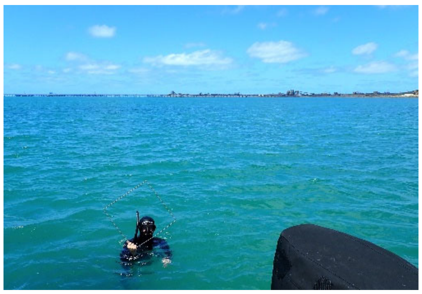
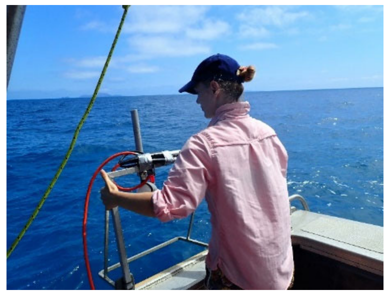


ANNUAL SEAGRASS MONITORING IN THE MACKAY-HAY POINT REGION – 2019

York PH and Rasheed MA

Report No. 20/11

April 2020

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KEY FINDINGS

Deepwater
Hay Point-Mackay

VERY GOOD
(Interim)

Coastal
Dudgeon Point

GOOD
(Interim)

Offshore Island
Keswick and St Bees

GOOD
(Interim)

Likely causes of seagrass condition:

- *Favourable climate and light conditions for seagrass growth*
- *No significant adverse weather events over the last two years allowing seagrass to recover*

- In 2019 overall seagrass condition in the Hay Point-Mackay region improved and is now classified as good to very good in all monitoring locations, with biomass and area found to be very high in comparison to previous surveys.
    - Hay Point offshore deep-water seagrasses improved from poor in 2018 to very good in 2019 due to substantial increases in both biomass and meadow area with the highest biomass since 2004.
    - Deep-water seagrass in the Mackay offshore monitoring area more than doubled in biomass and increased in area more than fourfold compared to the previous year, the highest recorded since commencement of monitoring in 2015.
    - Coastal meadows at Dudgeon Point improved from satisfactory to good condition in 2019 due to an increase in the above ground biomass, the highest since 2016.
    - Meadows at offshore Islands (Keswick and St Bees) maintained their good condition from 2018 through to 2019.
- The improved seagrass condition was likely due to two consecutive years with an absence of major storm and cyclone events following a series of almost yearly cyclones and floods culminating in Cyclone Debbie in 2017.
- Maintenance dredging during 2019 did not appear to have an impact on seagrass condition with management measures implemented likely successful in protecting seagrass growing requirements.

IN BRIEF

A long-term seagrass monitoring program and strategy was developed for the Mackay-Hay Point region following a broad-scale extended survey of the region in 2014. The annual monitoring strategy now assesses two deep offshore monitoring areas at Mackay and Hay Point, a coastal intertidal area between Dudgeon Point and Hay Point, and two 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 for those are still being established.

The 2019 annual survey of seagrass monitoring meadows in the Hay Point, Mackay and Keswick Island regions showed an overall improvement in the condition of seagrass and meadows from the previous survey. Across all locations and they are now all classified as good to very good and in some of the best condition since annual monitoring began. The assessment in 2019 showed some variation among individual meadows with the deep-water meadows offshore from Hay Point improving from poor condition to very good; coastal meadows at Dudgeon Point improved from satisfactory to good; the Keswick Island meadow were still in good condition; and the St Bees Island meadow declined from very good to good.

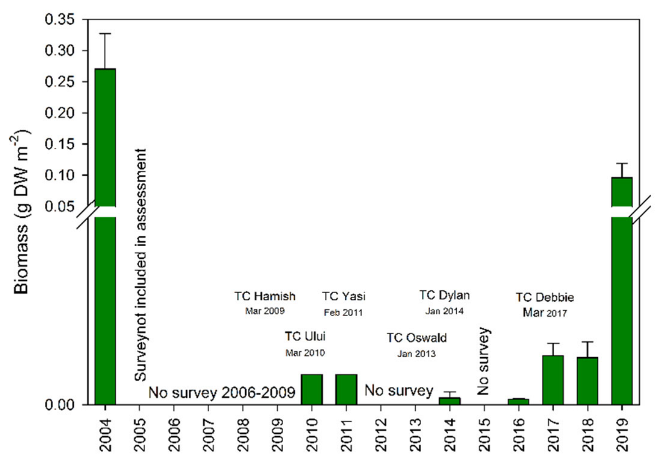

Figure 1. Mean seagrass biomass of Hay Point offshore monitoring site

Deep-water seagrasses in the monitoring area offshore from Hay Point were comprised of colonising *Halophila* species (mainly *H. decipiens*), adapted to surviving in low light conditions. These meadows have naturally high inter-annual variability in biomass and meadow area and an annual occurrence between July and December. Since 2004 there have been regular disturbances that may have kept the seagrass meadows at low biomass including six tropical cyclones (Figure 1). In the 2019 survey, biomass in this meadow reached levels higher than those observed over the last 15 years. These levels were still less than half that in the peak year of 2004 (Figure 1). The meadows also increased in area to cover more than double that found the previous year (Figure 2). Deep-water seagrass in the Mackay offshore monitoring area also improved in condition from the previous two years but the monitoring history is still too short for a score to be generated. Seagrass within the Mackay offshore area was found to have doubled in biomass and increased in area more than fourfold compared to the survey in 2018.

The seagrass communities around Keswick and St Bees Island also include *Halophila* species, however, these meadows are dominated by structurally larger species (*H. tricostata* and *H. spinulosa*). These meadows were classified as in good condition in 2019. The biomass and area of these meadows are presently around the long-term averages that have been established for these locations over six years of monitoring. These meadows are further offshore than the Hay Point meadows and are less susceptible to fluctuations in light and water quality, which provides a more favourable environment for seagrass growth.

The inshore monitoring area around Dudgeon Point consisted of seagrass meadows dominated by *Halodule uninervis* with *Zostera muelleri* and *Halophila* species also present. The species dominating this meadow have higher light requirements than the deeper *Halophila* dominated meadows offshore, however, they are much more resistant to disturbance and can persist for greater periods in poor light conditions. These coastal intertidal meadows improved from a satisfactory condition in 2018 to good condition in 2019. The improvement was due to an increase in above ground biomass in the meadows to their highest levels since 2016.

The condition of seagrasses in the Hay Point – Mackay – Keswick Island region are largely driven by climate and extreme weather events. At the time of the 2019 survey, the region had experienced a two-and-a-half-year period with no major flooding or cyclones allowing seagrass meadows in the area time to recover following several consecutive years where floods and cyclones had impacted the region. Climate conditions for seagrass growth were favourable for much of the year prior to the survey in October 2019. Throughout this period, the region experienced below average rainfall, average river flows and solar exposure, and sea surface temperatures that were slightly above the long term average (Figure 3).

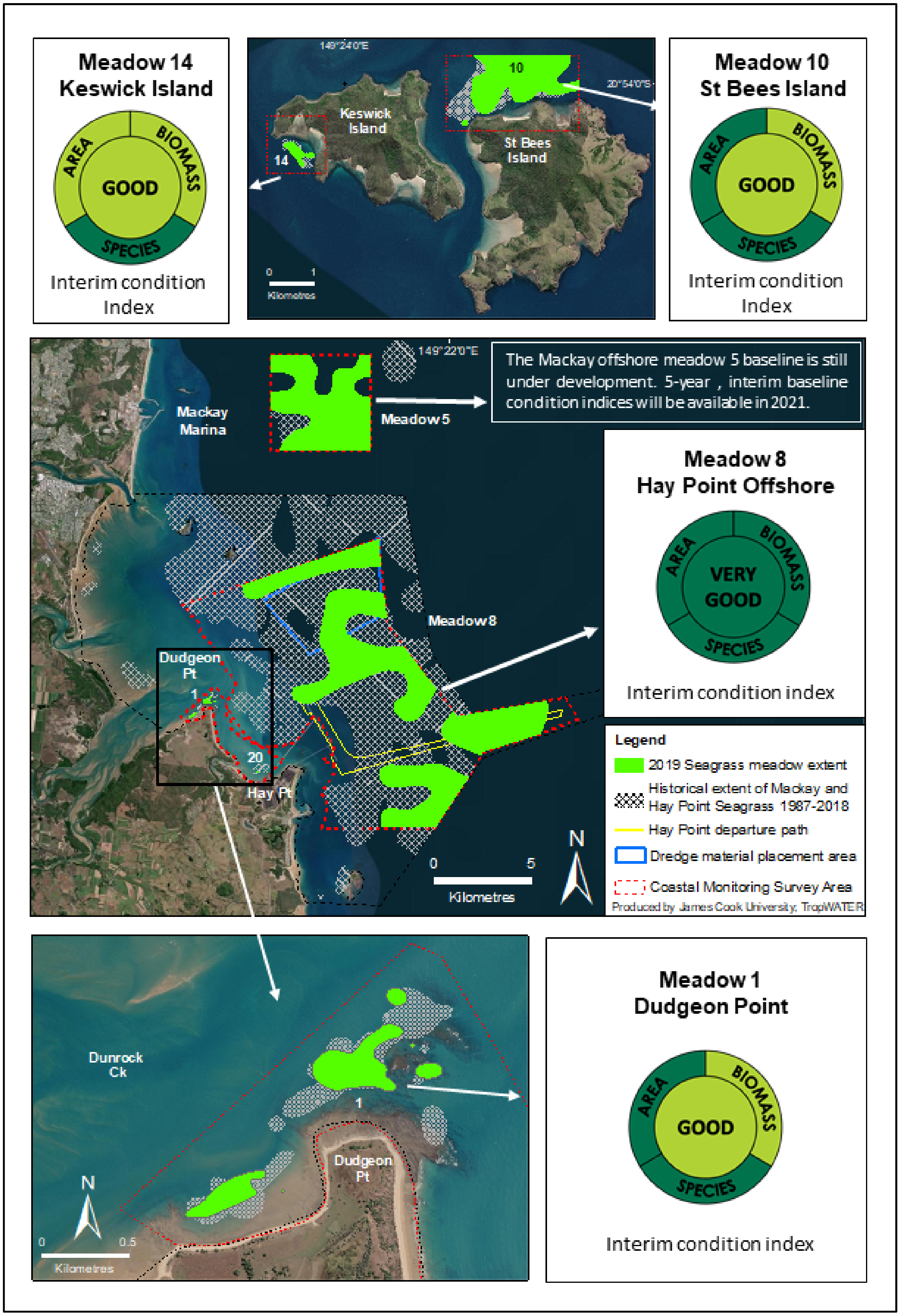

Figure 2. Seagrass meadow condition for the ports of Mackay, Hay Point, Keswick and St Bees Island 2019.

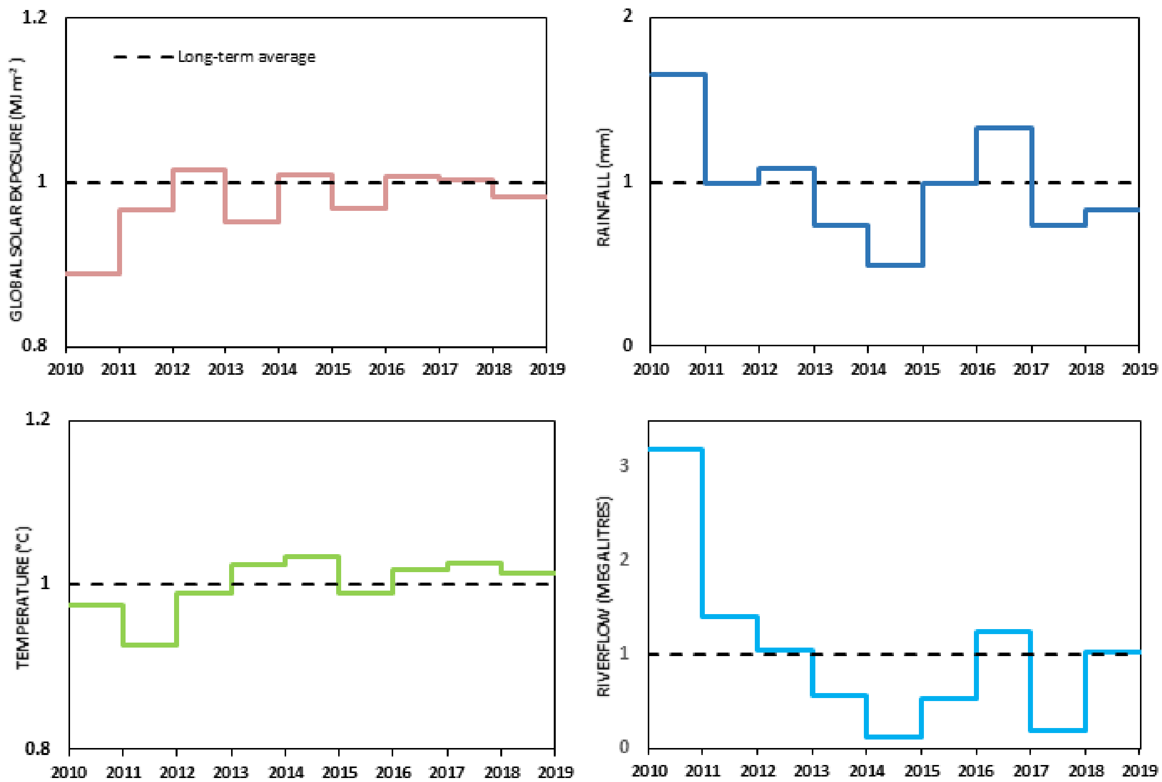

Figure 3. Recent climate trends in the Hay Point Area: change in climate variables as a proportion of the long-term average over the last 10 years (2010 – 2019). Black dotted line represents the long-term average. (See section 3.3 for detailed climate data).

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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 megaherbivores like dugongs and sea turtles (Heck et al. 2008; Scott et al. 2018). Seagrasses also play a major role in the cycling of nutrients (McMahon and Walker 1998), sequestration of carbon (Fourqurean et al. 2012; Lavery et al. 2013; York et al. 2018, Rasheed et al. 2019), stabilisation of sediments (James et al. 2019), and the improvement of water quality (McGlathery et al. 2007).

Globally, seagrasses have been declining due to 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). 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 occur in the same sheltered coastal locations where 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 (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 Queensland port authorities. A common methodology and rationale is used to provide a network of seagrass monitoring locations throughout the state (Figure 4).

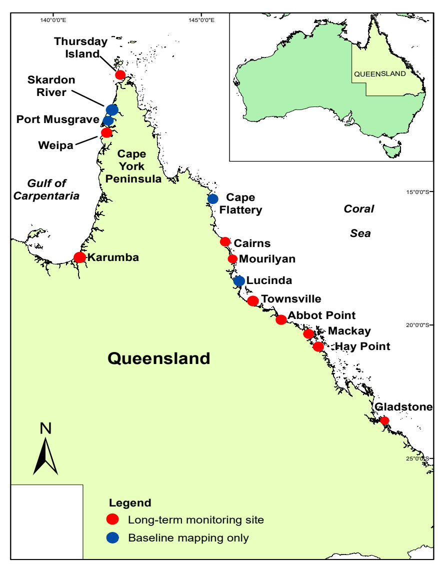

Figure 4. Location of Queensland Port Seagrass assessment sites

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 provides an ongoing assessment of many of the most threatened seagrass communities in the state.

The program delivers key information for the management of port activities to minimise impacts on seagrass habitat and has 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 causes 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: https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/

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 and the Hay Point Coal Terminal.

The Port of Mackay is a multi-commodity port mainly exporting sugar and grain; 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). The program has also shown that the natural spatial extent of deep water seagrasses around Hay Point is extremely variable with an annual cycle of absence and 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 also show that inshore seagrass meadows at Hay Point are highly variable in distribution and species composition. A collection of small meadows at Dudgeon Point are intermittent through time and also shift in species composition between domination by more persistent species (*H. uninervis* and *Z. muelleri*) and the colonising *H. ovalis* and *H. decipiens* species.

The monitoring program between 2004 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). Monitoring has also 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 had been conducted between 2005 and 2012. The broad-scale survey in 2014 was used as a platform to re-establish the program, with added monitoring in the Keswick Island (southern Whitsunday Islands) and Mackay areas (Figure 5). The long-term monitoring program coupled with regular broad-scale surveys and other research programs 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 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 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 related to 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 area these seagrasses limiting the effectiveness of the fixed design. The spatial variability is a natural consequence of the ephemeral nature of deep-water *Halophila* meadows. The new level of sampling is achieved by spreading sampling during annual monitoring to cover the same footprint as the original 2004 extended survey. Historically, this was already done in extended 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 footprint of the 2004 survey limit this condition index will become permanent. Since 2018, the surveys of the annual monitoring areas along the coast between Dudgeon Point and Hay Point and at meadows adjacent to Keswick and St Bees Islands have been used to calculate seagrass condition scores. This is possible now due to the availability of 5-years of survey data at these sites allowing for the establishment of interim long-term averages. These averages will be adjusted with additional annual data until a permanent baseline can be established with 10 years of data. The recently established monitoring meadow offshore from Mackay still requires two more years of data before an interim baseline can be established. These changes bring the assessment of seagrass meadows 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 2019 in the Hay Point-Mackay region. The objectives of these studies were to:

- Map seagrass distribution and determine seagrass density and community type at the monitoring areas in the Hay Point-Mackay region;
- Compare with results of previous monitoring surveys and assess any changes in seagrass area 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;
- 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.

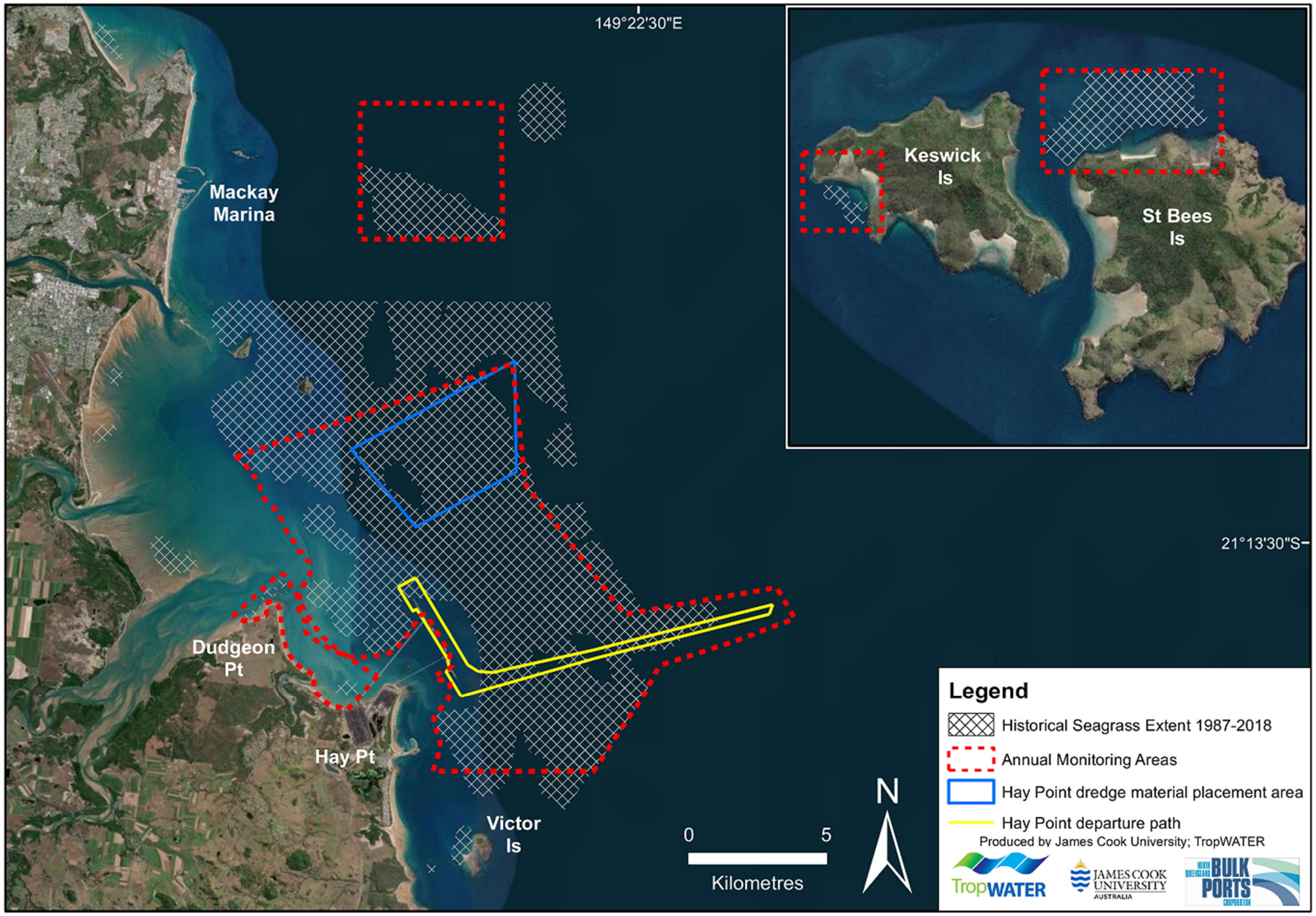

Figure 5. Location of survey limits and annual seagrass monitoring areas around Mackay, Hay Point and the Keswick Island group in 2019.

2 METHODS

2.1 Annual monitoring within the intensive monitoring area

The approach of annual monitoring of representative meadows with a broader survey every three years has 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. Monitoring meadows were selected for detailed assessment because they were representative of the range of seagrass meadow communities identified in initial surveys and because they were located in areas likely to be vulnerable to impacts from port operations and developments or act as reference sites. 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. The annual survey of seagrass communities in intensive monitoring areas within the Hay Point-Mackay region (including Keswick and St Bees Islands) were conducted in October 2019 (Figure 5). More inclusive broad-scale mapping and monitoring of meadows across the greater region was last undertaken in 2017 and is scheduled to occur again in 2020.

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

2.2 Seagrass monitoring, habitat mapping and Geographic Information System

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

1. Intertidal areas: Walking at low tide;
2. Subtidal inshore areas <8m below MSL: Boat based underwater digital camera mounted on a drop frame; or visual observation by an experienced free diver
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 was present, seagrass above-ground biomass was measured using a "visual estimates of biomass" technique (Kirkman 1978; Mellors 1991). At camera drop and free diving sites this technique involved an observer ranking seagrass biomass within three randomly placed 0.25m^2 quadrats at each site (Figure 6A-B). 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 6C-D). 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.

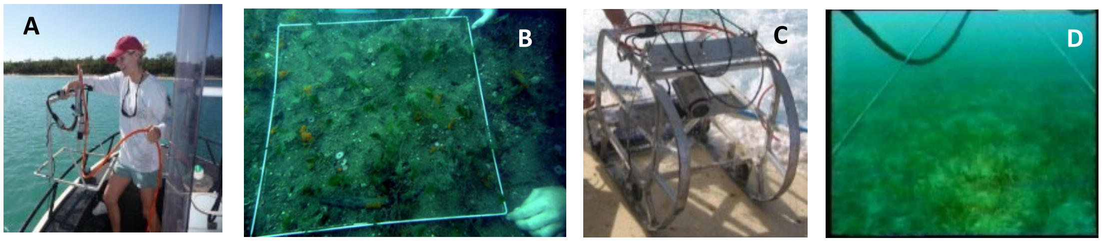

Figure 6. (A) Shallow subtidal mapping of seagrass meadows using digital camera mounted on a $0.25 m^2$ drop frame, (B) visual observation by free diver and (C-D) offshore underwater sled tows with digital camera.

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.7®. Three GIS layers were created to describe seagrass in the survey area: a site layer, meadow layer and biomass interpolation layer.

- *Site Layer:* The site (point) layer contains data collected at each site, including:
  - Site number
  - Temporal details – Survey date and time.
  - Spatial details – Latitude, longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
  - Habitat information – Sediment type; seagrass information including presence/absence, above-ground biomass (total and for each species) and biomass standard error (SE); dugong feeding trail (DFT) presence/absence.
  - Sampling method and any relevant comments.

- *Meadow layer:* The meadow (polygon) layer provides summary information for all sites within each meadow, including:
  - Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys
  - Temporal details – Survey date.
  - Habitat information – Mean meadow biomass $\pm$ standard error (SE), meadow area (hectares) $\pm$ reliability estimate (R) (Table 3), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 1 & 2), meadow landscape category (Figure 7).
  - Sampling method and any relevant comments.

- *Interpolation layer*: The interpolation (raster) layer describes spatial variation in seagrass biomass across each meadow and was created using an inverse distance weighted (IDW) interpolation of seagrass site data within each meadow.

Table 1. Nomenclature for Queensland seagrass community types.

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 the Hay Point-Mackay region.

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

Isolated seagrass patches
The majority of area within the meadow consists of unvegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches
The meadow consists of numerous seagrass patches but still features substantial gaps of unvegetated sediment within the boundary.

Continuous seagrass cover
The majority of meadow area consists of continuous seagrass cover with a few gaps of unvegetated sediment.

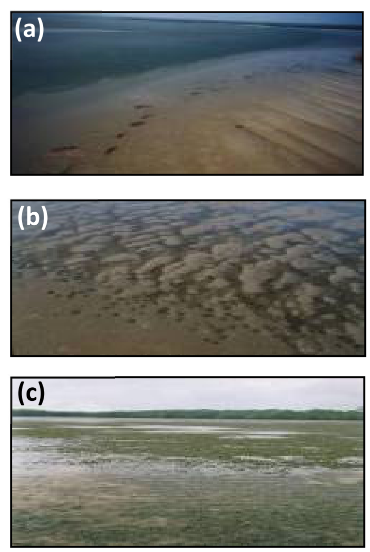

Figure 7. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

Seagrass meadow boundaries were determined from a combination of techniques. Exposed inshore boundaries were guided by recent satellite imagery of the region (Source: ESRI; Google Earth). Subtidal boundaries were interpreted from a combination of subtidal survey sites and the distance between sites, field notes, depth contours and recent satellite imagery.

Meadow area was measured using the calculate geometry function in ArcGIS®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 3). Mapping precision ranged from $\leq$10 m for intertidal seagrass meadows with boundaries mapped by walking to 100 m for subtidal meadows with boundaries mapped by distance between sites with and without seagrass. The mapping precision estimate was used to calculate a buffer around each meadow representing error; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

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

Mapping precision	Mapping methodology
10 m	Subtidal meadow boundaries determined from walking in meadows at low tide; Relatively high density of survey sites; Recent aerial photography aided in mapping.
20-50 m	Subtidal meadow boundaries determined from underwater CCTV camera drops; Moderate to high density of survey sites.
100 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 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). Overall meadow condition is the lowest indicator score where this is biomass or area. Where species composition is the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The flow chart in Figure 8 summarises the methods used to calculate seagrass condition. See Appendix 1 for full details of score calculation.

In 2019, the condition index was applied to the offshore monitoring sites at Hay Point, and coastal monitoring meadows at Dudgeon Point, Keswick Island and St Bees Island. The Hay Point offshore meadow condition is presently based on 8-years of data (2004, 2010, 2011, 2014, 2016, 2017, 2018 & 2019). Scores will vary until 10 years of data become available to establish a 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 long-term average biomass data. Presently, interim scores for the Dudgeon Point, Keswick Island and St Bees Island monitoring meadows are assessed against 6 years of averaged data (2014-2019). These averages will vary annually until 10 years of data become settled in 2023. The monitoring meadow at Dudgeon Point comprises an amalgamation of meadows previously reported as meadows 1, 2 and 3 in previous reports. The Mackay offshore monitoring meadow is newly established (2017) and there is insufficient data available to calculate meadow condition scores until 2021.

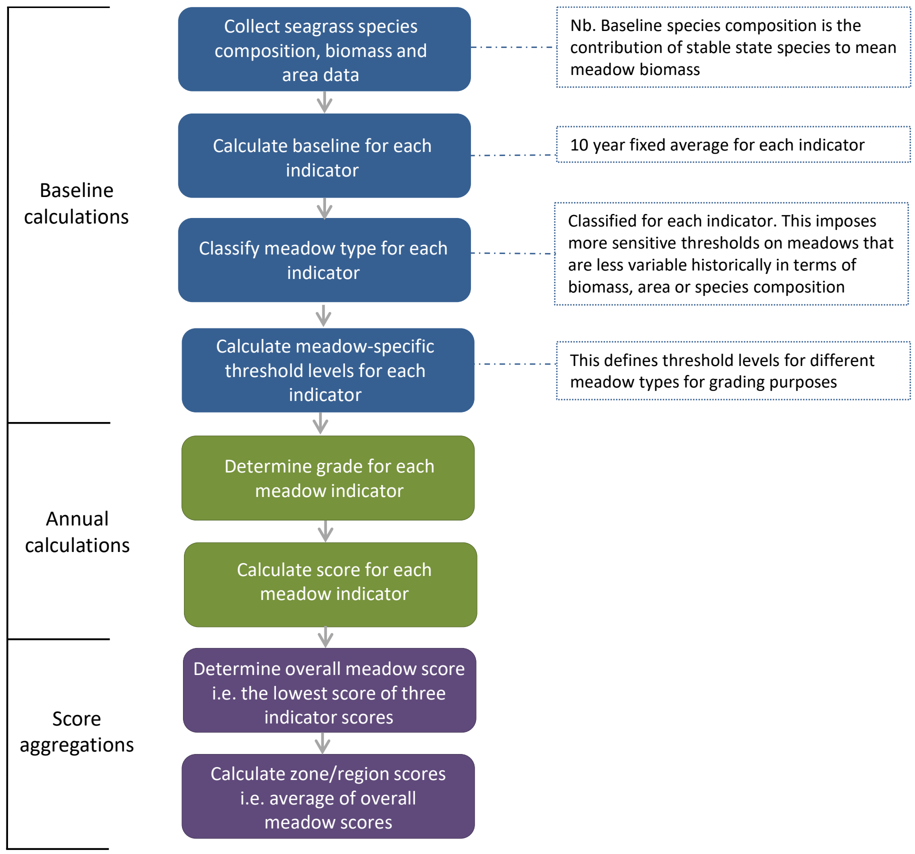

Figure 8. Flow chart to assess seagrass monitoring meadow condition.

2.4 Environmental data

Environmental data was collated for the 12 months preceding the survey. River flow was provided by the Queensland Government Water Monitoring Information Portal (Station 125016A – Pioneer River at Dumbleton Weir). Total daily rainfall, temperature and global solar exposure was obtained for the nearest weather station from the Australian Bureau of Meteorology (Mackay Aero station #033045; http://www.bom.gov.au/climate/data/). Wave data and sea surface temperature was provided by Queensland Government coastal data system – (Hay Point).

Irradiance measured as photosynthetically active radiation (PAR - mol photons m^{-2} day^{-1}) was collected at two locations (Victor Island and Round Top Island) within or nearby to offshore seagrass meadows as part of the Ambient Water Quality monitoring Program at the Ports of Mackay and Hay. Data was collected from a PAR Sensor positioned on the horizontal surface of a multiparameter water quality logging instrument, which takes a PAR measurement at ten (10) minute intervals for a one second period (Waltham et al. 2019).

3 RESULTS

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

A total of 308 sites were surveyed as part of the annual monitoring survey in the Hay Point, Mackay and Keswick Island area in October 2019 (Figure 10). Seagrass was present at 31.2 % of the coastal sites (21.6 % at Dudgeon Point and 49.4 % Keswick and St Bees Islands) and at 45.7 % of the offshore sites, a marked increase from 16.2 % the previous year (Hay Point & Mackay; Figure 10). Deep-water seagrass communities offshore from Hay Point and Mackay covered an area of 5898 ha while coastal meadows covered 18.7 ha at Dudgeon Point and 211.5 ha adjacent to Keswick and St Bees Islands (Appendix 2; Tables A4-6).

The seagrass species found in the monitoring meadows were typical of those found for coastal and offshore seagrasses in Hay Point/ Mackay and more broadly in central Queensland (Figure 11, Appendix 2). Six seagrass species were observed in 2019 (Figure 9). Deepwater assemblages offshore from Hay Point were dominated by *Halophila decipiens* while *H. spinulosa* was most abundant in the Mackay Offshore monitoring area (Figure 11, Appendix2; Figure A2). *Halophila tricostata* dominated the two meadows at Keswick and St Bees Islands with smaller amounts of *H. decipiens, H. spinulosa and H. ovalis* also occurring (Figure 11, Appendix 2). *Halodule uninervis* (both wide and narrow forms) dominated the inshore meadows at Dudgeon Point with Z*ostera muelleri* and *H. ovalis* and *H. decipiens* also occurring in these meadows (Figure 11, Appendix 2) This is the second consecutive year that *Z. muelleri* has been present since disappearing from the meadow in 2014.

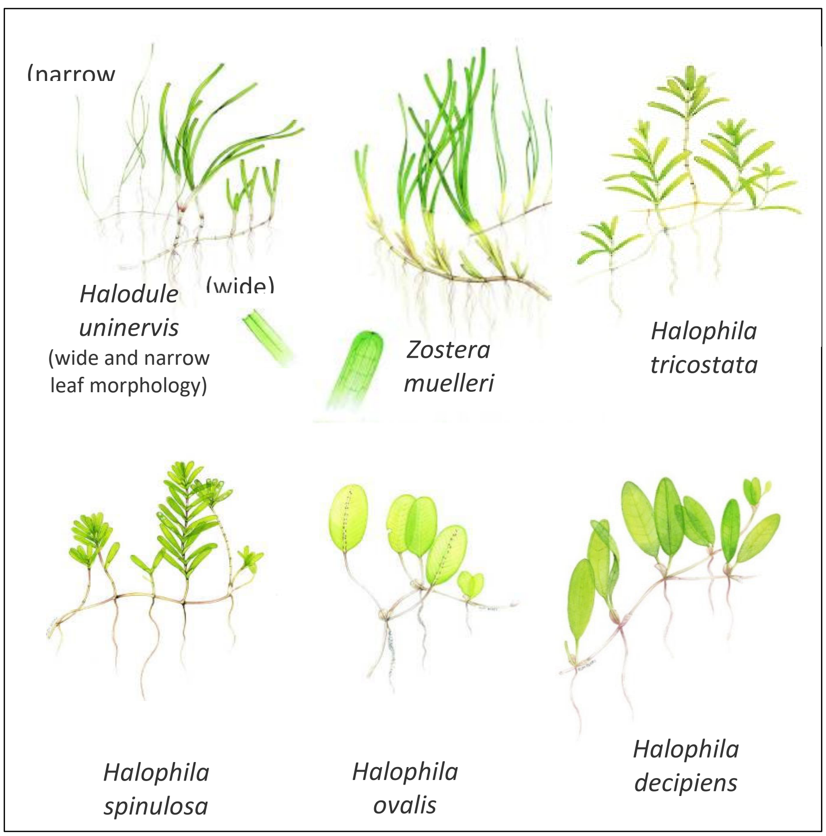

Figure 9. Seagrass species identified in the Hay Point-Mackay annual monitoring program in 2019. Leaf size varies widely within species and diagrams are not to scale.

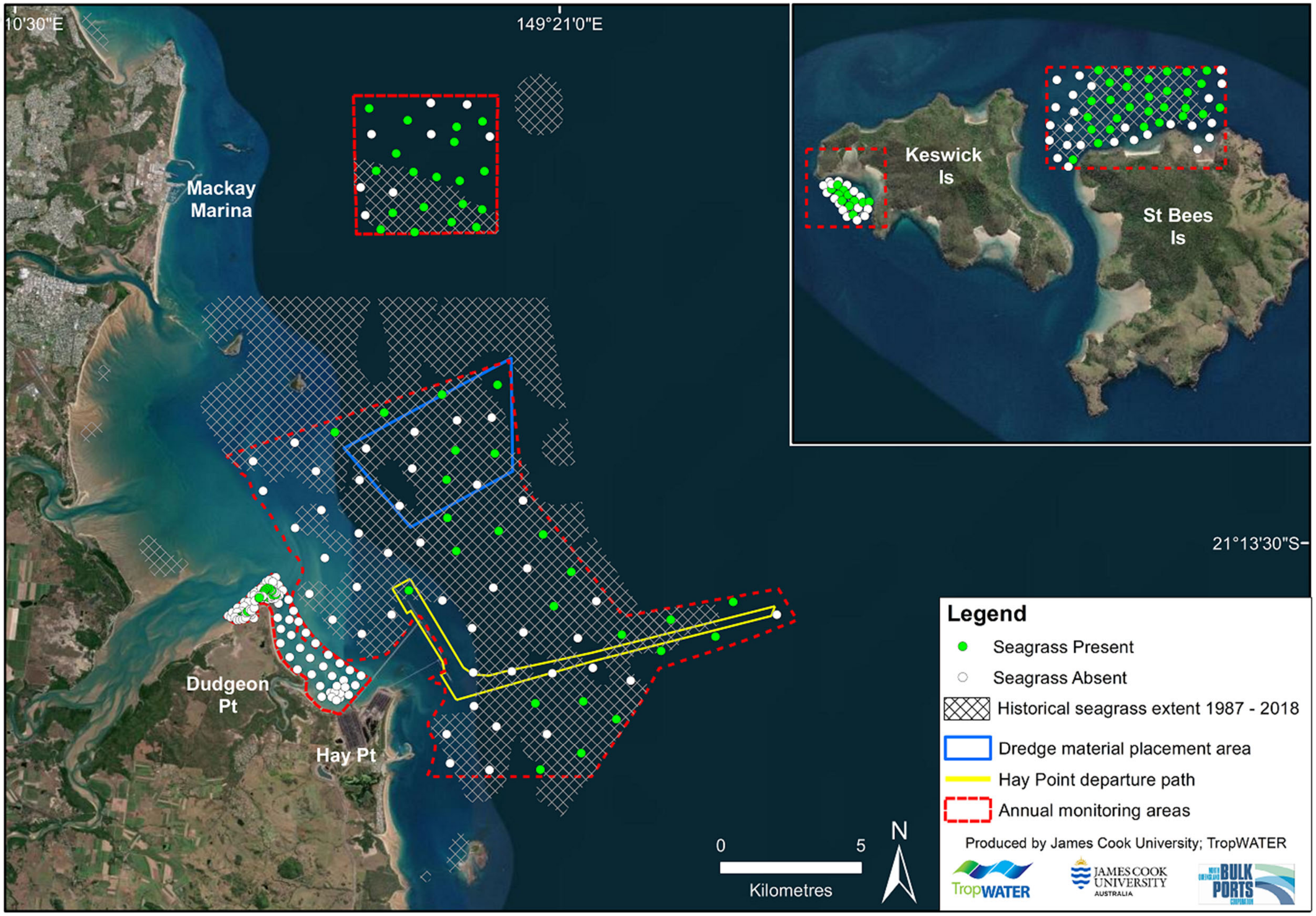

Figure 10. Location of 2019 annual seagrass monitoring survey sites in the Hay Point-Mackay region.

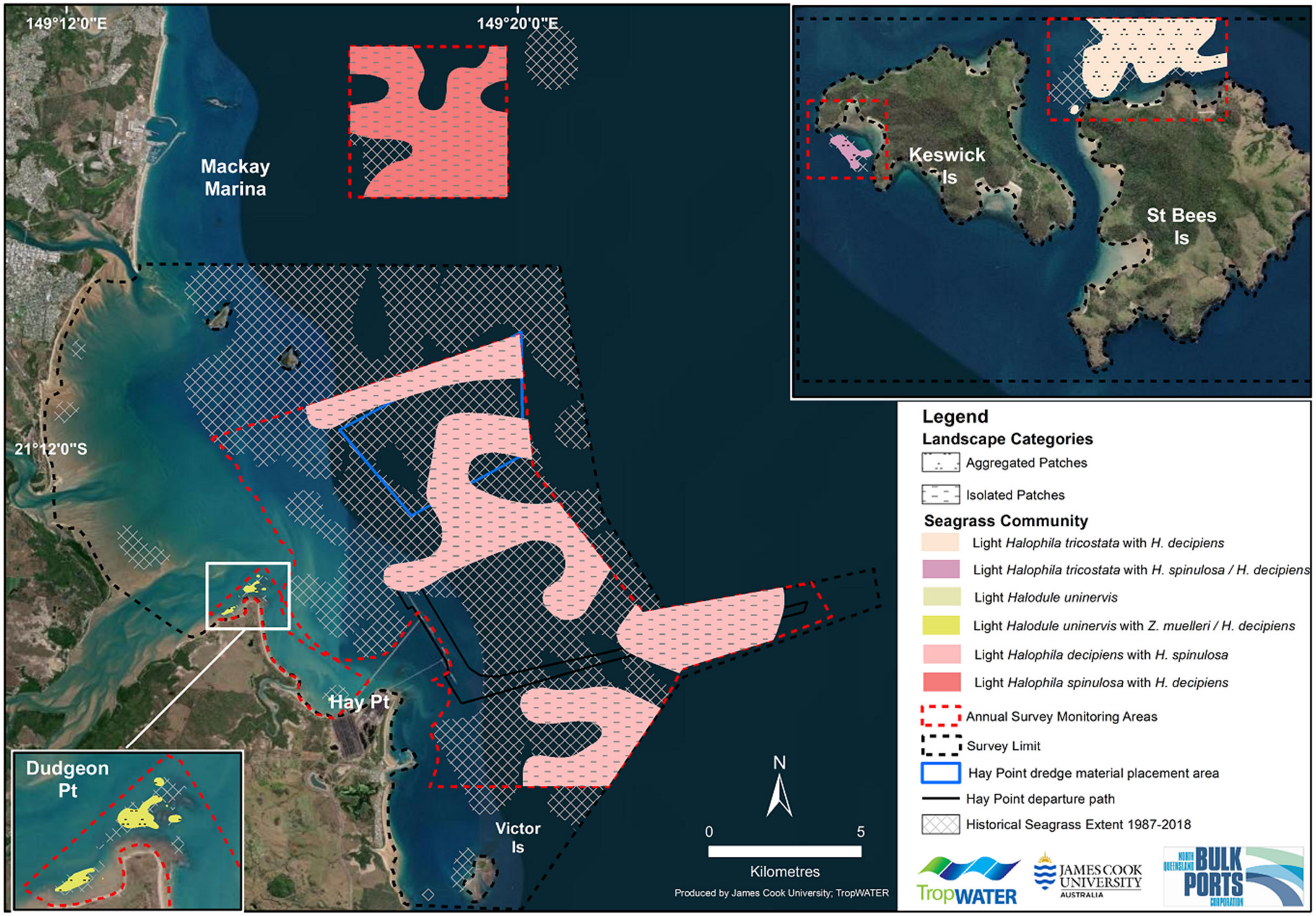

Figure 11. Location of 2019 seagrass meadows in the Hay Point region showing seagrass communities and landscape categories.

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

Offshore seagrass at Hay Point and Mackay

The overall condition of offshore seagrasses in the Hay Point monitoring area scored very good in 2019 for the first time since the condition index was introduced in 2017. The improvement in condition was the result of increases in seagrass meadow area and biomass. In the 2019 survey, biomass in this meadow reached levels higher than those observed over the last 15 years, although still less than half of those observed in the peak year of 2004 (Figures 12 & 16, Appendix 2; Table A4). Biomass in 2019 (mean ± 1SE = 0.096 ± 0.023 g DW m^2) increased more than 7-fold compared to the levels recorded in 2018 (0.013 ± 0.004 g - Figure 12, Appendix 2; Table A4). The area of the meadow also increased in 2019 to 4160.8 ± 777.8 ha, a spatial footprint more than double that found in the previous year and the highest recorded since 2014 (Figure 12, Appendix 2; Table A4). As the meadow classification for species in offshore meadows is based on the pioneering *H. decipiens,* which was again the major seagrass found in 2019, the offshore seagrass area was graded very good for species composition. *H. spinulosa* (26.7 %) was more abundant in the 2019 survey than usual, occurring at 50 percent of sites where seagrass was present (Appendix 2; Figure A2).

The 2019 survey of the area offshore from Mackay Harbour found the largest seagrass area (1737.3 ± 277.4 Ha) since this location was included in the monitoring program. The two previous surveys in 2017 and 2018 mapped considerably less seagrass area (652.8 ± 151.9 Ha and 381.6 ± 141.1 Ha respectively, Appendix 2; Table A4). The seagrass biomass recorded in the 2019 survey (mean ± 1SE = 0.135 ± 0.073 g DW m^2) was also greater than in the previous two surveys when the previous highest mean biomass was 0.0625 ± 0.0153 g DW m^2 in 2018 (Appendix 2; Table A4). The species composition shifted in the 2019 survey with *H. spinulosa* (54.4 %) becoming the dominant species in the meadow, while in previous surveys *H. decipiens* (45.6 % in 2019) had been dominant (Appendix 2; Figure A2). As this is only the third year that the Mackay offshore meadow has been monitored it is not yet possible to produce a condition score as 5 years of information is required to do this.

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

The coastal intertidal monitoring meadow at Dudgeon Point improved in condition from satisfactory to good in 2019. The change in score was primarily the result of an increase in biomass at the site in 2019 to 3.41 ± 0.61 g DW m^2 compared to the previous year (1.09 ± 0.35 g DW m^2, Figure 13, Appendix 2; Table A5). The Dudgeon Point meadow occurred as aggregated patches in 2019 with a combined area of 17.0 ± 3.8 Ha, a decline from the previous year's peak (22.56 ± 4.18 Ha), although still scoring as very good for this meadow (Figure 13 & 17, Appendix 2; Table A5). Four species occurred in the monitoring meadow in 2019, dominated by *H. uninervis* (67.6 % - both wide and narrow leaf forms) with *Zostera muelleri* (21.8 %), *H. decipiens* (7.9 %), and *H. ovalis* (2.7 %) also present (Appendix 2; Figure A2). A small patch of *H. uninervis*, was also observed in Meadow 20 North of the Hay Point terminal for the first time since 2010 (Appendix 2; Table A5, Meadow 20). This meadow is not included in the assessment of monitoring scores at Dudgeon Point due to its distance from the other meadow and its infrequent appearance, however its presence speaks to the strong conditions for seagrass growth during 2019.

The seagrass monitoring meadow adjacent to St Bees Islands was scored as in good condition in 2019, down from a very good classification in 2018 (Table 4). The change in classification was due to a decline in the biomass at the site in 2019 to 1.38 ± 0.15 g DW m^2 from a peak in 2018 of 2.40 ± 0.38 g DW m^2 (Figure 14, Appendix 2; Table A6). The area of the meadow also declined slightly in 2019 to 197.3 ± 42.9 but remained in a very good condition (Figure 14 & 18, Appendix 2; Table A6). Three species were found in the meadow in 2019 dominated by *Halophila tricostata* (86.7 %) with *H. decipiens* (10.7 %), and *H. spinulosa* (2.7 %) also occurring (Apendix 2; Figure A2). The Keswick Island monitoring meadows were in a good condition in 2019 with biomass and area around the long term average (Figure 15, Appendix 2; Table A6). The size of this meadow declined in 2019 resulting in the area indicator decreasing from very good in 2018. In 2019 this meadow consisted of four species dominated by *H. tricostata* (56.8 %) with *H. decipiens* (31.8 %), *H. spinulosa* (23.4 %) and *H. ovalis* (7.8 %) also present (Appendix 2, Figure A2).

Table 4. Grades and scores for seagrass indicators (biomass, area and species composition) for the Hay Point-Mackay monitoring meadow in 2019.

Meadow	Location	Biomass	Area	Species Composition	Overall Meadow Score
1	**Dudgeon Point**	0.82	0.86	0.89	0.82
8	**Hay Point - Offshore**	0.86	0.87	1.00	0.86
10	**St Bees Island**	0.67	0.89	0.86	0.67
14	**Keswick Island**	0.73	0.73	0.93	0.73
Overall Score for the Hay Point-Mackay region					**0.77**

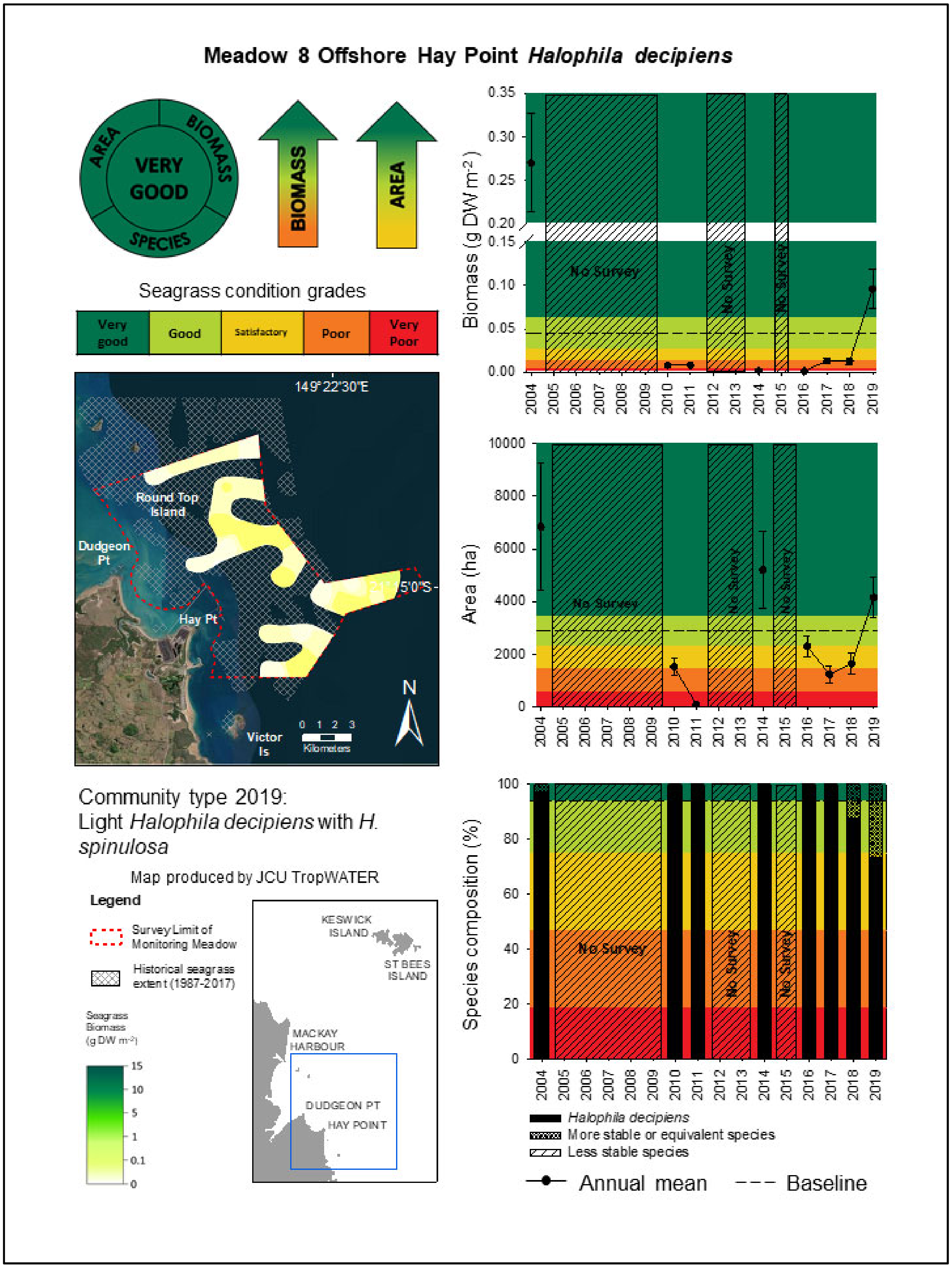

Figure 12. Changes in meadow biomass, area and species composition for seagrass in the Hay Point offshore area (Meadow 8), 2004 – 2019 (biomass error bars = SE).

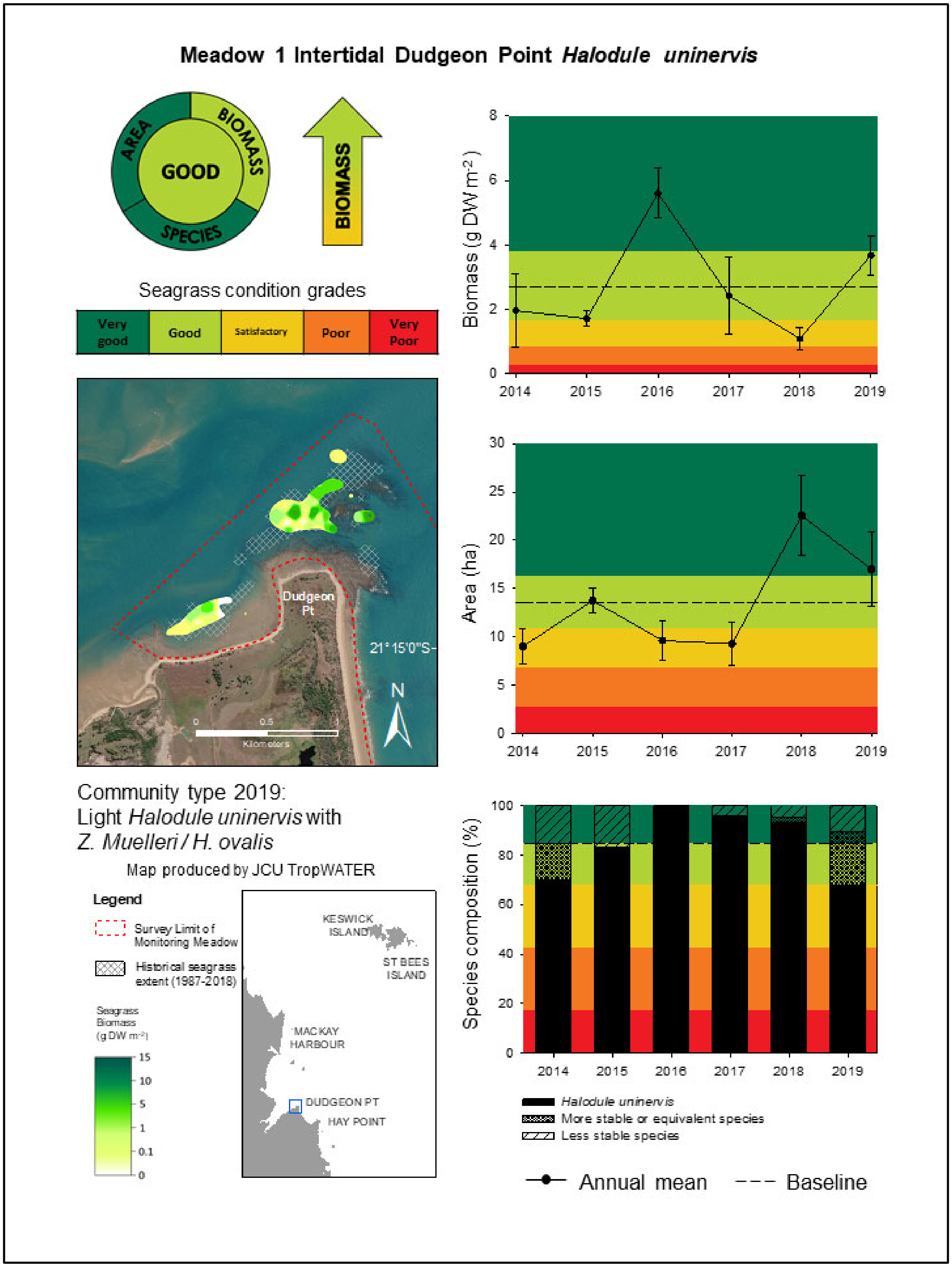

Figure 13 Changes in meadow biomass, area and species composition for seagrass in the Dudgeon Point coastal area (Meadow 1), 2014 – 2019 (biomass error bars = SE).

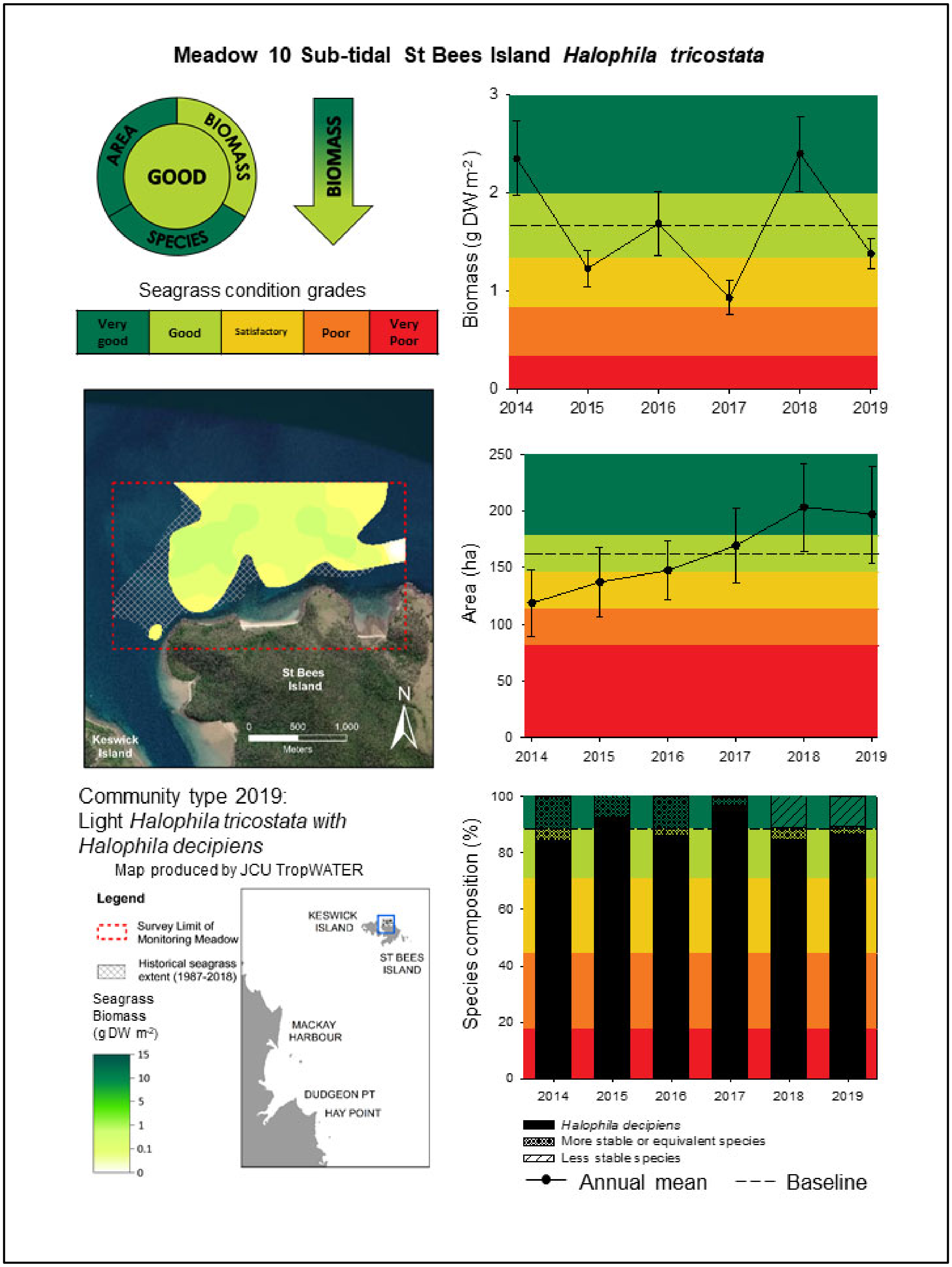

Figure 14 Changes in meadow biomass, area and species composition for seagrass in the St Bees Island coastal area (Meadow 10), 2014 – 2019 (biomass error bars = SE).

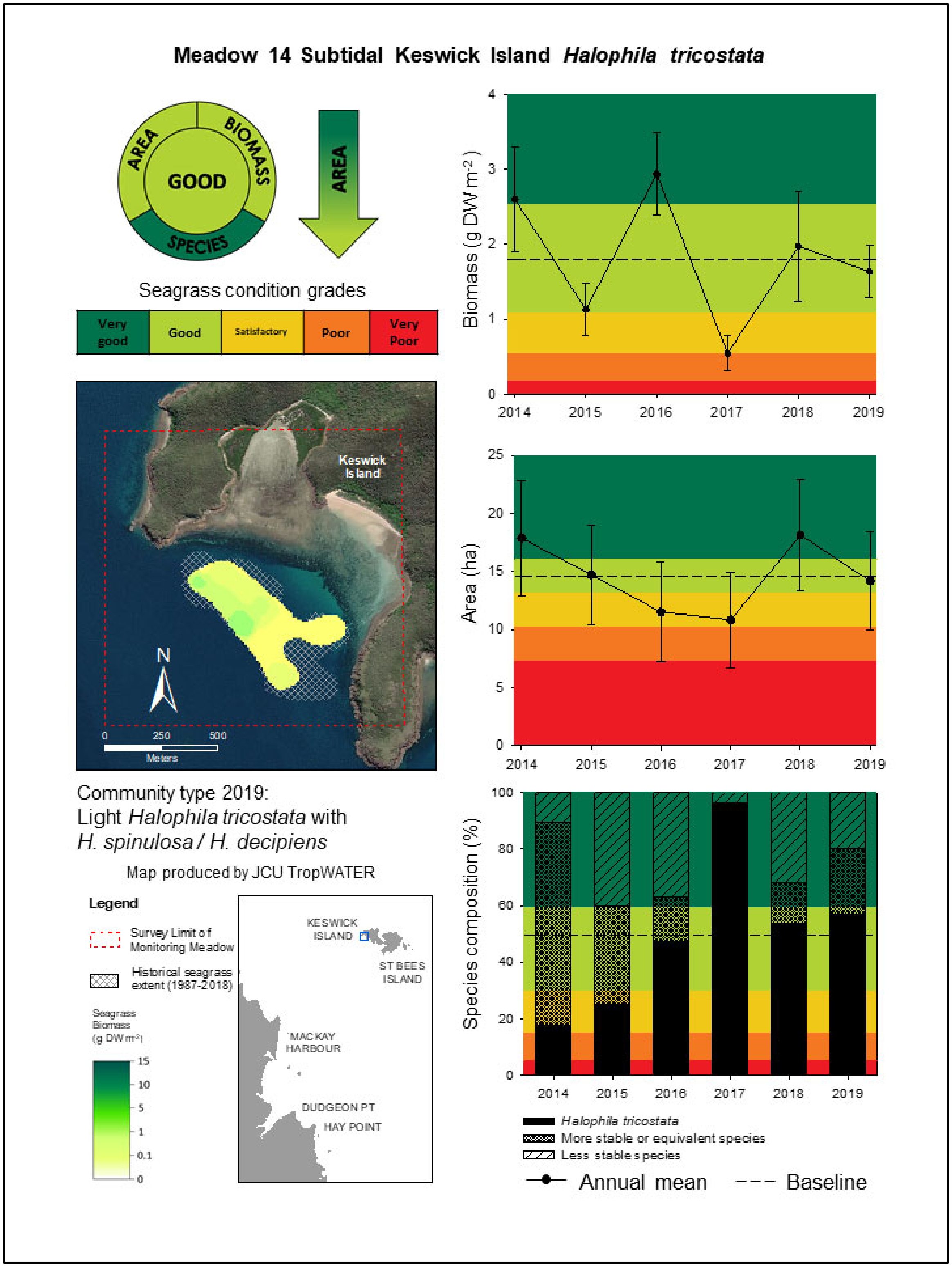

Figure 15 Changes in meadow biomass, area and species composition for seagrass in the Keswick Island coastal area (Meadow 14), 2014 – 2019 (biomass error bars = SE).

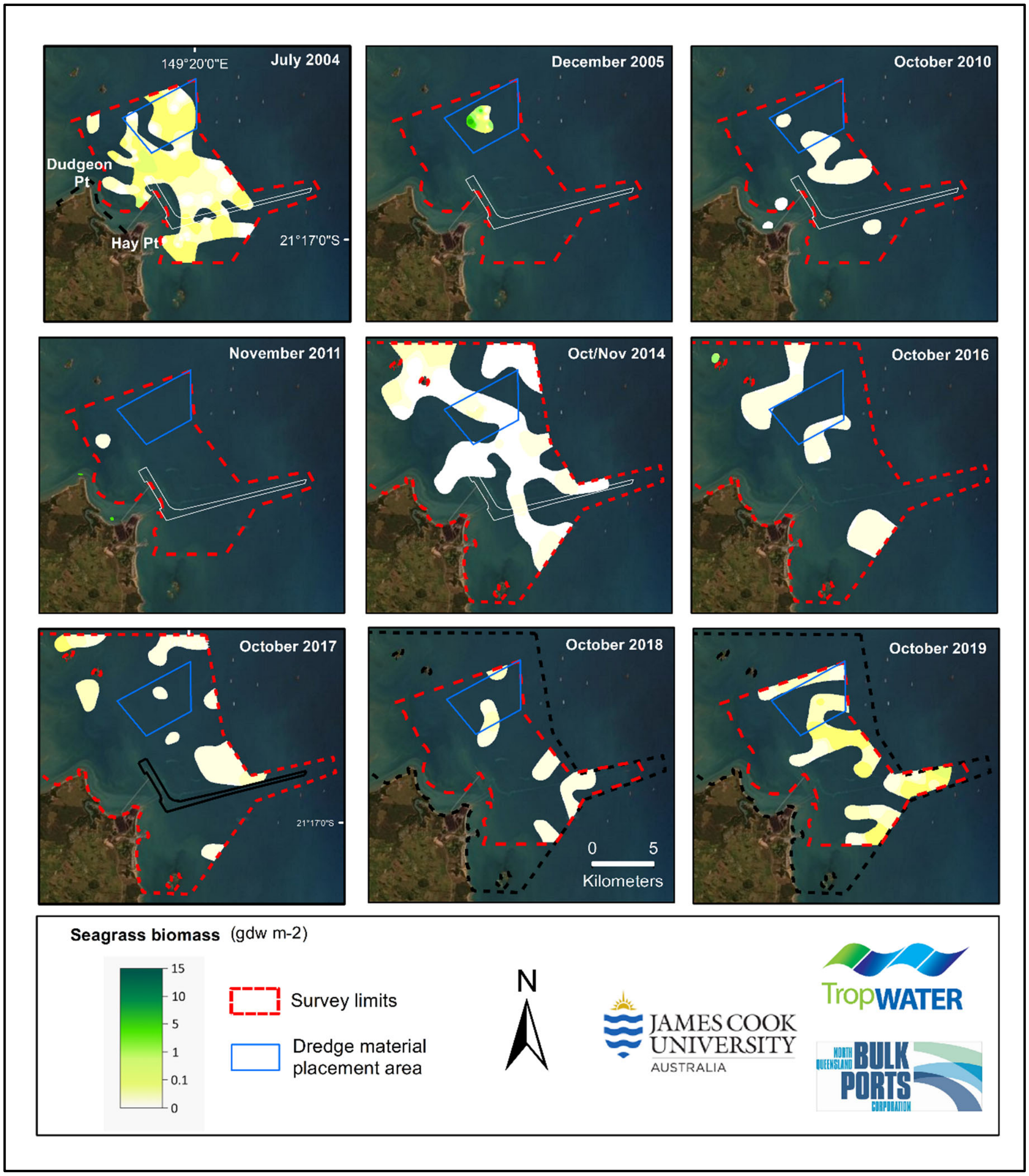

Figure 16. Seagrass biomass distribution in the Hay Point offshore monitoring area when surveys were conducted between 2004-2019.

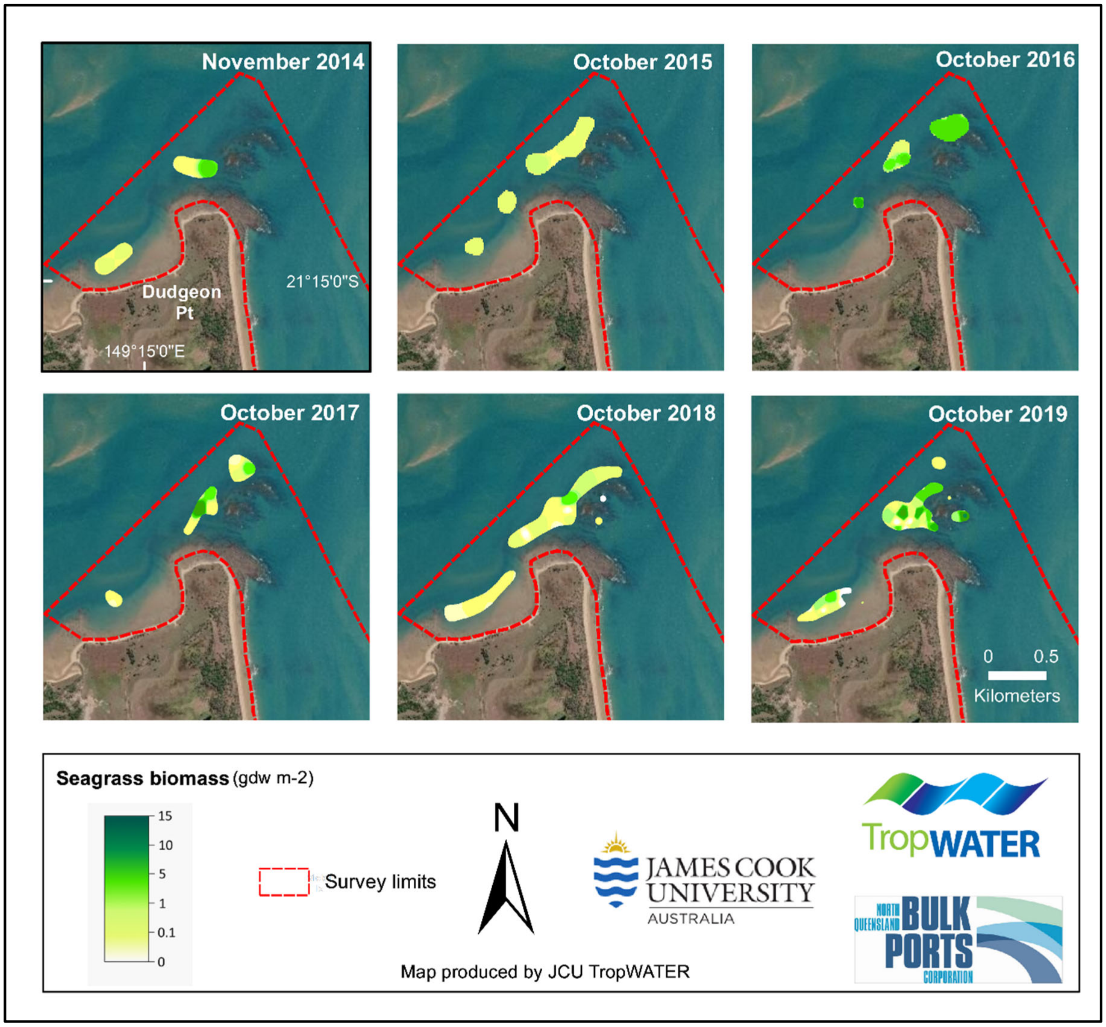

Figure 17. Seagrass biomass distribution in the Dudgeon Point to Hay Point annual monitoring area 2014 -2019.

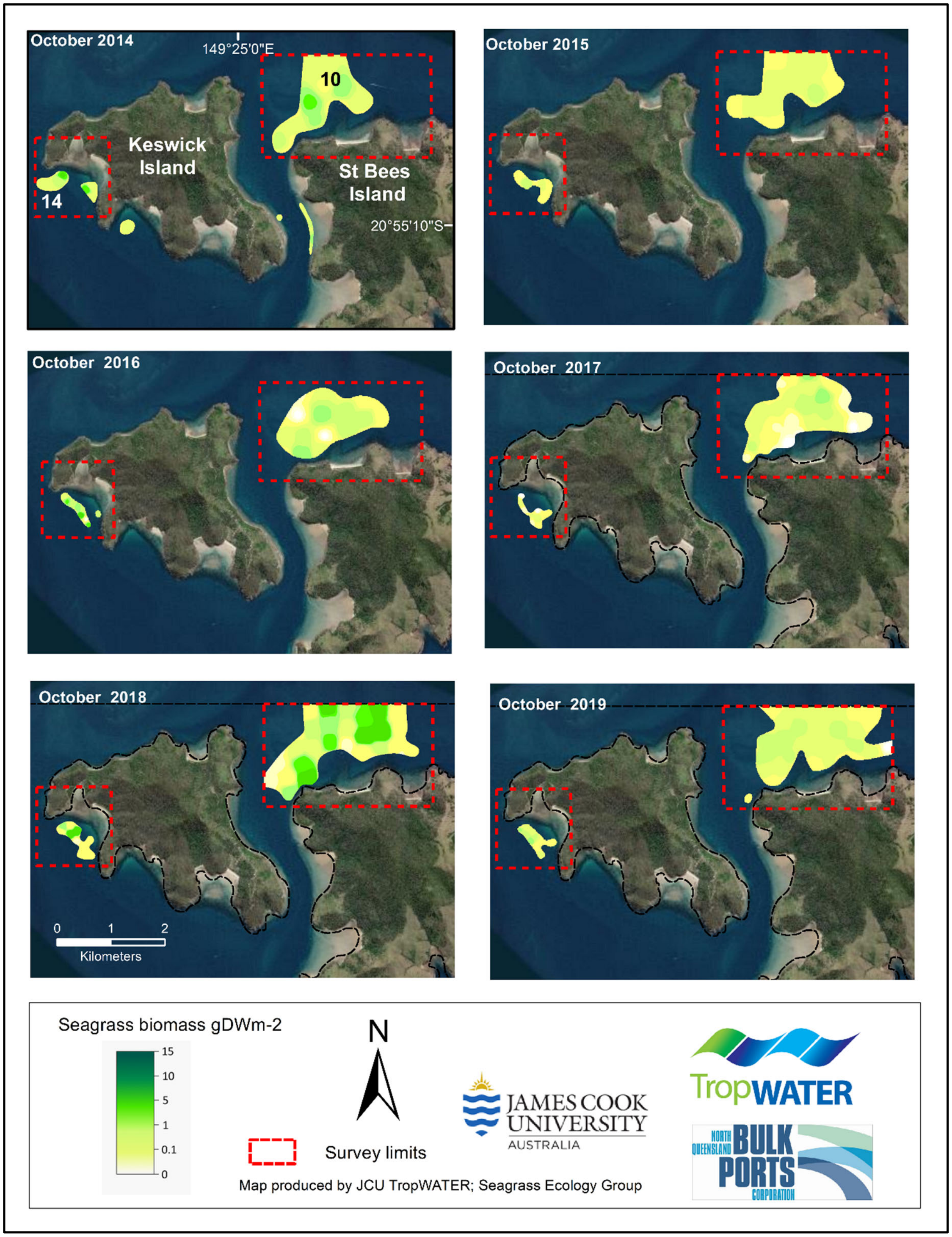

Figure 18. Seagrass biomass distribution in the annual monitoring meadows at Keswick and St Bees Islands 2014 – 2019.

3.3 Environmental conditions

Rainfall

Annual rainfall was below the long term average in 2018/19 for the second consecutive year (Figure 19a). This followed a year of above average precipitation mainly due to significant rainfall in January and March of 2017. Throughout the year the monthly rainfall was below long term averages apart from Decmmber 2018 when rainfall was more than double the long term average for the month. Very little rainfall was recorded in the five months prior to the annual sampling in 2019 (Figure 19b).

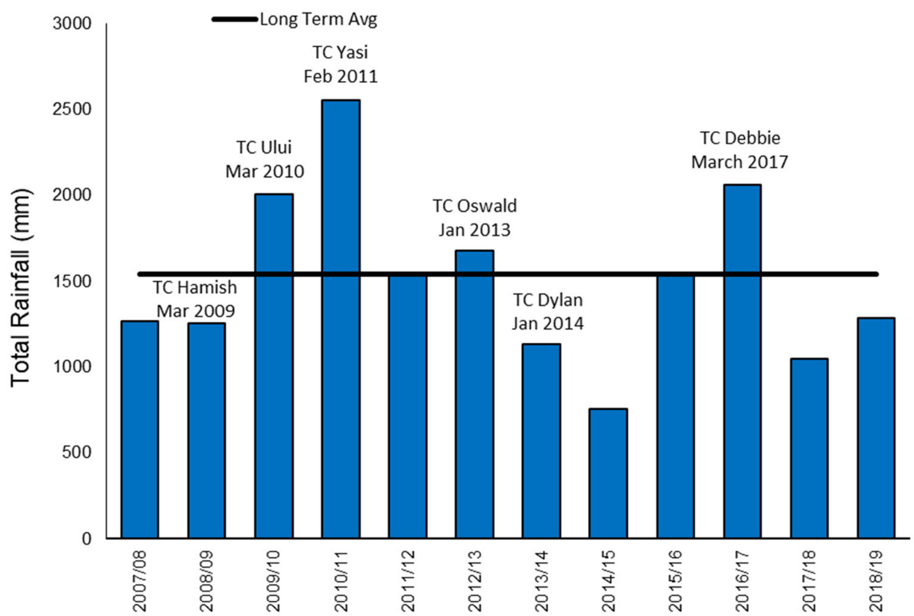

Figure 19a. Total annual rainfall (mm) recorded at Mackay Aero, 2007/08-2018/19. Twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033045.

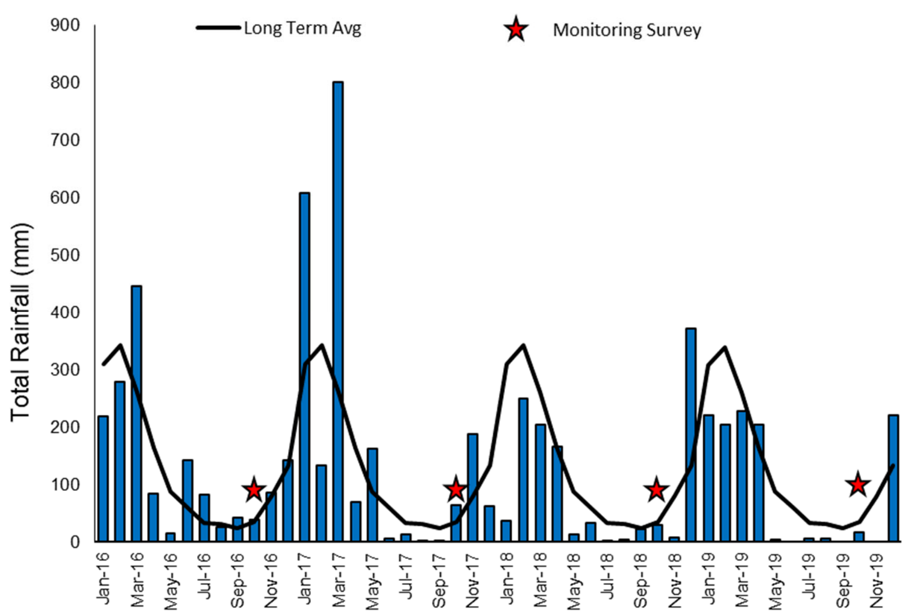

Figure 19b. Total monthly rainfall (mm) recorded at Mackay Aero, January 2016 - December 2019. Source: BOM, Station number 033045.

River flow

Annual river flow of the Pioneer River was close to the long-term average in the year leading up to the survey (Figure 20a). Monthly levels were around the long-term average throughout the year with the exception of January and February 2019 when river flows peaked for the year at well above average for these months. July river flows were also considerably above the long-term average (Figure 20b).

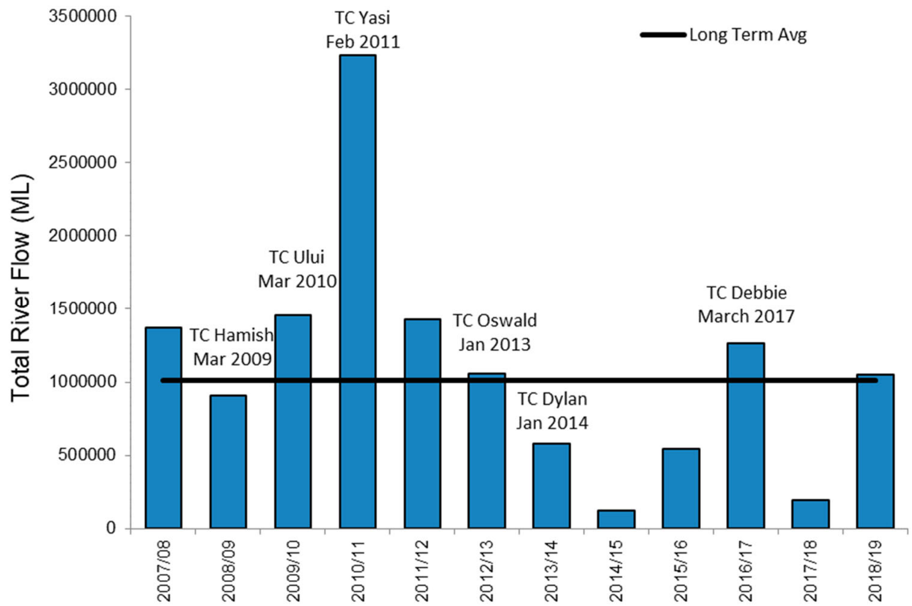

Figure 20a. Annual river flow (Mega litres) for the Pioneer River, 2007/08-2018/19. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

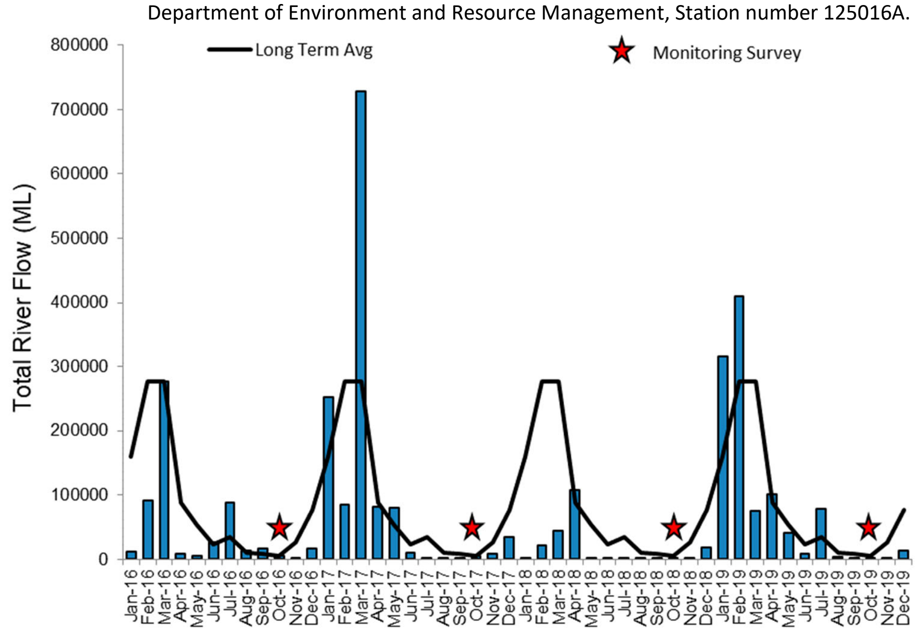

Figure 20b. Monthly river flow (Mega litres) for the Pioneer River January 2016-December 2019. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

Sea surface temperature

Sea surface temperature has been collected by the Queensland Government half hourly at Hay Point since 2008. The mean annual maximum daily sea surface temperature of 25.15° C in 2018-19 was 0.36° C above the long-term average for this location (Figure 21a). Monthly data shows that sea surface temperature was above the long-term monthly average around the start of 2019 (November 2018 to June 2019) but was below the monthly average in the two months preceding the annual survey (Figure 21b).

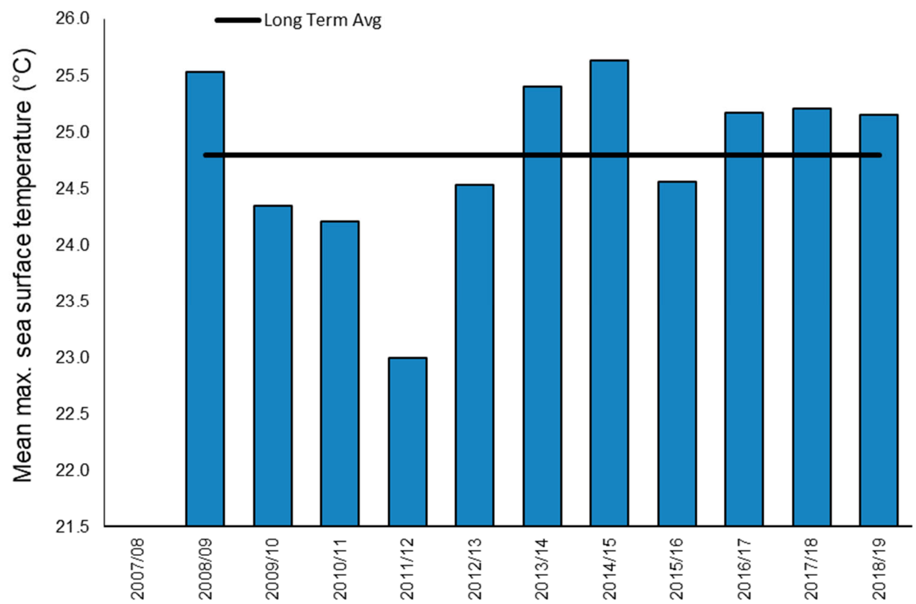

Figure 21a. Mean annual maximum sea surface temperature (°C) recorded at Hay Point 2008/09-2018/19.
Source: QLD Department of Science, Information technology and Innovation

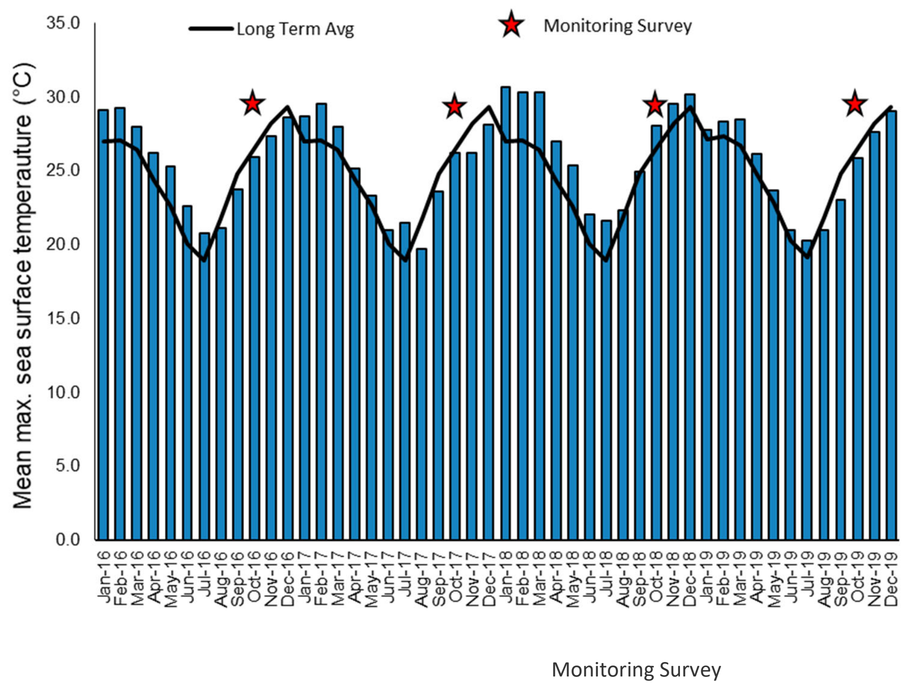

Figure 21b. Monthly maximum sea surface temperature (°C) recorded at Hay Point; January 2016 to December 2019. Source: QLD Department of Science, Information technology and Innovation

Daily solar radiation

Solar exposure in the Hay Point area was below the regional long-term average (20.70 MJ m^{-2}) in the twelve months to the 2018/19 survey (Figure 22a). This low annual average was mainly due to below average monthly exposure from December 2018 through to May 2019. Monthly exposure was very close to the long-term average in the four months preceding the annual survey in October 2019 (Figure 22b).

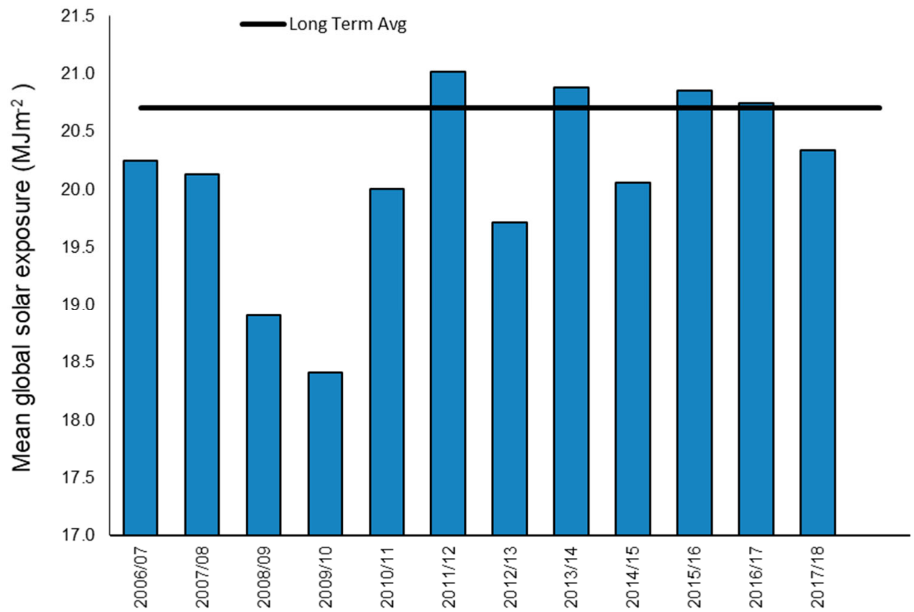

Figure 22a. Mean annual solar radiation (MJm^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) 2007/08 -2018/19.
Source: BOM

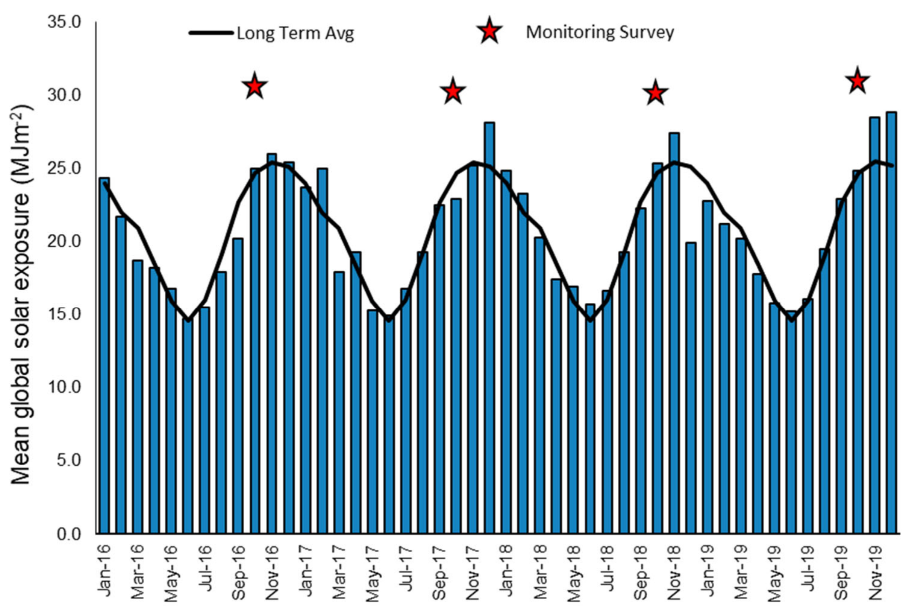

Figure 22b. Mean monthly daily global solar exposure (MJ m^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) January 2016-December 2019. Source: BOM.

Significant wave height

In the 12 months prior to the survey, the highest maximum monthly average wave height of 1.62m was recorded in April 2019, with the lowest of 0.60 recorded in September (Figure 23). The general trend in the year prior to the annual survey consisted of above average maximum wave heights from December 2018 through to May 2019 with the exception of March, then average to below average in the three months prior to the survey (July – September 2019).

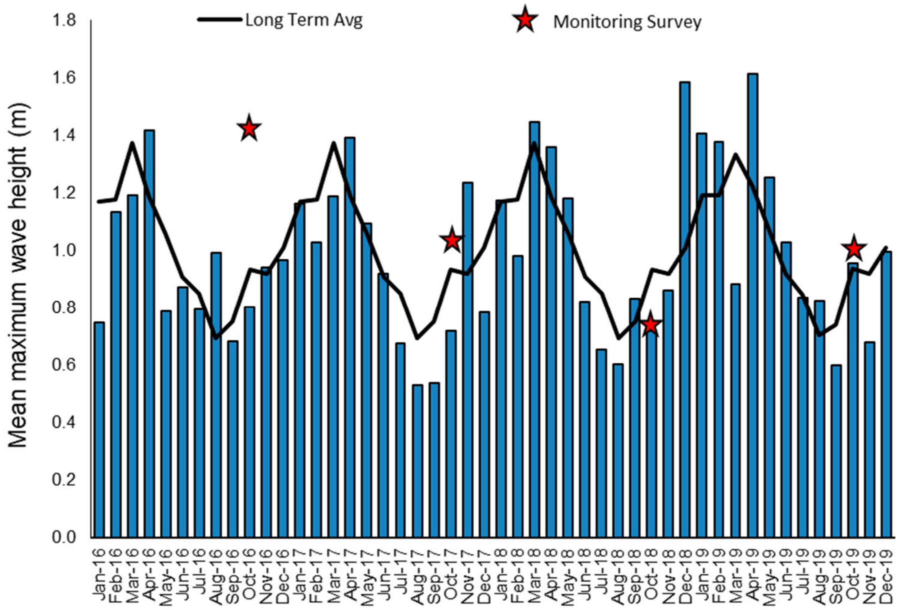

Figure 23. Mean monthly maximum wave height (m) recorded at Hay Point, January 2016-December 2019.
Source: DSITI.

Benthic daily light (Photosynthetically active radiation - PAR)

Total daily light measured as photosynthetically active radiation (PAR) is monitored as part of the Ambient Marine Water Quality Monitoring Program for the ports of Mackay and Hay Point. Locations where PAR is collected within or near offshore seagrass meadows are Victor Island, and Round Top Island (Multiparameter water quality loggers – Figure 24). PAR showed general seasonal trends with higher benthic light availability from late July through to November 2019. The PAR at both sites during this time of the year was generally above the light requirements for deep-water seagrass in the region (McKenna et al. 2015). These light levels are linked to environmental conditions and are higher when lighter winds and fewer rainfall events occurred. This period coincides with the presence and growing season of offshore seagrass in the Mackay area (York et al. 2015). Strong onshore winds and more regular rain events that characterize the period between January/February and June in combination with fine particulate sediment matter near the coast drive resuspension of particles and lower benthic PAR levels (Waltham et al. 2019). This period coincides with the annual period of dormancy in the deep-water meadows off Hay Point and Mackay.

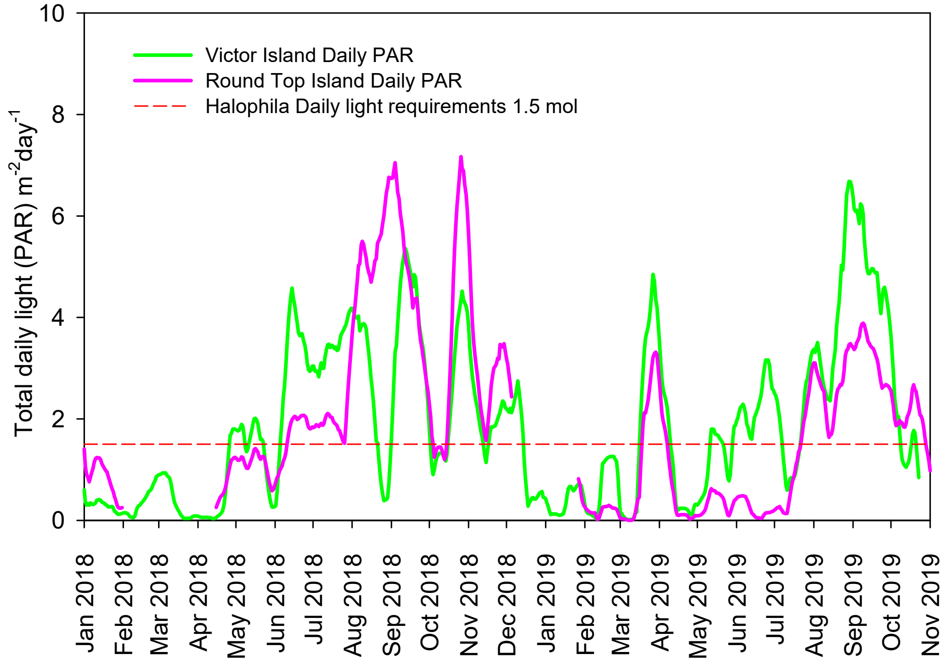

Figure 24. Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1}) at Victor Island and Round Top Island. Data presented from January 2018 to December 2019. Source: Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program (Waltham et al. 2019).

4 DISCUSSION

The condition of seagrass meadows in the Hay Point, Mackay and Keswick Island regions improved in 2019 to be classified as good to very good in all monitoring locations. This is the best condition status for the region since the reporting index was developed in 2017 and included some of the highest biomass and area for some habitat since annual monitoring began. In 2019 there was variation among individual meadows with the deep-water meadows offshore from Hay Point shifting from poor condition to very good, coastal meadows at Dudgeon Point improving from satisfactory to good, while the Keswick Island meadow remained in good condition and the St Bees Island meadow decreased from very good to good. The condition of seagrasses in the region is likely influenced most by climate and extreme weather events. At the time of the 2019 survey, the region had experienced two-and-a-half-years with no major flooding or cyclones, allowing seagrass meadows time to recover following several consecutive years of flood, storm and cyclone impacts. Climate conditions for seagrass growth were favourable for much of the year prior to the seagrass survey in October 2019. Throughout this time the region experienced below average rainfall, average river flows and solar exposure, and sea surface temperatures that were slightly above the long term average for the region.

The deep-water seagrass meadows offshore from the port of Hay Point were in very good condition in 2019 for the first time, with biomass at its highest level since it peaked in 2004. This improvement from poor in 2018 was due to substantial increases in seagrass biomass and meadow area, with the spatial footprint of the meadow more than doubling. The increase in occurrence of *H. spinulosa* in the offshore meadows contributed to the higher average biomass in these meadows. Deep-water seagrasses in the monitoring area offshore from Hay Point consists of colonising *Halophila* species (mainly *H. decipiens*) that are adapted to surviving in low light conditions (Josselyn et al. 1986, McKenna et al. 2015, Chartrand et al. 2017). *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). At Hay Point the meadow dynamics are characterised by naturally high inter-annual variability in biomass and meadow area and an annual occurrence between July and December each year (York et al. 2015). This occurrence coincides with higher light levels, measured as photosynthetically active radiation (PAR), due to lighter winds and less rainfall in the dry season (see Waltham et al. 2019). 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 culminating when TC Debbie hit the region in March 2017. In 2019 seagrass biomass in this meadow, reached levels considerably higher than those observed over the last decade and a half, although biomass was still well below the peak observed in 2004. Deep-water seagrass in the Mackay offshore monitoring area also improved in condition from the previous two years. However, as only three years of data have been collected, a condition score cannot yet be calculated (requires 5 years of baseline data). The Mackay offshore area saw more than a doubling in biomass and increased in area more than fourfold compared to the survey from 2018.

Seagrass meadows at Keswick Island and St Bees Island were in good condition in 2019 with area and biomass at both locations close to the long-term averages from the six years that monitoring has been conducted here. 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 compared to *H. decipiens* (Collier et al. 2016). These meadows are considerably further offshore than the Hay Point deep-water meadows, occur in sandy sediments and are therefore less susceptible to fluctuations in light and water quality from turbid coastal plumes following rainfall events or wind-driven resuspension of particles in the water column. These conditions generally provide a more-favourable and less-seasonal environment for seagrass growth, as indicated by the more consistent pattern of light (PAR) throughout the year here (Waltham et al. 2019). Such conditions allow for the meadows to persist throughout the year as opposed to the annual lifecycle of meadows offshore from Hay Point.

Coastal meadows in the Dudgeon Point monitoring area improved from a satisfactory condition in 2018 to good condition in 2019 due to an increase in the levels of above ground biomass of seagrass found in the meadows. The inshore monitoring area around Dudgeon Point consisted of seagrass meadows dominated by *Halodule uninervis* with *Zostera muelleri* and *Halophila* species also present. The species dominating this meadow have higher light requirements than the deeper *Halophila* dominated meadows offshore. They are much more resistant to disturbance and can persist for much greater periods in poor light conditions (Collier et al. 2016), particularly during a senescent growth period corresponding with wet and windy conditions in this region between January and June (Chartrand et al. 2016). In these meadows, the extended time since the last major disturbance (TC Debbie) in March 2017 has provided a much needed window for recovery and an opportunity for meadows to build resilience.

The highly variable and low biomass nature of seagrass in the Mackay-Hay Point region suggests 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 focus on ensuring the resilience of these habitats remains high enough to withstand impacts and risks. This will allow seagrass habitat to continue to deliver the important ecosystem services and functions such as the sequestration of carbon (Rasheed et al. 2019) and support of important food webs (Jinks et al. 2019). While previous research has shown that these meadows are susceptible to impacts from large scale prolonged capital 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 (Kenworthy 2000). 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. This can be achieved by managing activities in a way that minimises the time they are exposed to stress or taking advantages of the windows available when they are seasonally absent (York et al. 2015, Wu et al. 2017).

The improved conditions of seagrass in the region in 2019 occurred despite a maintenance dredging campaign for the port during the year. Measures implemented to manage the dredging and maintain water quality targets within background levels were effective in protecting seagrasses. These included real-time information on water quality provided throughout the dredging campaign to inform dredge management. These results are similar to previous smaller dredging campaigns in the Hay Point region, which unlike the major extended capital dredging campaign of 2004, have not resulted in measurable declines in seagrass (York et al. 2015). A study that examined the resilience of *Halophila* meadows to repeated maintenance dredging that included Hay Point data suggests that the short duration of these maintenance dredging campaigns falls well within the window of time where they remain resilient to any long-term impacts (Wu et al. 2018).

The Mackay-Hay Point long-term monitoring program is now 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 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 coverage for seagrass assessment and condition. Monitoring at other sites in the network has shown a range of results during 2019. Along the coast of north Queensland seagrass condition improved at most locations due to favourable growing conditions (e.g. Gladstone – Smith et al. 2020; Abbot Point – van de Wetering et al. 2020a; Mourilyan - van de Wetering et al. 2020b; Cairns - Reason et al. 2020; and Weipa – Hoffmann et al. 2020). In other locations where local flooding occurred in early 2019 seagrass condition has declined (e.g. Karumba – Shepherd et al. 2020; and Townsville – McKenna et al. 2020).

Ongoing development of seagrass condition indices

This is the third year of the new monitoring program and reporting of seagrass condition established in 2017 for Hay Point, Mackay and the Southern Whitsundays. As the program develops it will align 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 continue to be incorporated into the Mackay Whitsunday Healthy Rivers to Reef Partnership report card.

Hay Point offshore

The present survey (2019) was the third time that an assessment of offshore seagrasses incorporating seagrass area has been used to measure the seagrass condition of the Hay Point offshore meadows. The long-term averages for meadow indicator conditions now has 8 years of data and will become a baseline when 10 years of data is available in 2021. During this time, the influence of the 2004 survey will be continually reviewed to determine if this single year is having a disproportionate influence and skewing the condition index.

Coastal meadows and Keswick & St Bees Islands

The Dudgeon Point and Keswick and St Bees Islands monitoring areas have now established an interim 6-year long-term average against which to benchmark annual monitoring results to produce condition scores. The long-term averages will continue to change for these locations until a permanent baseline is established in 2023 after 10 years of data collection (see appendix 1).

Mackay offshore

The Mackay offshore seagrasses were mapped for only the third time in 2019. An interim score for this area will not be available until 2021 after 5-years of data is collected for all metrics.

Conclusion

Seagrasses in the Hay Point – Mackay – Keswick Island region are in good condition in 2019 for the first time since a condition status score was introduced in 2017, and with area and biomass at many places reaching levels amongst the highest recorded since annual monitoring began. The condition has improved markedly for the Hay Point offshore meadows which have increased from poor in 2018 to very good and for coastal meadows around Dudgeon Point which increased from satisfactory to good. The improvement is likely due to favourable growing conditions for seagrass over the 12 months prior to the survey and no major disturbances since cyclone Debbie in March 2017, allowing for an extended window of recovery. This improvement is in line with other locations in the central Queensland region such as Gladstone to the south and Abbot Point to the north that also experienced improvements in seagrass condition in 2019.

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6 APPENDICES

Appendix 1 Score Calculation Methods.

Baseline Calculations
Baseline conditions for seagrass biomass, area and species composition for the Hay Point offshore meadow were established from annual means calculated from 8 years of data for biomass, area and species composition (2004 no seagrass present). Baseline conditions for Dudgeon Point, Keswick Island and St Bees Island were established from annual means calculated from 6 years of data for biomass, area and species composition (2014-18). These baselines were set based on results of the Gladstone Harbour report card (Carter et al. 2015). The 2004–2019 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		BIOMASS	Decrease below threshold from previous year		BIOMASS

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 (Table A3; 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 2019 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 A3). 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 2019 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).

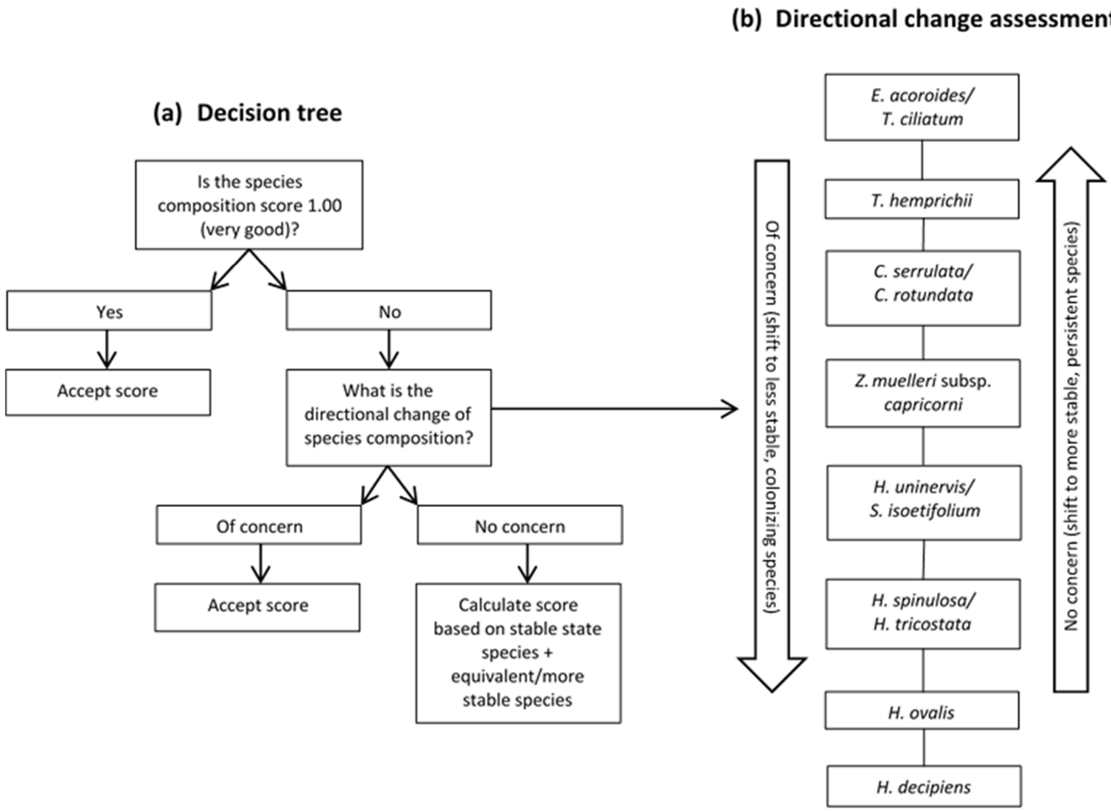

Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Hay Point.

Score Aggregation

A review in 2017 of how meadow scores were aggregated from the three indicators (biomass, area and species composition) led to a slight modification from previous years' annual report. This change was applied to correct an anomaly that resulted in some meadows receiving a zero score due to species composition, despite having substantial area and biomass. The change acknowledges that species composition is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience, and ecosystem services, but is not as fundamental as having some seagrass present, regardless of species, when defining overall condition. The overall meadow score was previously defined as the lowest of the three indicator scores (area, biomass or species composition). The new method still defines overall meadow condition as the lowest indicator score where this is driven by biomass or area as previously; however, where species composition was the lowest score, it contributes 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributes the remaining 50%. The calculation of individual indicator scores remains unchanged.

Both seagrass meadow area and biomass are fundamental to describing the condition of a seagrass meadow. A poor condition of either one, regardless of the other, describes a poor seagrass meadow state. Importantly they can and do vary independently of one another. Averaging the indicator scores is not appropriate as in some circumstances the area of a meadow can reduce dramatically to a small remnant, but biomass within the meadow is maintained at a high level. Clearly such a seagrass meadow is in poor condition, but if you were to take an average of the indicators it would come out satisfactory or better. The reverse is true as well, under some circumstances the spatial footprint of a meadow is maintained but the biomass of seagrass within is reduced dramatically, sometimes by an order of magnitude. Again, taking an average of the two would lead to a satisfactory or better score which does not reflect the true state of the meadow. As both of these characteristics are so fundamental as to the condition of a seagrass meadow, the decision was to have the overall meadow score be the lowest of the indicators rather than an average. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014).

Seagrass species composition is an important modifier of seagrass meadow state. A change in species to more colonising forms can be a key indicator of disturbance and a meadow in recovery from pressures. As not all seagrass species provide the same services a change in species composition can lead to a change in the function and services a meadow provides. Originally the species composition indicator was considered in the same way as biomass and area, if it was the lowest score, it would inform the overall meadow score. However, while seagrass species is an important modifier it is not as fundamental as the actual presence of seagrass (regardless of species). While the composition may have changed there is still seagrass present to perform at least some of the roles expected of the meadow such a food for dugong and turtle for example. The old approach led to some unintended consequences with some meadows receiving a "0" score despite having good area and biomass simply because the climax species for that meadows base condition had not returned after losses had occurred. So while it is an important modifier, species composition should not be the sole determinant of the overall meadow score (even when it is the lowest score). As such the method for rolling up the 3 indicator scores was modified so that in the circumstances where species composition is the lowest of the 3 indicators, it contributes 50% of the score, with the other 50% coming from the lower of the 2 fundamental indicators (biomass and area). This maintains the original design philosophy but provides a 50% reduction in weighting that species composition could effectively contribute.

The change in weighting approach for species composition was tested across all previous years and meadows in Hay Point as well the other seagrass monitoring locations where we use this scoring methodology (Cairns, Townsville, Abbot Point, Mackay, Weipa, Mourilyan Harbour, Torres Strait, Gladstone and Karumba). A range of different weightings were examined, but the 50% weighting consistently provided the best outcomes. The change resulted in sensible outcomes for meadows where species composition was poor and resulted in overall meadow condition scores that remained credible with minimal impact to the majority of meadow scores across multiple locations, where generally meadow condition has been appropriately described. Changes only impacted the relatively uncommon circumstance where species composition was the lowest of the 3 indicators. The reduction in weighting should not allow a meadow with very poor species composition to achieve a rating of good, due to the reasons outlined above, and the 50% weighting provided enough power to species composition to ensure this was the achieved compared with other weightings that were tested.

Hay Point regional grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the region (e.g. Keswick and St Bees Islands), 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 2019 (current) biomass value (i.e. satisfactory).

2. Calculate the difference in areas (A_{diff}) between the 2019 area value (A_{2015}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$A_{diff} = A_{2019} - A_{satisfactory}$$

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:

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

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:

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

5. Determine the biomass score for 2019 ($Score_{2019}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$Score_{2019} = LA_{satisfactory} + (B_{prop} \times SR_{satisfactory})$$

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

Appendix 2. Seagrass community types and species composition

Table A4. Seagrass community types, mean above-ground biomass and meadow area in the Hay Point (Meadow 8) and Mackay (Meadow 5) offshore area 2004, 2005, 2010, 2011, 2014, 2016, 2017, 2018 and 2019. **(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	6837.6 ± 2415.3
		Total		**6837.6 ± 2415.3**
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 ± 346.6
		Total		**1528.6 ± 346.6**
November 2011				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. decipiens*	0.008	105.1 ± 39.8
		Total		**105.1 ± 39.8**
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	5204.7 ± 1448.1
		Total		**5204.7 ± 1448.1**
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 ± 387.0
		Total		**2311.0 ± 387.0**
October 2017				
5	Offshore	Light *H. decipiens* with *H. spinulosa*	0.011 ± 0.003	652.8 ± 151.9
8	Offshore	Light *H. decipiens*	0.046 ± 0.032	1234.1 ± 309.9
		Total		**1886.9 ± 461.8**
October 2018				
5	Offshore	Light *H. decipiens* with *H. spinulosa*	0.062 ± 0.015	381.6 ± 141.2
8	Offshore	Light *H. decipiens*	0.013 ± 0.004	1642.7 ± 406.2
		Total		**2024.3 ± 547.4**
October 2019				
5	Offshore	Light *H. spinulosa* with *H. decipiens*	0.135 ± 0.073	1737.3 ± 277.4
8	Offshore	Light *H. decipiens* with *H. spinulosa*	0.096 ± 0.023	4160.8 ± 777.8
		Total		**5898.1 ± 1055.2**

Table A5. Seagrass community type, mean above-ground biomass and meadow area in the Dudgeon Point - Hay Point annual survey areas, 2010 – 2019.

Hay Point – Dudgeon Point inshore survey area				
Meadow ID	**Meadow location**	**Seagrass meadow community type**	**Meadow biomass (mean g dw m^{-2} ± SE)**	**Area ± R (ha)**
October 2010				
1, 2 & 3	Inshore	Light *Halodule uninervis* (wide) with *H. ovalis*	na	12.2 ± 4.9
20	Inshore	Light *Halodule uninervis* (narrow)	na	36.5 ± 12.2
			Total	**48.7 ± 17.1**
November 2011				
1, 2 & 3	Inshore	Light *Halodule uninervis* (wide)	na	4.3 ± 1.9
20	Inshore	Light *Halodule uninervis* (narrow)	na	6.3 ± 1.9
			Total	**10.6 ± 3.8**
October/November 2014				
1, 2 & 3	Inshore	Light *Halodule uninervis* (wide) with *Z. muelleri* and *H. ovalis*	1.96 ± 1.14	9.0 ± 1.8
20	Inshore	Not present	np	np
			Total	**9.0 ± 1.8**
October 2015				
1, 2 & 3	Inshore	Light *Halodule uninervis* (wide) with *H. decipiens*	1.72 ± 0.23	13.7 ± 1.3
20	Inshore	Not present	np	np
			Total	**13.7 ± 1.3**
October/November 2016				
1, 2 & 3	Inshore	Moderate *Halodule uninervis* (wide)	5.60 ± 0.76	9.6 ± 2.0
20	Inshore	Not present	np	np
			Total	**9.6 ± 2.0**
October 2017				
1, 2 & 3	Inshore	Light *Halodule uninervis* (wide)	2.42 ± 1.20	9.3 ± 2.3
20	Inshore	Not present	np	np
			Total	**9.3 ± 2.3**
October 2018				
1, 2 & 3	Inshore	Light *Halodule uninervis* (wide) *with H. ovalis*	1.09 ± 0.35	22.6 ± 4.2
20	Inshore	Not present	np	np
			Total	**22.6 ± 4.2**
October 2019				
1, 2 & 3	Inshore	Light *Halodule uninervis* (wide) with *Z. muelleri /H. decipiens*	3.41 ± 0.61	17.0 ± 3.8
20	Inshore	Light *Halodule uninervis*	1.38 ± 1.38	1.7 ± 1.1
			Total	**18.7 ± 4.9**

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

Table A6. Seagrass community type, mean above-ground biomass and meadow area in the Keswick Island and St Bees Island annual survey areas, 2014 – 2019.

Keswick/St Bees Islands inshore survey areas				
Meadow ID	**Meadow location**	**Seagrass meadow community type**	**Meadow biomass (mean g dw m^{-2} ± SE)**	**Area ± R (ha)**
October/November 2014				
10	Inshore	Light *Halophila tricostata* with *H. decipiens*	2.34 ± 0.38	118.6 ± 29.5
14	Inshore	Moderate *H. decipiens* with mixed species	2.6 ± 0.71	17.9 ± 5.0
			Total	**136.5 ± 34.5**
October 2015				
10	Inshore	Light *Halophila tricostata*	1.23 ± 0.19	137.2 ± 30.5
14	Inshore	Light *H. spinulosa* with mixed species	1.13 ± 0.35	14.7 ± 4.3
			Total	**151.9 ± 34.8**
October/November 2016				
10	Inshore	Light *Halophila tricostata*	1.69 ± 0.33	147.6 ± 25.9
14	Inshore	Light *H. spinulosa* with mixed species	2.94 ± 0.54	11.5 ± 4.3
			Total	**159.1 ± 30.2**
October 2017				
10	Inshore	Light *Halophila tricostata*	1.09 ± 0.23	169.6 ± 32.5
14	Inshore	Light *Halophila tricostata*	0.54 ± 0.23	10.8 ± 4.1
			Total	**180.4 ± 36.6**
October 2018				
10	Inshore	Light *Halophila tricostata with H. decipiens*	2.40 ± 0.38	203.6 ± 38.7
14	Inshore	Light *Halophila tricostata*	1.97 ± 0.74	18.1 ± 4.8
			Total	**221.7 ± 43.5**
October 2019				
10	Inshore	Light *Halophila tricostata with H. decipiens*	1.38 ± 0.15	197.3 ± 42.9
14	Inshore	Light *Halophila tricostata with H. spiniulosa / H. decipiens*	1.63 ± 0.35	14.2 ± 4.2
			Total	**211.5 ± 47.1**

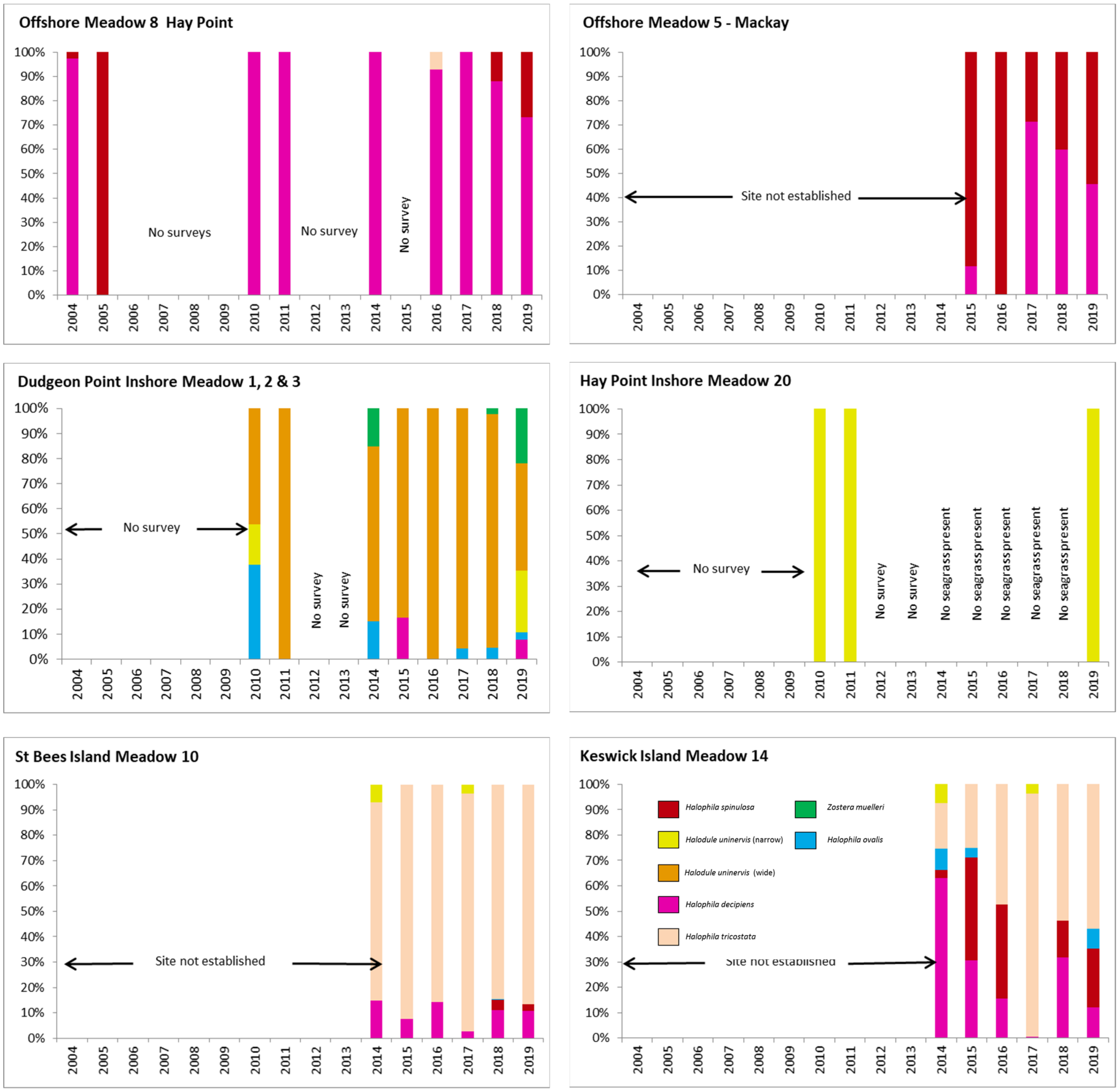

Figure A2: Species composition of monitoring meadows in the Hay Point-Mackay region, and the Keswick Island group.