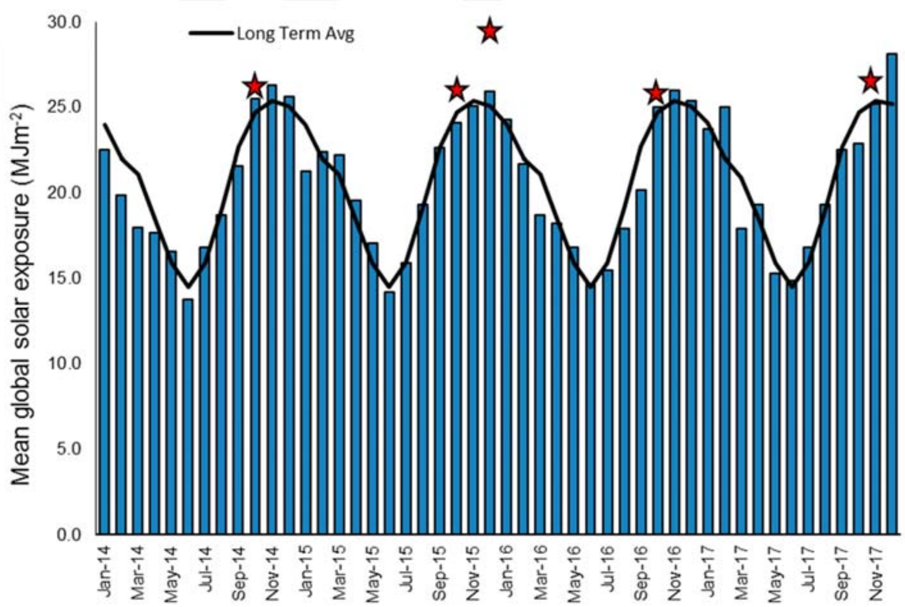

Figure 18b. Mean monthly daily global solar exposure (MJ m^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) January 2013-December 2017. Source: BOM.

4 DISCUSSION

The 2017 broad-scale survey of seagrass in the Hay Point, Mackay and Keswick Island regions found seagrass present in much the same areas with roughly the same species present as seen in historical surveys since 2004, however, generally the meadows were of lower biomass. The new monitoring program, adopted from 2017, allowed for the first full condition assessment of the deep-water meadows offshore from Hay Point. The new reporting incorporates area as a metric into the scoring to supplement biomass and species composition which had been used in previous years. The overall condition of this meadow had a grading of poor, which was an improvement on the very poor grade from the 2016 survey. The poor condition of these offshore meadows in the 2017 survey results from the seagrass biomass being well below the long-term average (Data derived from 6 years of broad surveys between 2004 and 2017). This long-term average is dominated by the 2004 survey where seagrass was at an abundance not since observed and an order of magnitude higher than all subsequent surveys. Since 2004 there have been regular disturbances that may have kept the seagrass meadows at low biomass such as a long-term capital dredging event in 2006 (see York et al. 2015) and a series of six tropical cyclones occurring either annually or every few years including in March 2017 when TC Debbie hit the region. As the monitoring program progresses and the long-term average incorporates new data, the seagrass biomass will either improve to levels closer to or above the long-term average, or the larger number of low-biomass years will reduce the long-term average to levels more commonly observed in this meadow.

The deep-water seagrass meadows offshore from the ports of Hay Point and Mackay consist of colonising *Halophila* species, dominated by *H. decipiens* with naturally high inter-annual variability in biomass and meadow area and an annual occurrence between July and December each year (York et al. 2015, McKenna and Rasheed 2017a & b). These species are structurally small and have low biomass relative to other seagrass species, which means they have lower respiratory demands from photosynthesis and therefore lower light requirements for growth and survival (Josselyn et al. 1986, Chartrand et al 2017). This allows *Halophila* to survive at greater depths than other species. Their small structure, however means that they have limited carbohydrate stores to support them once light levels drop below their requirements (Longstaff et al. 1999). *Halophila* species have been shown to have much lower resistance to light deprivation than other seagrass species with mortality occurring in days to weeks rather than months (Collier et al. 2016). To compensate for low resistance to light stress and seasonal variability in water quality, *Halophila* species rely on sexual reproduction and the dispersal of seeds to recover quickly once a disturbance or stress has abated (Kenworthy 2000, Rasheed et al. 2014). The regular disturbance events that have occurred following the 2004 survey have likely kept the species at low levels of resilience by not providing enough time between events to build up a healthy seed base from which to recover and thrive.

The seagrass communities around Keswick and St Bees Island meadows also consist of *Halophila* species, however, these meadows are dominated by species of larger biomass (*H. tricostata* and *H. spinulosa*) and therefore higher resistance levels to disturbance (though still low compared to other seagrass genera – Collier et al. 2016). These meadows maintained and even increased their footprint compared to surveys conducted over the previous three years, however, similar to the Hay Point offshore meadows, their biomass was also lower than historical levels for the site. This lower biomass, particularly in the Keswick Island meadow in Singapore Bay (Meadow 14) was, in part, due to a shift in species dominance from *H. spinulosa* to *H. tricostata,* a smaller seagrass species. The inshore monitoring area around Dudgeon Point saw the return of an inshore meadow dominated by *Halophila ovalis* which was not present in the 2016 survey. Other coastal meadows between Hay Point and the Pioneer River consisting of *Halodule uninervis* species were similar to the previous broad-scale survey in 2016, with the exception of the absence of a small meadow south of the Pioneer River (Meadow 16) in 2017.

Tropical cyclone Debbie, which impacted the Mackay area for several days in late March of 2017 was the major event likely to have influenced the condition of seagrass communities in the 12 months since the previous survey. The cyclone occurred during the senescent season for seagrass in the deep-water *Halophila* meadows off Hay Point when above ground seagrass was not present. This means that associated rainfall and prolonged turbidity from flood plumes would have been negligible to the health of these meadows. However, the high energy environment and large waves associated with the passing of the cyclone would have disturbed bottom sediments and relocated, buried or removed many of the seeds from the seedbank resulting in decreased germination and recruitment during the seagrass growing season (Bell et al. 2008). This relocation of seed banks may also explain the large inter-annual spatial variation in these deep-water seagrass meadows as large storms and cyclones shift seedbanks around from year to year (Bell et al. 2008).

For the coastal seagrasses and those around Keswick and St Bees Islands that are present year round, the heavy rainfall events and mechanical damage caused by waves during the cyclone had the potential for large scale impact (Carlson et al. 2010). As Keswick and St Bees Islands are considerably further offshore than the Hay Point meadows they are less susceptible to turbid plumes from coastal flooding and water quality would likely have returned to favourable conditions for seagrass growth soon after the cyclone and rainfall events passed. This shorter period of disturbance may have allowed these seagrasses to resist the poor conditions of the cyclone, and although being reduced in biomass, the remaining seagrass and seed bank has allowed the meadows to persist or re-establish (Collier et al. 2016). The inshore meadows around Dudgeon Point would have sustained a much greater and more prolonged level of disturbance. A combination of high rainfall, high river flow and increased wave/wind activity can negatively impact seagrass either physically (e.g. burial, scouring, direct removal of plants and seed-banks; Preen et al. 1995; Bach et al. 1998; Campbell & McKenzie 2004) or physiologically (light limitation, excess nutrients and herbicides, and changes in salinity) (Björk et al. 1999; Ralph et al. 2007; Chartrand et al. 2017). As these meadows are dominated by *Halodule uninervis* which is a much more resistant species than the deeper water seagrasses, and can persist for over a month in poor light conditions (Collier et al. 2016) it seems they were able to withstand the disturbance from the cyclone in most meadows with reductions in biomass. Previous climatic events in the region have seen a greater impact on inshore seagrass meadows than deeper water meadows (Rasheed et al. 2014), however those disturbances included a series of prolonged flooding events of greater duration than experienced by cyclone Debbie that coastal species are less able to resist.

More generally, climate conditions for seagrass growth were favourable for much of the year prior to the seagrass survey in October 2017. While the region experienced above average rainfall and river flows, these were driven by just two high rainfall events in January 2017 and the end of March (TC Debbie). In the three month period leading into the survey both rainfall and river flow were very low and well below the monthly averages for the region. These conditions would also have allowed for the recovery of meadows following the impacts of TC Debbie.

The highly variable and low biomass nature of seagrass in the Mackay/Hay Point region indicates that seagrasses are living at the limits of light required to support their growth and reproduction and can be heavily impacted by disturbance events, both natural and anthropogenic. The management of seagrass therefore should remain focused on ensuring the resilience of these habitats remains high enough to withstand expected impacts and risks. While previous research has shown that these meadows are susceptible to impacts from large scale and prolonged dredging (in 2006), they also had an ability to rapidly recover, and were able to persist during smaller and shorter capital and maintenance dredging activities (York et al. 2015). Critical to this recovery is the ability of offshore seagrasses to produce a seed bank that allows for seagrass recruitment each growing season, especially for the annual *H. decipiens* in offshore areas. The growth strategy of these offshore seagrasses provides good opportunities for their successful management and protection during planned activities with the potential to impact on them, by managing activities in a way that minimises the time they are exposed to stress or keeping levels within the range that doesn't impede their growth and also potentially taking advantage of the windows available when they are seasonally absent (York et al. 2015, Wu et al. 2017).

The Mackay-Hay Point long-term monitoring program is now fully incorporated into the broader Queensland Ports seagrass monitoring program using the consistent state-wide monitoring methodology. This enables direct comparisons with regional and state-wide trends to put local changes into a regional context. It also provides a key input into the condition and trend of seagrasses in the Mackay-Whitsundays NRM region, an area which otherwise has a poor spatial coverage for seagrass assessment and condition. Monitoring at other sites in the network has shown a range of results during 2017. For many locations coastal seagrasses have improved (e.g., Cairns - Reason and Rasheed 2018), some have remained stable (e.g., Townsville - Bryant and

Rasheed 2018, Gladstone – Chartrand et al. 2018) and at others they have declined (Abbot Point – Davey and Rasheed 2018). The declines in Abbot Point offshore *Halophila* meadows in 2017 were more severe than at Hay Point and are likely a result of a more intense disturbance from Tropical Cyclone Debbie in late March 2017 in that region (Davey et al. 2018).

Ongoing development of the Hay Point – Mackay – Keswick Island seagrass condition index

The current survey (2017) was the first time that a broader assessment of offshore seagrasses incorporating seagrass area has been used to determine the seagrass condition of the Hay Point offshore meadows. As such the establishment of baseline conditions is still under development and requires a 10 year baseline of data (seagrass biomass, meadow area and species composition) before it can be fully implemented. The Hay Point offshore seagrass now has 6 years of baseline data and the condition index will therefore be an interim grade until 2021 when a permanent baseline is established. The next annual survey (2018) will see a n interim 5-year baseline established for the inshore meadows at the Hay Point-Dudgeon Point and Keswick and St Bees Islands monitoring areas. This will allow for interim condition indices to be applied to these meadows next year with permanent baselines established in 2023 given continuing annual surveys. The Mackay offshore seagrasses have been mapped for the first time in 2017 and an interim score for this area will not be available until 2021 after a 5-year baseline is established for all metrics. The new monitoring program and reporting of seagrass condition established in 2017 for Hay Point, Mackay and the Southern Whitsundays aligns with reporting of seagrass at most of the major ports in north Queensland (e.g. Gladstone, Abbott Point, Townsville, Mourilyan, Cairns, Karumba, Weipa and Thursday Island) and the information will also be incorporated into the Mackay Whitsunday Healthy Rivers to Reef (HR2R) Partnership report card.

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6 APPENDICES

Appendix 1.

Baseline Calculations

Baseline conditions for seagrass biomass and species composition for the Hay Point offshore meadow were established from annual means calculated from 6 years of data for biomass, area and species composition (2004 no seagrass present). This baseline was set based on results of the Gladstone Harbour report card (Carter et al. 2015). The 2004–2017 period incorporates a range of conditions present in the Hay Point region, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events. Once the monitoring program has collected over 10 years of data, the 10 year long-term average will be used in future assessments. This will be reassessed each decade.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). In 2016 an additional rule was applied: where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Figure A1).

Meadow Classification

A meadow classification system was developed for the two condition indicators (biomass and species composition) in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. The coefficient of variation (CV) for each baseline for each meadow was used to determine historical variability. Meadow biomass and species composition was classified as either stable or variable (Table A1). Two further classifications for meadow area were used: highly stable and highly variable, in recognition that some meadows are very stable while others have a naturally extreme level of variation (Table A1). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

Table A1. Coefficient of variation (CV) thresholds used to classify historical stability or variability of meadow biomass and species composition.

Indicator	Class			
	Highly stable	**Stable**	**Variable**	**Highly variable**
Biomass	-	CV < 40%	CV ≥ 40%	-
*Area	< 10%	CV ≥ 10, < 40%	CV ≥ 40, <80%	CV ≥ 80%
Species composition	-	CV < 40%	CV ≥ 40%	-

Threshold Definition

Seagrass condition for each indicator was assigned one of five grades (very good (A), good (B), satisfactory (C), poor (D), very poor (E)). Threshold levels for each grade were set relative to the baseline and based on meadow class. This approach accounted for historical variability within the monitoring meadows and expert knowledge of the different meadow types and assemblages in the region (Table A2).

Table A2. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

Seagrass condition indicators/ Meadow class		Seagrass grade				
		A Very good	**B Good**	**C Satisfactory**	**D Poor**	**E Very Poor**
Biomass	Stable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable	>40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Area	Highly stable	>5% above	5% above - 10% below	10-20% below	20-40% below	>40% below
	Stable	>10% above	10% above - 10% below	10-30% below	30-50% below	>50% below
	Variable	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Highly variable	> 40% above	40% above - 40% below	40-70% below	70-90% below	>90% below
Species composition	Stable and variable; Single species dominated	>0% above	0-20% below	20-50% below	50-80% below	>80% below
	Stable; Mixed species	>20% above	20% above - 20% below	20-50% below	50-80% below	>80% below
	Variable; Mixed species	>20% above	20% above- 40% below	40-70% below	70-90% below	>90% below
	Increase above threshold from previous year			Decrease below threshold from previous year		

Grade and score calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows for the Hay Point region (TableA3; see Carter et al. 2015 for a detailed description).

Score calculations for each meadow's condition required calculating the biomass, area and species composition for that year, allocating a grade for each indicator by comparing 2017 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table A#). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period. For Hay Point this upper limit will be recalculated each year until the 10 year baseline period is complete

In previous report cards the upper limit was based on the mean + SE of any survey year, meaning biomass and area values in the very good range potentially would require constant recalculation; defining the upper limit using baseline years is a new approach in 2016 that "locks in" the upper value.

An example of calculating a meadow score for area in satisfactory condition is provided below.

Table A3. Score range and grading colours used in the 2017 Hay Point report card.

Grade	Description	Score Range	
		Lower bound	Upper bound
A	Very good	≥0.85	1.00
B	Good	≥0.65	<0.85
C	Satisfactory	≥0.50	<0.65
D	Poor	≥0.25	<0.50
E	Very poor	0.00	<0.25

Where species composition was determined to be anything less than in "perfect" condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were driving this grade/score (Figure A1). If this was the case then the species composition score and grade for that year was recalculated including those species. Concern regarding any decline in the stable state species should be reserved for those meadows where the directional change from the stable state species is of concern (Figure A1). This would occur when the stable state species is replaced by species considered to be earlier colonisers. Such a shift indicates a decline in meadow stability (e.g. a shift from *Z. uninervis* subsp. *capricorni* to *H. decipiens*). An alternate scenario can occur where the stable state species is replaced by what is considered an equivalent species (e.g. shifts between *C. rotundata* and *C. serrulata*), or replaced by a species indicative of an improvement in meadow stability (e.g. a shift from *H. decipiens* to *H. uninervis* or any other species). The directional change assessment was based largely on dominant traits of colonising, opportunistic and persistent seagrass genera described by Kilminster et al. (2015). Adjustments to the Kilminster model included: (1) positioning *S. isoetifolium* further towards the colonising species end of the list, as successional studies following disturbance demonstrate this is an early coloniser in Queensland seagrass meadows Rasheed 2004); and (2) separating and ordering the *Halophila* genera by species. Shifts between *Halophila* species are ecologically relevant; for example, a shift from *H. spinulosa* to *H. decipiens*, the most marginal species found in Hay Point, may indicate declines in water quality and available light for seagrass growth as *H decipiens* has a lower light requirement (Collier et al. 2016) (Figure A1).

The decision tree used in 2016 expands on the 2015 model and provides a more thorough assessment of species composition condition. Specific changes include the separation and positioning of *Z. muelleri* subsp. *capricorni* above *H. uninervis* (grouped as equivalent species in 2015), the separation and positioning of *H. spinulosa* above *H. ovalis* (also grouped as equivalent species in 2015), and triggering the directional change assessment if the species composition score was <1.00 (the trigger was based on a grade less than very good in 2015, meaning no score adjustment occurred in the highest grade even if more persistent species present could have improved the score).

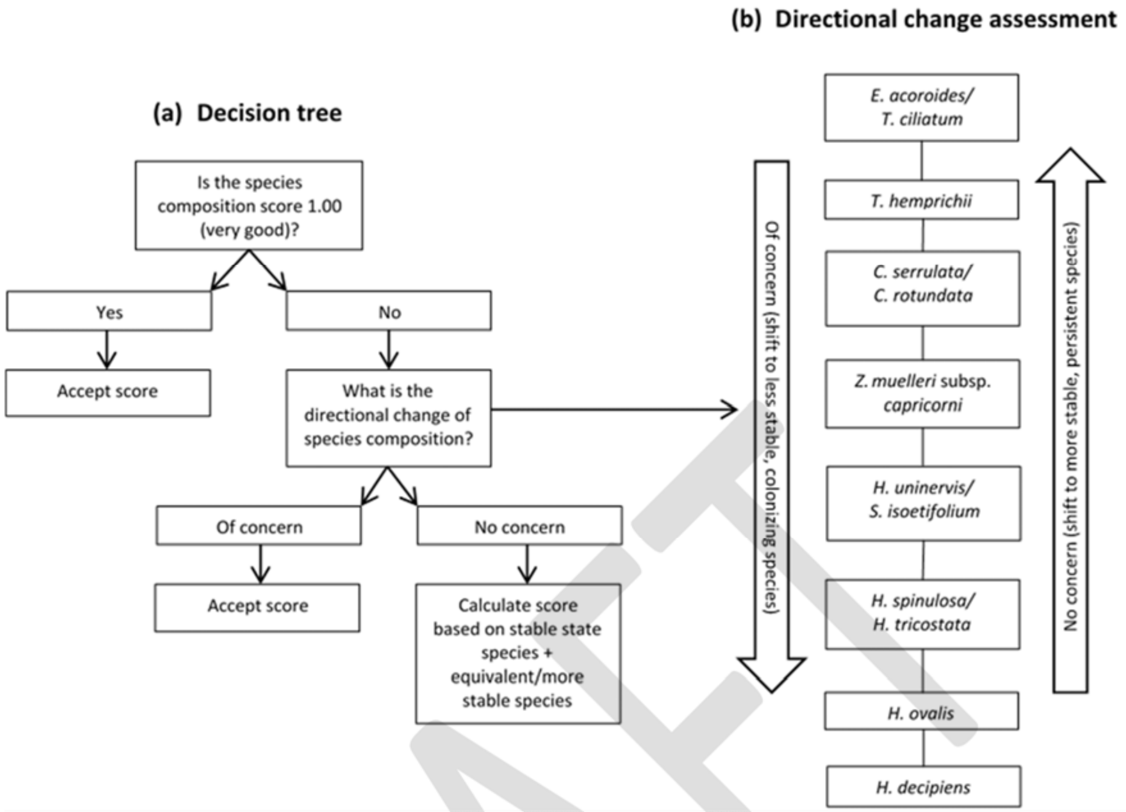

Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

Score Aggregation

Each overall meadow grade/score was defined as the lowest grade/score of the two condition indicators within that meadow. The lowest score, rather than the mean of the two indicator scores, was applied in recognition that a poor grade for any one of the three described a seagrass meadow in poor condition. Maintenance of each of these fundamental characteristics of a seagrass meadow is required to describe a healthy meadow. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014).

Hay Point grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Table A2). Where multiple meadows were present within the port, meadows were not subjected to a weighting system at this stage of the analysis. The classification process at the meadow analysis stage applied smaller and therefore more sensitive thresholds for meadows considered stable, and less sensitive thresholds for variable meadows. The classification process served therefore as a proxy weighting system where any condition decline in the (often) larger, stable meadows was more likely to trigger a reduction in the meadow grade compared with the more variable, ephemeral meadows. Port grades are therefore more sensitive to changes in stable than variable meadows.

Example Score Calculation

An example of calculating a meadow score for area in satisfactory condition.

1. Determine the grade for the 2017 (current) biomass value (i.e. satisfactory).

2. Calculate the difference in areas (A_{diff}) between the 2017 area value (A_{2015}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$\mathrm{A_{diff}} = \mathrm{A_{2017}} - \mathrm{A_{satisfactory}}$$

Where $A_{satisfactory}$ or any other threshold boundary will differ for each condition indicator depending on the baseline value, meadow class (highly stable [area only], stable, variable, highly variable [area only]), and whether the meadow is dominated by a single species or mixed species.

3. Calculate the range for biomass values (A_{range}) in that grade:

$$\mathrm{A_{range}} = \mathrm{A_{good}} - \mathrm{A_{satisfactory}}$$

Where $A_{satisfactory}$ is the upper threshold boundary for the satisfactory grade.
Note: For species composition, the upper limit for the very good grade is set as 100%. For area and biomass, the upper limit for the very good grade is set as the maximum value of the mean plus the standard error (i.e. the top of the error bar) for a given year during the baseline period for that indicator and meadow.

4. Calculate the proportion of the satisfactory grade (A_{prop}) that A_{2015} takes up:

$$\mathrm{A_{prop}} = \frac{\mathrm{A_{diff}}}{\mathrm{A_{range}}}$$

5. Determine the biomass score for 2017 ($Score_{2017}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$\mathrm{Score_{2017}} = \mathrm{LA_{satisfactory}} + \left(\mathrm{B_{prop}} \times \mathrm{SR_{satisfactory}}\right)$$

Where $LA_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

Appendix 2.

Species composition of monitoring meadows in the Hay Point/Mackay region, and the Keswick Island group.