ANNUAL SEAGRASS MONITORING IN THE MACKAY-HAY POINT REGION – 2018

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Report No. 19/18

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KEY FINDINGS

Deepwater
Hay Point-Mackay

POOR
(Interim)

Coastal
Dudgeon Point

SATISFACTORY
(Interim)

Offshore Island
Keswick and St Bees

GOOD
(Interim)

- In 2018 seagrass condition varied among regions and remained fairly similar to 2017.
- The condition of offshore seagrasses at Hay Point remained poor driven by low biomass with no substantial change in any of the meadow attributes from 2017.
- Coastal meadows in the Dudgeon Point monitoring area were in a satisfactory condition with below average biomass, however, a greater than average meadow area and very good species composition.
- Meadows at Offshore Islands (Keswick and St Bees) were in good condition with increases in biomass and area of both meadows over the previous 12 months.
- 2018 is the first year that a full condition score has been applied to the Dudgeon Point, Keswick Island and St Bees Island monitoring meadows incorporating area into the indices as well as biomass and species composition following 5 years of baseline data. These are interim until a full 10 year baseline data set is available.
- The score for Hay Point offshore seagrasses is also interim as it is only the 7th year of data available incorporating assessments of area together with biomass and species composition.

Likely causes of seagrass condition:

Favourable climate and light conditions for seagrass growth, particularly offshore with no significant weather events (e.g. Cyclones or floods) during 2018.

Good conditions offshore allowed for increases in seagrass area and biomass at Keswick and St Bees Islands.

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.

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 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 2018 survey of seagrass monitoring meadows in the Hay Point, Mackay and Keswick Island regions found seagrass present in much the same areas with roughly the same biomass and species present as seen in historical surveys since 2004 and more regularly since 2014. The meadow assessments in 2018 showed varying levels of seagrass condition across the region with deep-water meadows in poor condition, coastal seagrass in satisfactory condition, and meadows around offshore islands in generally good condition. These results reflect the very different environmental conditions of where the seagrass occur and the weather and climatic conditions that influence them.

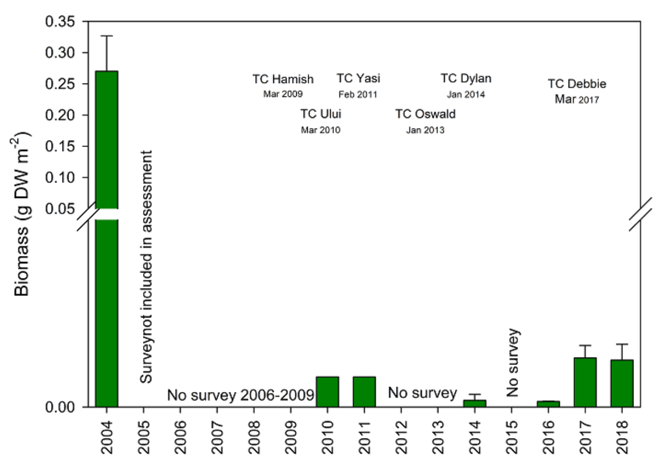

Figure 1. Mean seagrass biomass of Hay Point offshore monitoring site

Deep-water seagrasses in the monitoring area offshore from Hay Point consists of colonising *Halophila* species and remained in a poor condition in 2018, with biomass well below the long-term average which was driven by a year of high abundance in 2004 (Figure 1 & 3). 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 an extended major capital dredging campaign in 2006 and a series of six tropical cyclones.

Light levels (PAR) in deep-water seagrass meadows such as the Hay Point spoil ground and near Victor Island show long periods with very low light between February and April. This is the period when the dep-water seagrasses are in their dormant stage. The light levels present throughout the rest of the year are also close to the range of tolerance for these species and may explain the low biomass often found in these deep-water habitats.

The seagrass communities around Keswick and St Bees Island meadows also consist of *Halophila* species, however, these meadows are dominated by structurally larger species (*H. tricostata* and *H. spinulosa*). These meadows were scored as being in good and very good condition respectively in 2018 and both increased their biomass and area compared to the survey conducted in 2017. These meadows are considerably further offshore than the Hay Point meadows and are less susceptible to turbid water conditions from coastal flooding and have larger sediment particles that require greater wind speeds and wave heights to resuspend sediments. These conditions generally provide a more favourable environment for seagrass growth. Light data collected at Keswick Island shows a more consistent pattern throughout the year and higher levels than those found in deep-water environments off Hay Point.

The inshore monitoring area around Dudgeon Point consisted of seagrass meadows dominated by *Halodule uninervis* with *Zostera muelleri* and *Halophila ovalis* also present. These meadows covered a greater area in 2018 than previously mapped, however, biomass levels were lower than average and scored satisfactory as an indicator condition. This lower than average biomass drove the overall satisfactory meadow score. 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 much greater periods in poor light conditions.

Generally, climate conditions for seagrass growth were favourable for much of the year prior to the seagrass survey in October 2018. Throughout this period the region experienced below average rainfall and river flows, and temperature and solar exposure were around or slightly above the long term average for the region (Figure 2). Strong and steady onshore winds for the period from February through to April has likely increased wave heights and resuspended sediment in the coastal nearshore environments leading to low light environments (PAR) throughout this time of year.

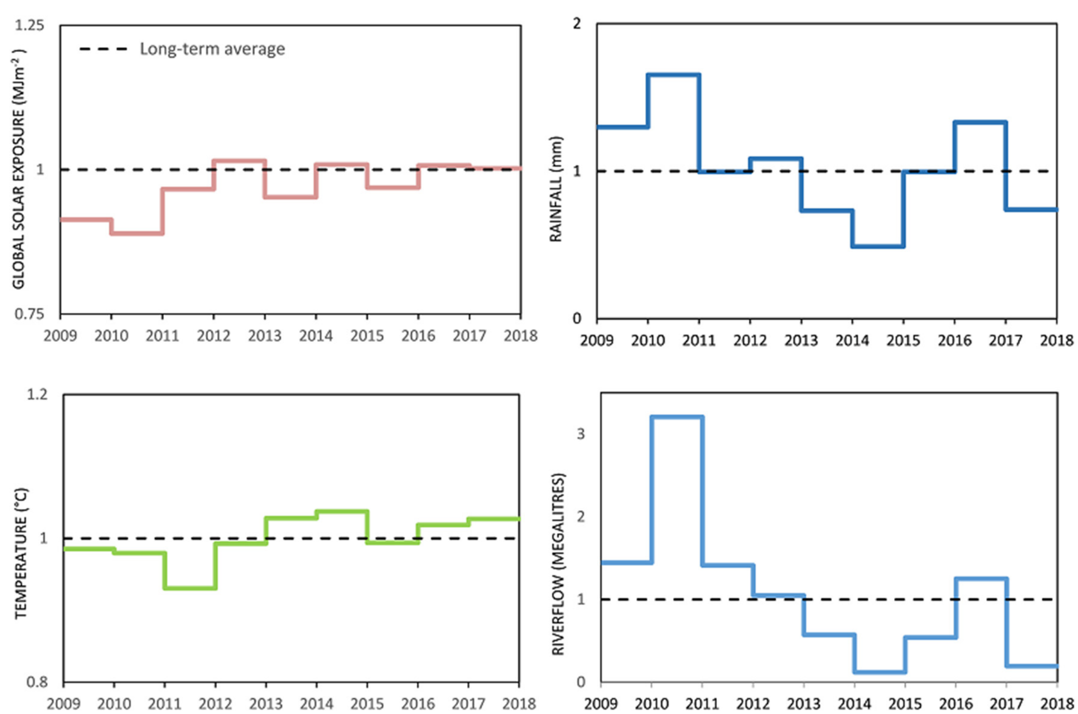

Figure 2. Recent climate trends in the Hay Point Area: change in climate variables as a proportion of the long-term average. (See section 3.5 for detailed climate data).

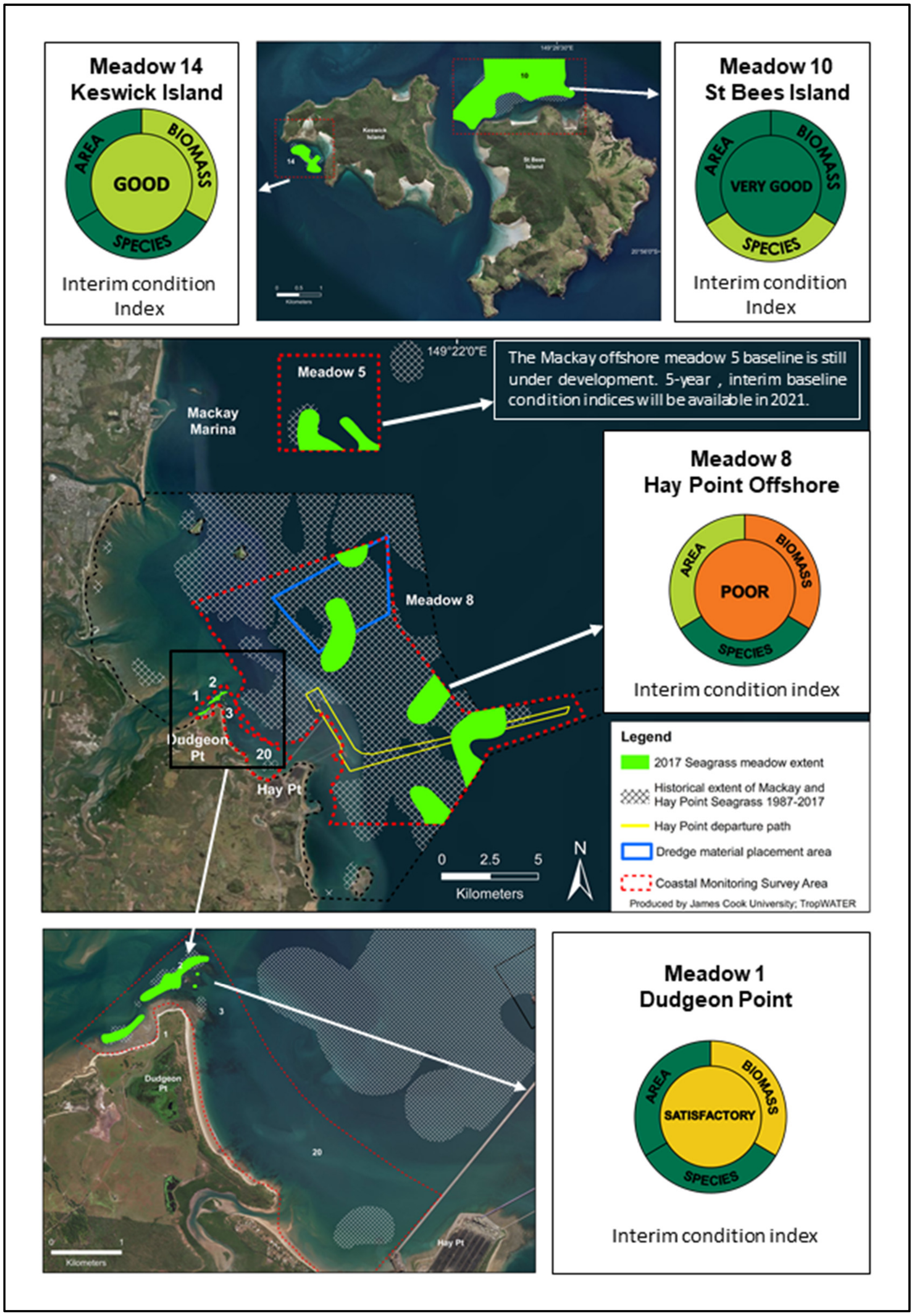

Figure 3. Seagrass meadow condition for the ports of Mackay, Hay Point, Keswick and St Bees Island 2018

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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). 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). 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 (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).

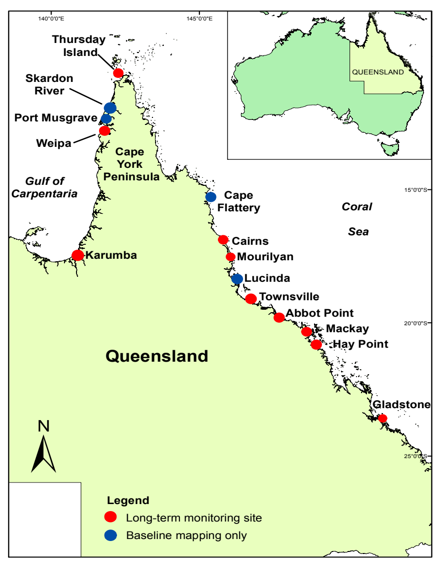


Figure 4. Location of Queensland Port Seagrass assessment sites

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). The program has also shown that 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 appear intermittently through time and also experienced shifts 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 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). 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 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 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 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 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. In 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 for the first time. This is possible now due to the availability of 5-years of survey data at these sites allowing for the establishment of interim baselines. This baseline 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 three 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 2018 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 identified monitoring areas in the Hay Point-Mackay region;
- 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 that incorporates the 2004 survey limits for offshore meadows and, for the first time, the coastal monitoring meadows around Dudgeon Point, Keswick Island and St Bees Island;
- 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.

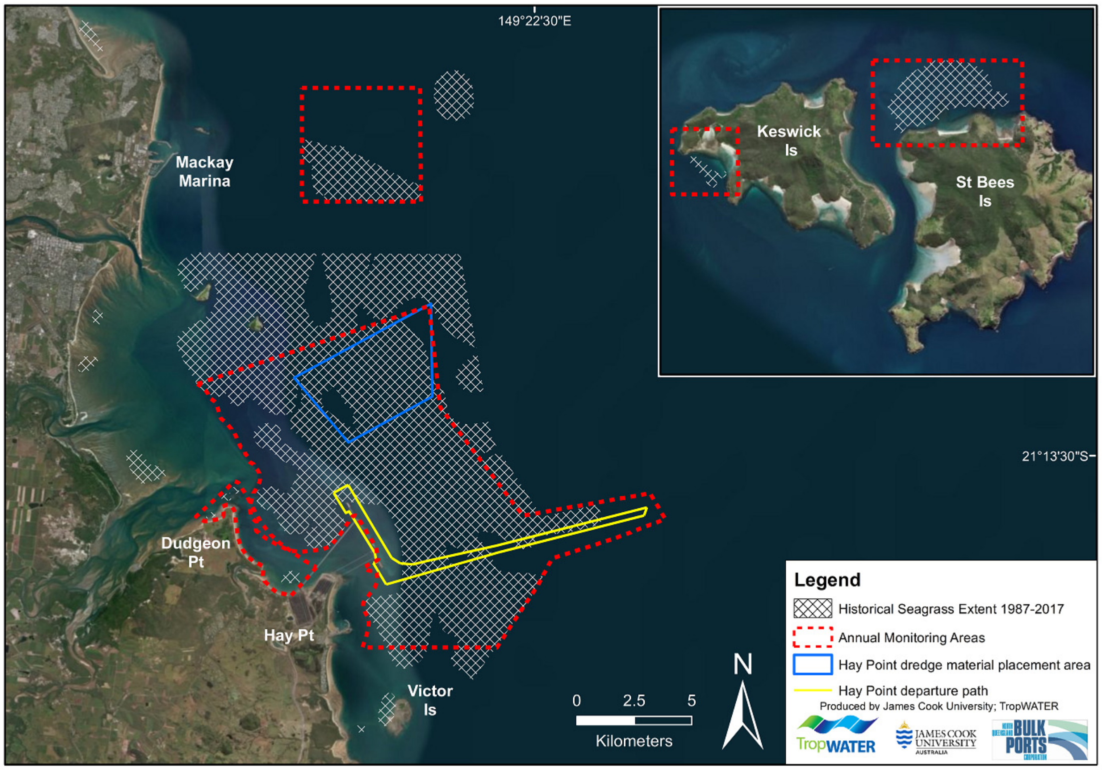


Figure 5. Location of survey limits and annual seagrass monitoring areas around Mackay, Hay Point and the Keswick Island group.

2 METHODS

2.1 Annual monitoring within the Intensive Monitoring Area

Annual surveys of seagrass communities in intensive monitoring areas within the Hay Point-Mackay region (including Keswick and St Bees Islands) were conducted in October 2018 (Figure 5). Broad-scale mapping and monitoring of meadows across the greater region was last undertaken in 2017 and is scheduled to occur again in 2020. Monitoring meadows were selected for detailed assessment because they were representative of the range of seagrass meadow communities identified in initial baseline surveys and because they were located in areas likely to be vulnerable to impacts from port operations and developments or act as reference sites. This 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 Seagrass monitoring, Habitat mapping and Geographic Information System

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. Intertidal areas : Walking at low tide;
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 measured using a "visual estimates of biomass" technique (Kirkman 1978; Mellors 1991). At camera drop 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 – B) Shallow subtidal mapping of seagrass meadows using digital camera mounted on a $0.25m^2$ drop frame and (C - D) offshore underwater sled tows with digital camera.

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.4®. 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); site benthic cover (percent cover of algae, seagrass, benthic macro-invertebrates, open substrate); 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 14).
    - 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.

Meadows were described using a standard nomenclature system developed for Queensland's seagrass meadows. Seagrass community type was determined using the dominant and other species' percent contribution to mean meadow biomass (for all sites within a meadow) (Table 1). Community density was based on mean biomass of the dominant species within the meadow (Table 2).

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 determined 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 ≤5 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
5-10 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 driven by 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.

Following the 2018 survey, the condition index is now applied to the offshore monitoring sites at Hay Point, and for the first time, coastal monitoring meadows at Dudgeon Point, Keswick Island and St Bees Island. The Hay Point offshore meadow condition is currently based on a 7-year baseline of data (2004, 2010, 2011, 2014, 2016, 2017 & 2018) 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, interim scores for the Dudgeon Point, Keswick Island and St Bees Island monitoring meadows are based on a 5-year baseline of data (2014-2018) which 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 baseline reports. The Mackay offshore monitoring meadow is newly established (2017) and there is insufficient data available to calculate an interim baseline and meadow condition scores until 2021.

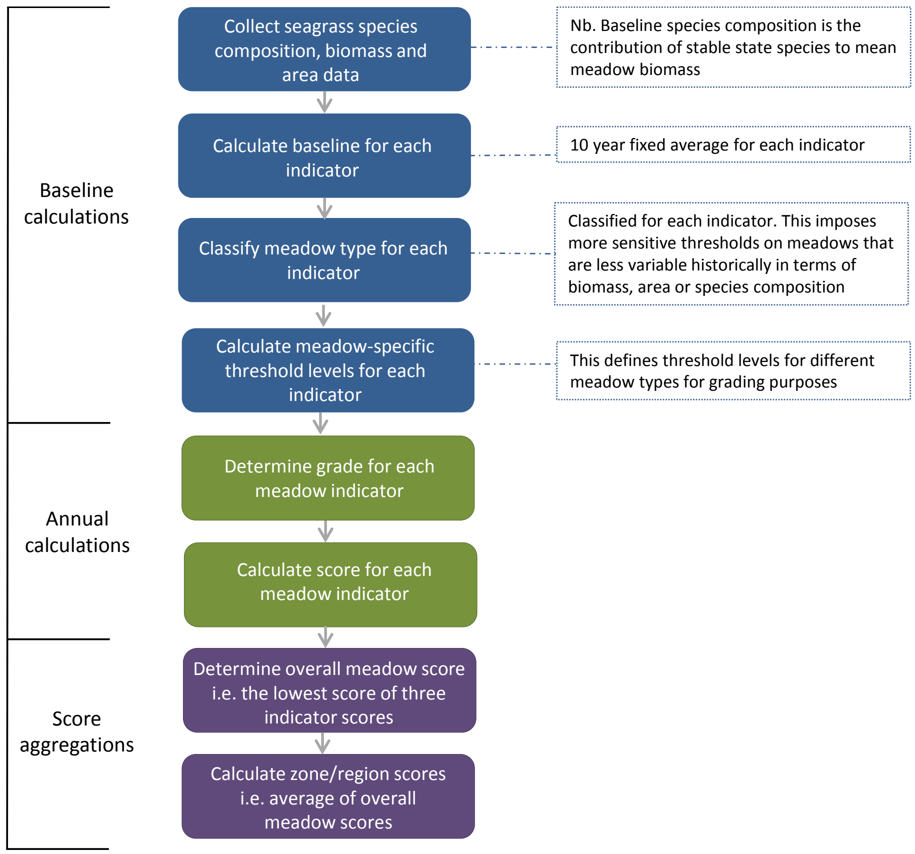


Figure 8. Flow chart to assess seagrass monitoring meadow condition.

2.4 Environmental data

Environmental data was collated for the 12 months preceding each 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 Environment and Science, Queensland Government coastal data system – (Hay Point).

Irradiance measured as photosynthetically active radiation (PAR - mol photons m^{-2} day^{-1}) was collected at five locations (Victor Island, Hay Reef, Round Top Island, Hay Point Spoil Ground and Keswick Island) within or nearby to 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. 2018).

3 RESULTS

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

A total of 215 sites were surveyed as part of the annual monitoring survey in the Hay Point, Mackay and Keswick Island area in October 2018 (Figure 10). Seagrass was present at 39.0 % of the coastal sites (21.0 % at Dudgeon Point and 54.5 % Keswick and St Bees Islands) and at 16.2 % of the offshore sites (Hay Point & Mackay; Figure 10). Deep-water seagrass communities offshore from Hay Point and Mackay covered an area of 2024.4 ha while coastal meadows covered 22.6 ha at Dudgeon Point and adjacent to Keswick and St Bees Islands seagrass covered 221.7 ha (Tables 5-7).

The seagrass species found in the monitoring meadows were typical of those found for coastal and offshore seagrasses both in Hay Point and more broadly in central Queensland (Figure 11, Appendix 2). Six seagrass species were observed in 2018 (Figure 9). Deepwater assemblages were dominated by *Halophila decipiens* with *H. spinulosa* also occurring in two sites in the Mackay Offshore monitoring area and one site in the Hay Point monitoring area (Figure 11, Appendix 2). *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* surveyed for the first time since 2014 and *H. ovalis* again occurring in these meadows.

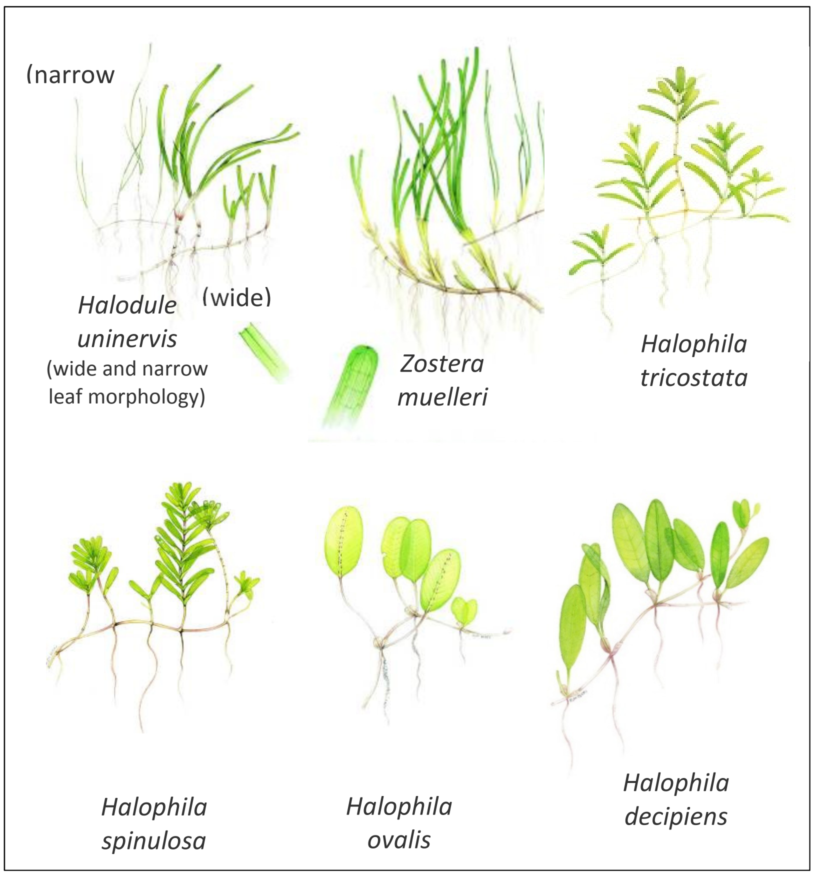


Figure 9. Seagrass species identified in the Hay Point-Mackay annual monitoring program in 2018. Leaf size varies widely within species and diagrams are not to scale.

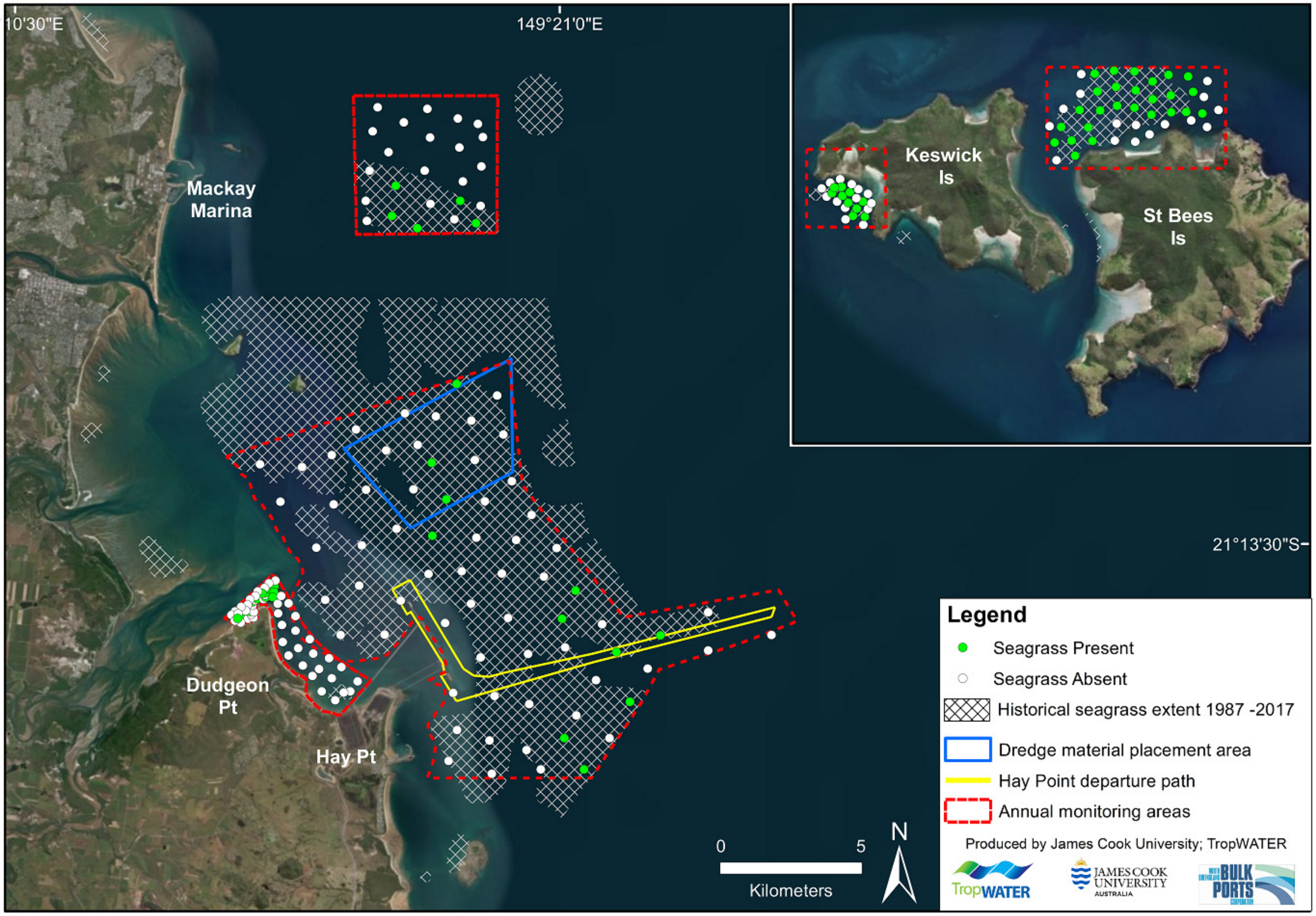


Figure 10. Location of 2018 annual seagrass monitoring survey sites in the Hay Point-Mackay region.

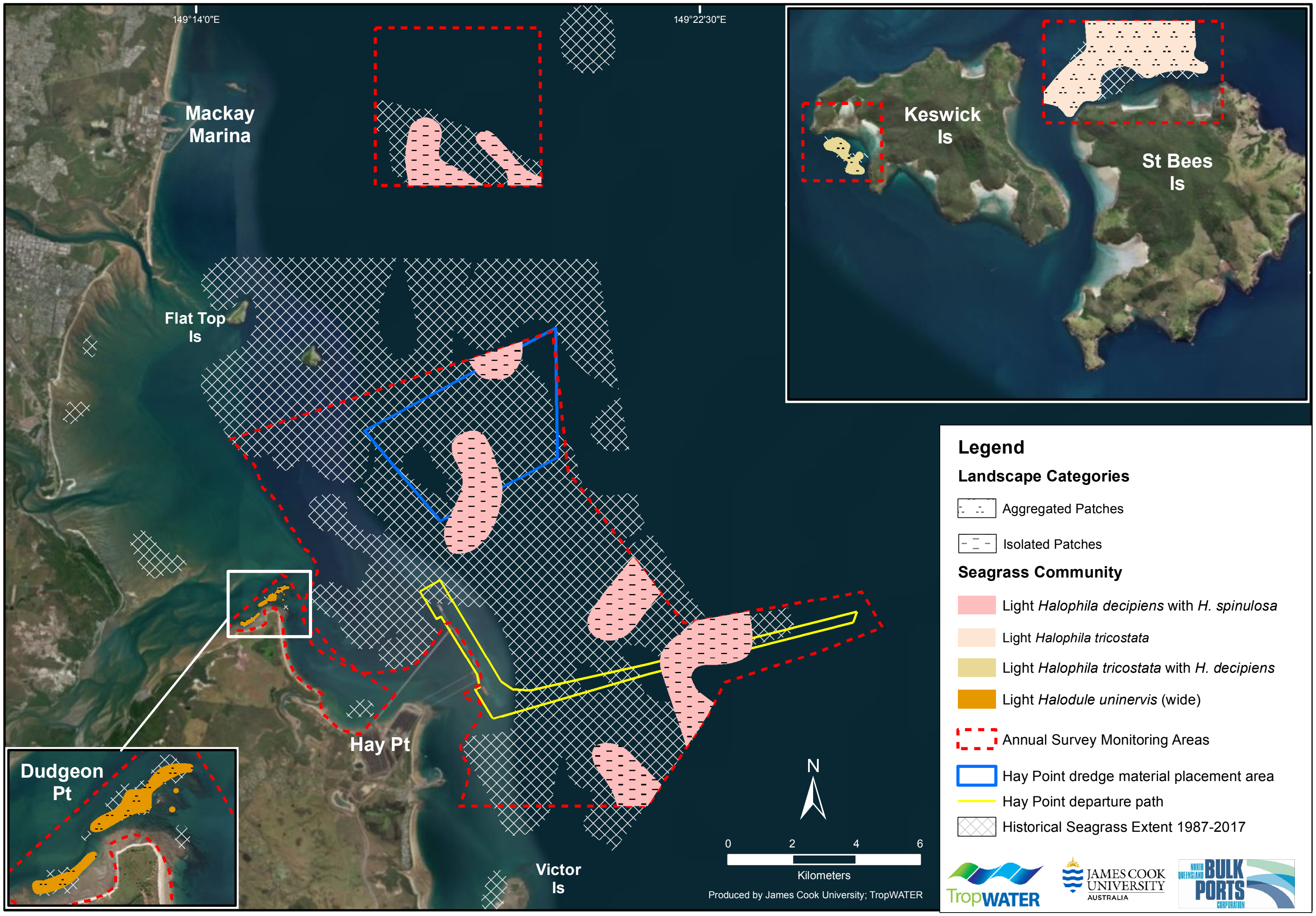


Figure 11. Location of 2018 seagrass meadows in the Hay Point region showing seagrass communities and landscape categories.

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

Offshore seagrass at Hay Point and Mackay

The overall condition of offshore seagrasses in the Hay Point monitoring area remained poor in 2018 primarily because of the low biomass of seagrass throughout the area (Table 4; Figure 12). Biomass (0.013 ± 0.004 g) remained at similar level to 2017 and well below the highest level of the baseline in 2004 resulting in a poor score for this attribute (Figure 12). The area of the meadow increased in 2018 from 1234.1 ± 309.9 Ha to 1642.7 ± 406.2 with this indicator achieving a condition score of good (Table 4, Figure 12). As the meadow classification for species is based on the pioneering *H. decipiens,* which was again the major seagrass found in 2018, the offshore seagrass area was graded very good for species composition. A small amount of *H. spinulosa* was also found at one site. Seagrass was recorded to a depth of 18.8 metres in the Hay Point survey area and 20.3 metres in the Mackay monitoring area.

As this is only the second 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 score the meadow against baseline information. The area covered by seagrass declined from the previous survey from 652.8 ± 151.9 Ha to 381.6 ± 141.1 Ha and the biomass increased from 0.011 ± 0.003 g DW m^2 in 2017 to 0.0625 ± 0.0153 g DW m^2 in 2018. The monitoring area was again dominated by *H. decipiens*, with *H. spinulosa* also present (Appendix 2).

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

The 2018 survey was the first time that interim condition scores were able to be applied to coastal monitoring meadows from Dudgeon Point to Hay Point and adjacent to offshore Islands (Keswick and St Bees). To determine a condition score in the Dudgeon Point to Hay Point monitoring area a decision was taken to amalgamate the three meadows that occur around Dudgeon Point (previously described as meadows 1, 2 and 3 in baseline reports). Historical surveys show that these combined meadows are present fairly consistently over time, cover a relatively small and connected geographic area and are representative of the meadow type commonly occurring in coastal habitats in the region.

This new monitoring meadow occurred as four patches in 2018 and was dominated by *Halodule uninerv*is (wide) (Figure 13, Table A5). The area of the combined meadows (22.56 ± 4.18 Ha) was considerably larger in 2018 than previously found (Figure 13, Table A5). This resulted in the meadow area being scored as very good (Table 4). The inshore limits of this meadow were mapped on foot at low tide for the first time and it was noted that this new technique may have increased the area of seagrass located on the survey. A decision has been made to continue to map this meadow by walking in future surveys if access is possible to limit potential sampling bias and gain a more accurate representation of the meadow. Biomass at this location has declined over the previous two years from a peak in 2016 of (5.60 ± 0.76 g DW m^2) to (1.09 ± 0.35 g DW m^2) in 2018. This lower amount, however, was still scored as satisfactory against the interim long-term baseline and also determined the overall score of the meadow as satisfactory (Table 4). Three species occurred in the monitoring meadow in 2018, dominated by *H. uninervis* (~93 % - both wide and narrow leaf forms) with small amounts of *H. ovalis* and *Zostera muelleri* (Figure A2) leading to a score of very good for species composition based on a target species of *H. uninervis* (Table 4). Meadow 20 inshore of Hay Point was absent for the sixth survey in succession and no seagrass has been observed in that area since 2010. For this reason we have omitted this meadow from monitoring scores.

The seagrass monitoring meadow adjacent to St Bees Islands was scored as very good condition in 2018 (Table 4). This meadow had both the highest biomass (2.40 ± 0.38 g DW m^2) and area (203.6 ± 38.7 Ha) in 2018 across the 5 years of monitoring (Figure 14). The distribution of this meadow has increased consistently for the last five years. Four species were found in the meadow in 2018 dominated by *Halophila tricostata* (84.7 %) with *H. decipiens* (11.1 %), *H. spinulosa* (4.0 %) and *H. ovalis* (0.2%) also occurring (Figure A2). The Keswick Island monitoring meadow was scored in a good condition with an increase in biomass from 0.54 ± 0.23 DW m^2 to 1.97 ± 0.73 DW m^2 and area from 10.8 ± 4.15 Ha to 18.1 ± 4.85 Ha over the previous twelve months (Table 4, Figure 15, Appendix 2). The increase in area resulted in an upgrade in meadow area score from satisfactory in 2017 to very good in 2018. In 2018 this meadow consisted mainly of *H. tricostata* (53.8 %) and *H. decipiens* (31.8 %) with H. spinulosa also present (Appendix 2).

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

Meadow	Location	Biomass	Area	Species Composition	Overall Meadow Score
1, 2 & 3 combined	Dudgeon Point	0.56	0.94	0.94	0.56
8	Hay Point - Offshore	0.47	0.65	1.00	0.47
10	St Bees Island	0.92	0.92	0.85	0.88
14	Keswick Island	0.77	0.89	0.89	0.77
Overall Score for the Hay Point-Mackay region					0.67

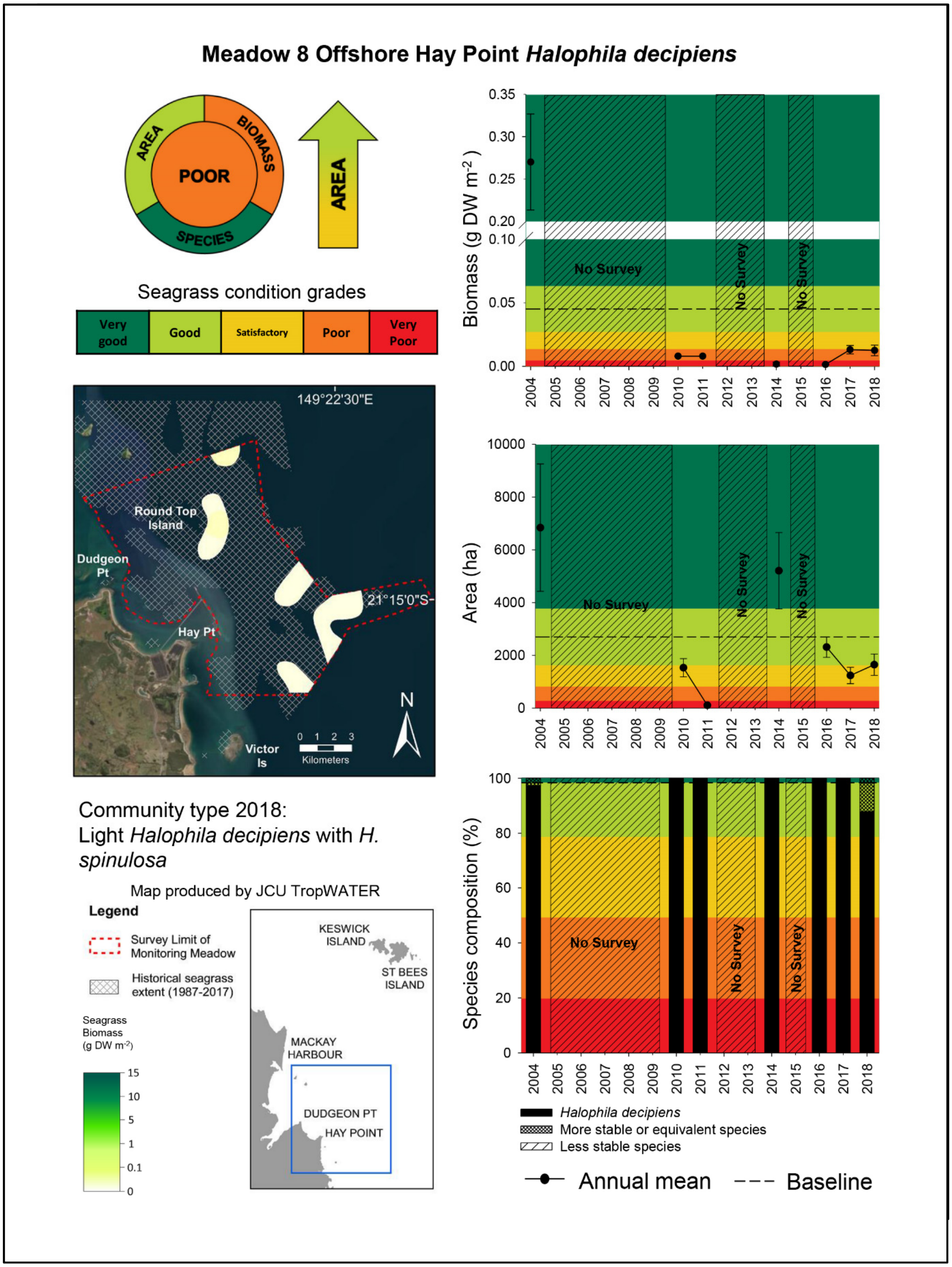


Figure 12. Changes in meadow biomass, area and species composition for seagrass in the Hay Point offshore area (Meadow 8), 2005 – 2018 (biomass error bars = SE).

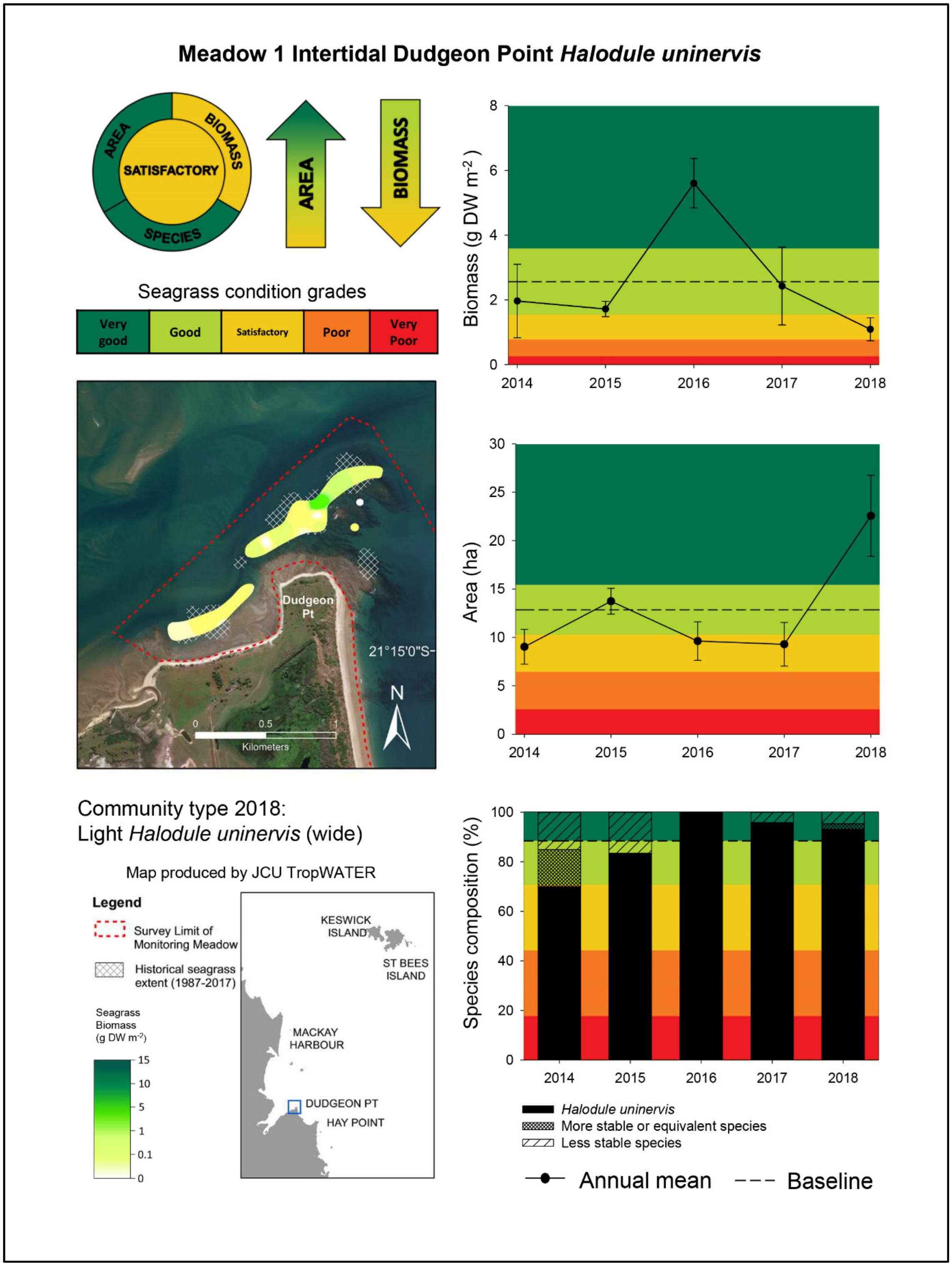


Figure 13 Changes in meadow biomass, area and species composition for seagrass in the Dudgeon Point coastal area (Meadow 1), 2014 – 2018 (biomass error bars = SE).

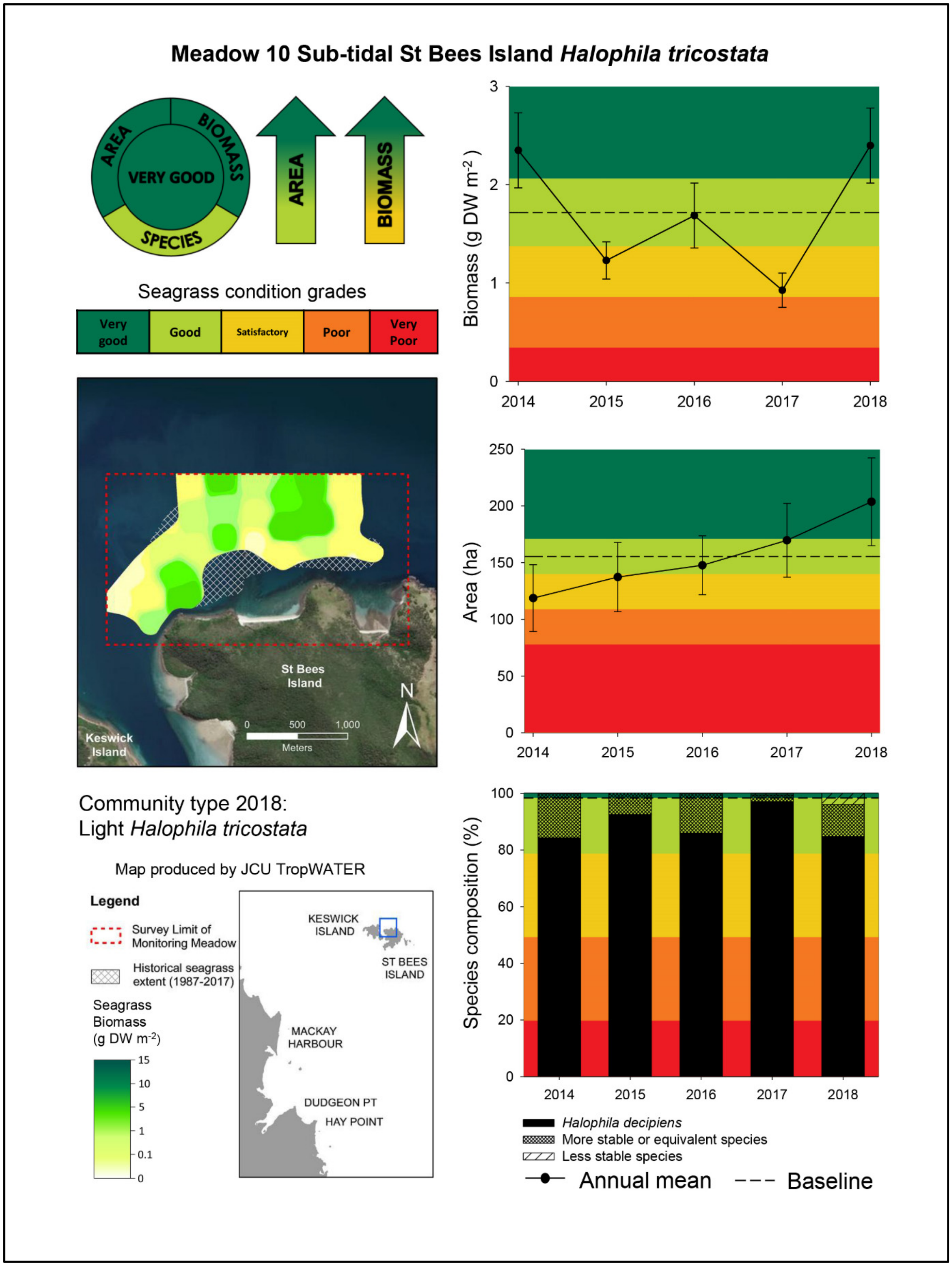


Figure 14 Changes in meadow biomass, area and species composition for seagrass in the St Bees Island coastal area (Meadow 10), 2014 – 2018 (biomass error bars = SE).

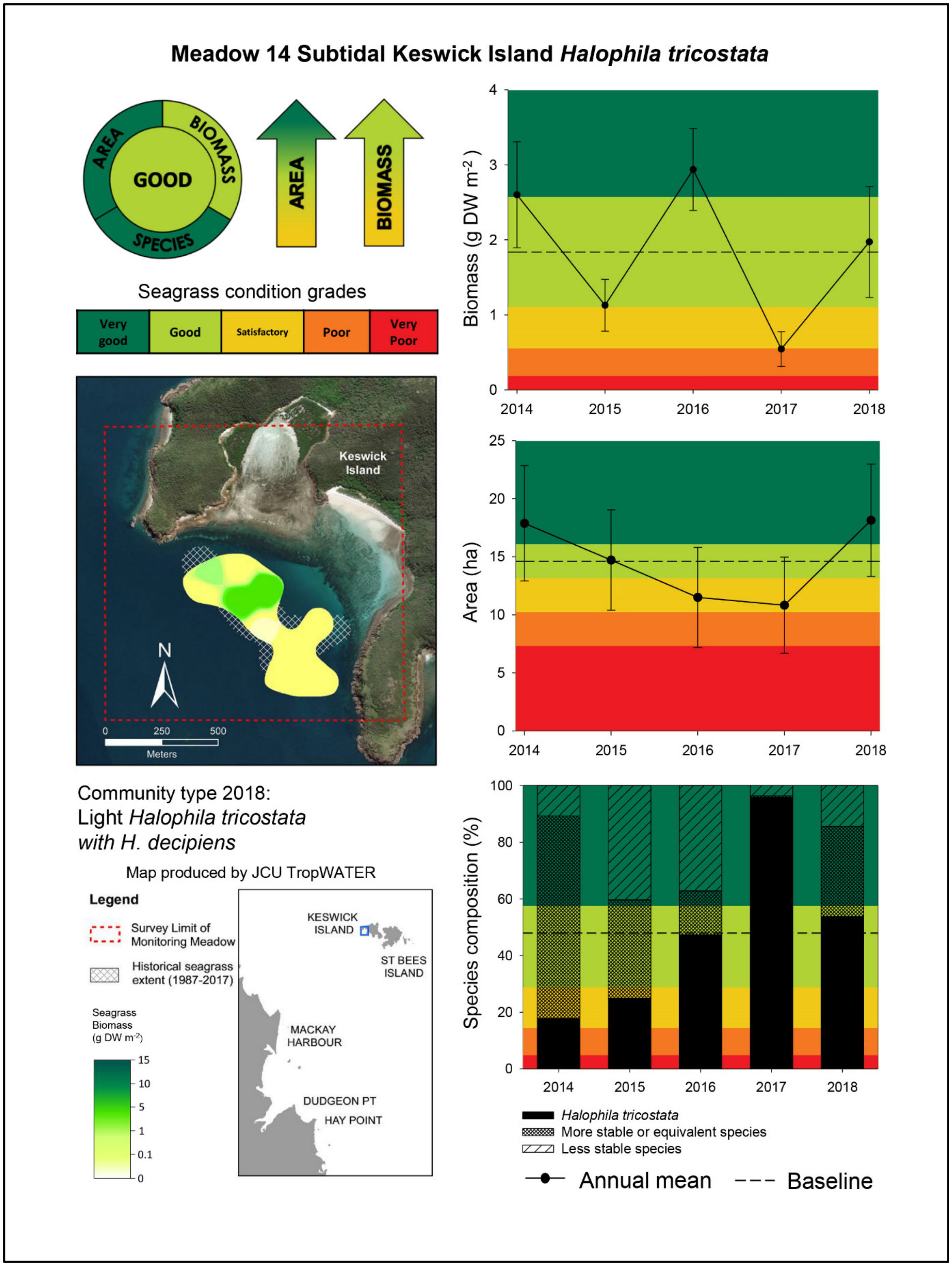


Figure 15 Changes in meadow biomass, area and species composition for seagrass in the Keswick Island coastal area (Meadow 14), 2014 – 2018 (biomass error bars = SE).

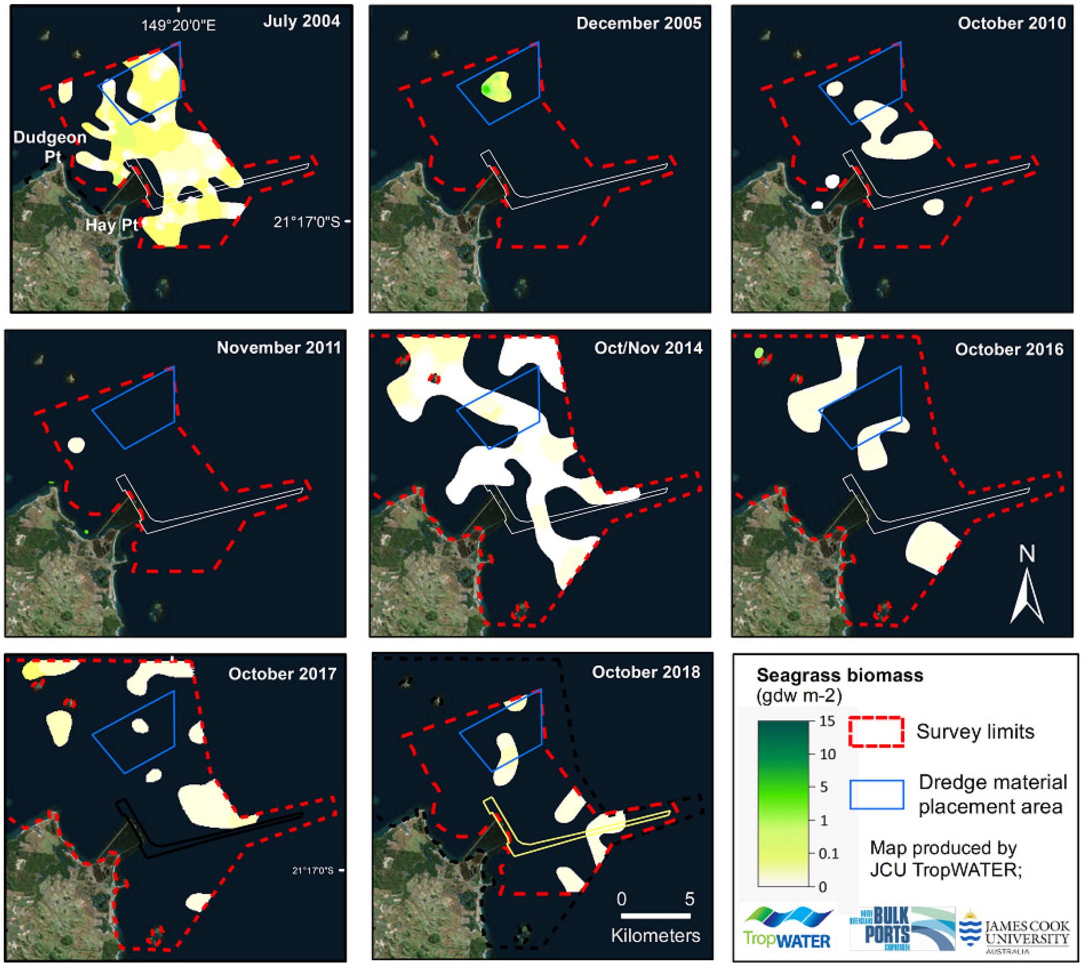


Figure 16. Seagrass biomass distribution in the Hay Point offshore monitoring area when surveys were conducted between 2004-2018.

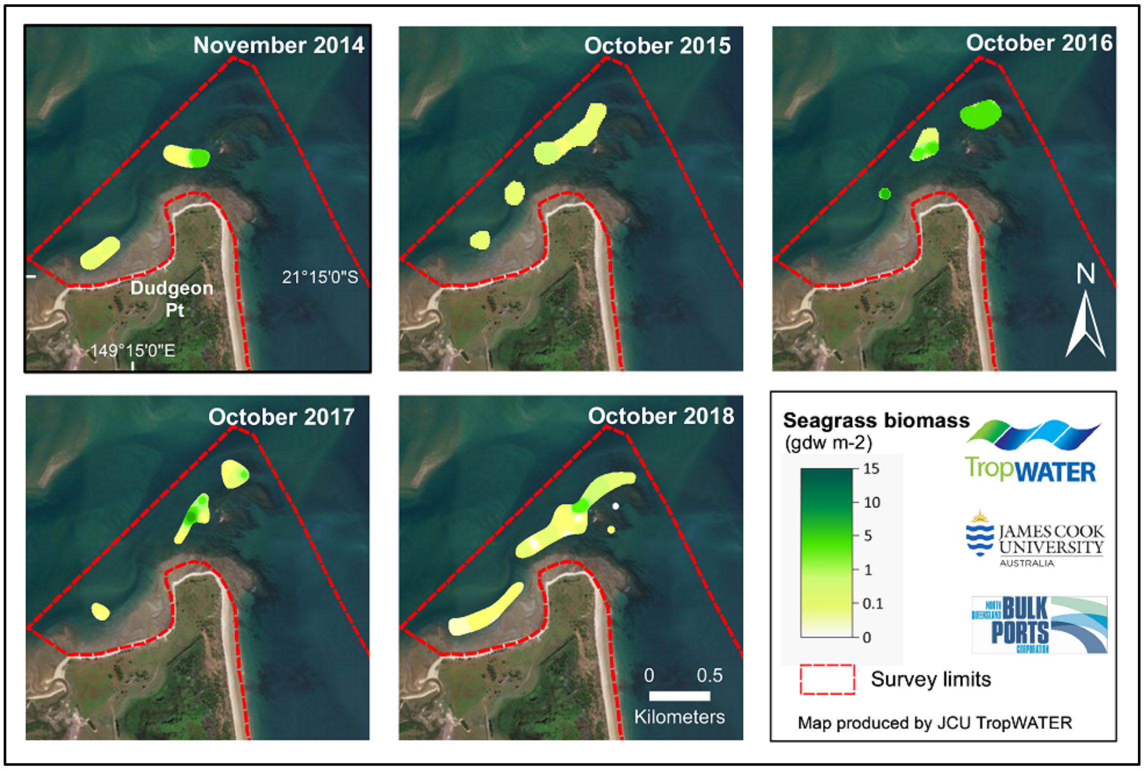


Figure 17. Seagrass biomass distribution in the Dudgeon Point to Hay Point annual monitoring area 2014 -2018.

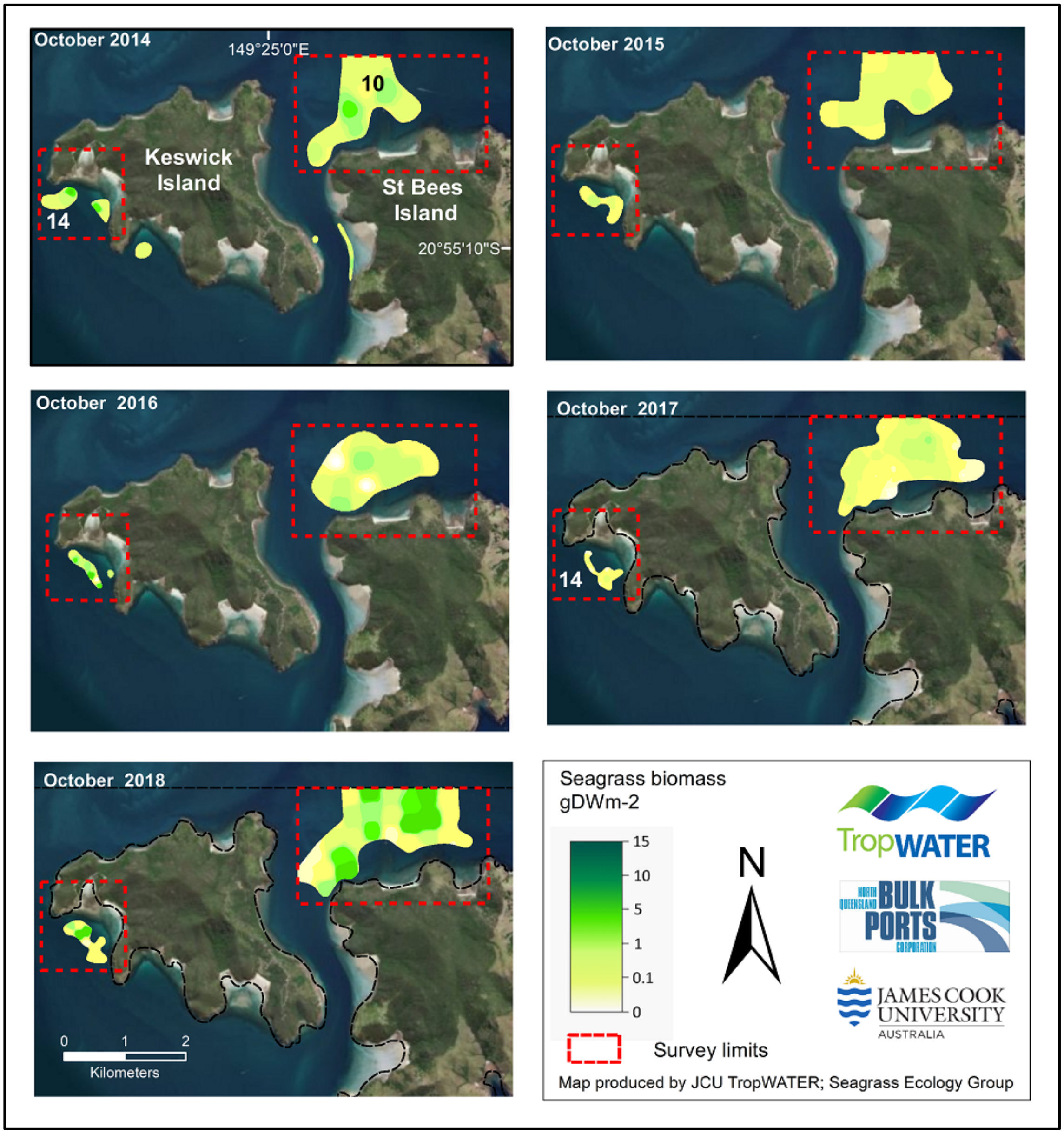


Figure 18. Seagrass biomass distribution in the annual monitoring meadows at Keswick and St Bees Islands 2014 – 2018.

3.3 Hay Point Environmental Parameters

Rainfall

Annual rainfall was approximately 400 mm below the long term average in 2017/18 (Figure 19a). This followed a year of above average precipitation mainly due to significant events in January and March of 2017. Throughout the year the monthly rainfall levels were either at or below long term averages apart from November 2017 when rainfall was almost double the long term average for the month (Figure 19b).

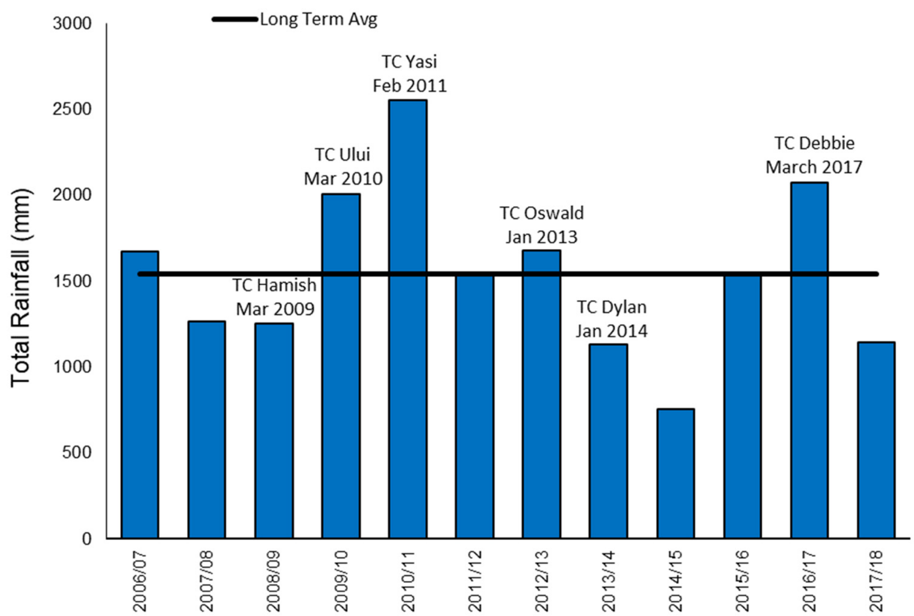


Figure 19a. Total annual rainfall (mm) recorded at Mackay Aero, 2006/07-2017/18. Twelve month year is twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033045.

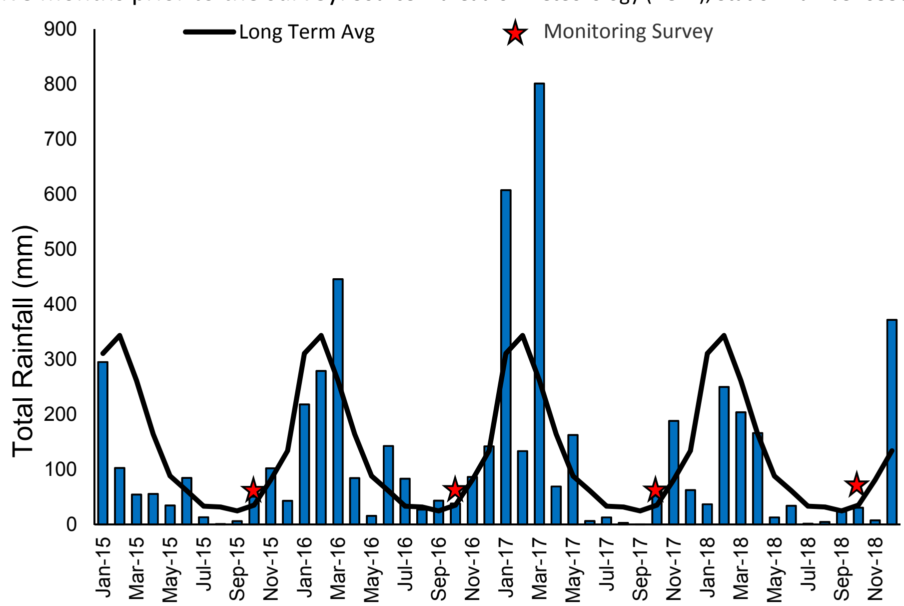


Figure 19b. Total monthly rainfall (mm) recorded at Mackay Aero, January 2015 - December 2018. Source: BOM, Station number 033045.

River flow

Annual river flow of the Pioneer River has was well below the long-term average in the year leading up to the survey (Figure 20a). Monthly levels were well below the long-term average throughout the year with the exception of April 2018 which experienced close to average river flow (Figure 20b).

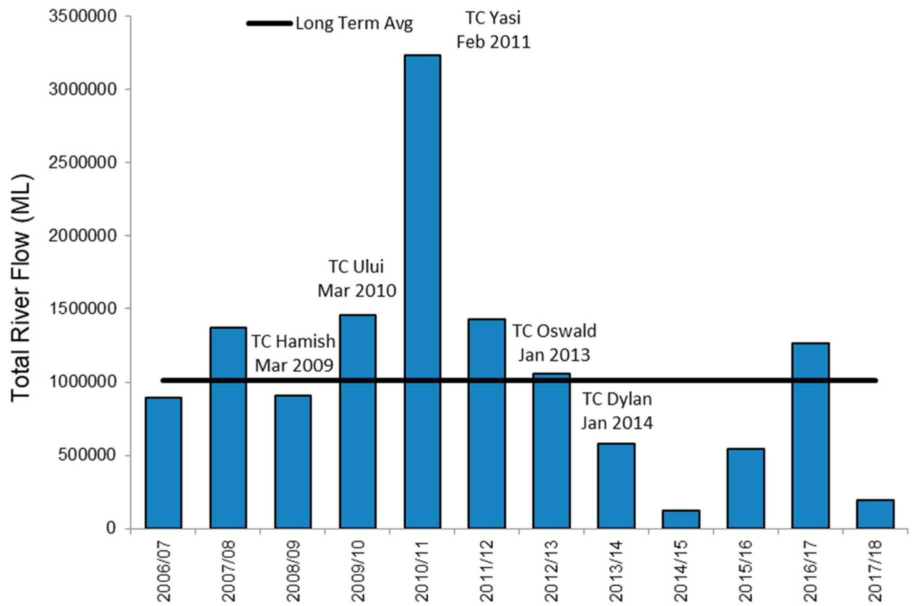


Figure 20a. Annual river flow (Mega litres) for the Pioneer River, 2006/07-2017/18. Twelve month year is twelve months prior to the survey. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

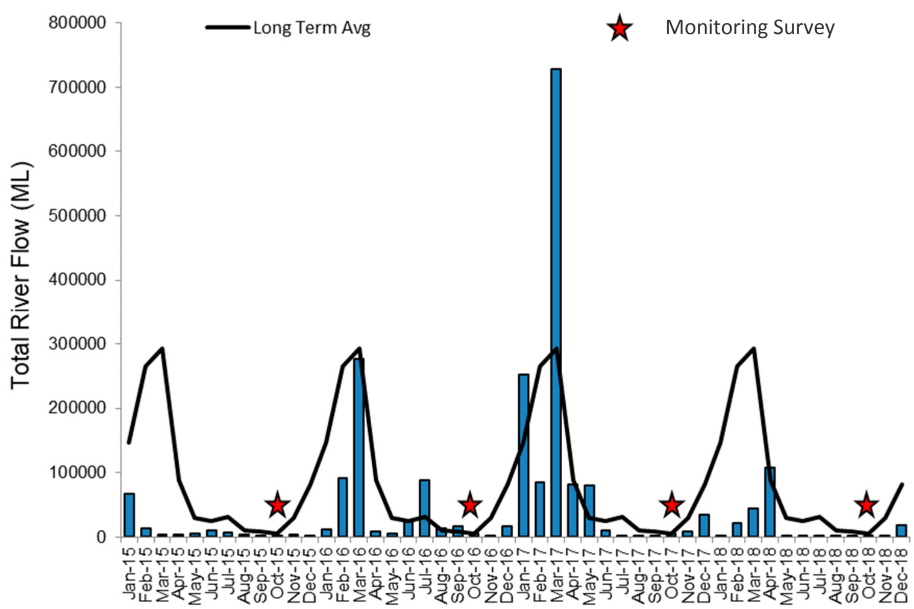


Figure 20b. Monthly river flow (Mega litres) for the Pioneer River January 2015-December 2018. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

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). The mean annual maximum daily sea surface temperature of 25.4 ° C was approximately 0.7° C above the long-term average (10 years) in 2017-18 (Figure 21a). Monthly data shows that sea surface temperature was above the long-term monthly average for almost the entire year with the exception of August and September 2018 (Figure 21b).

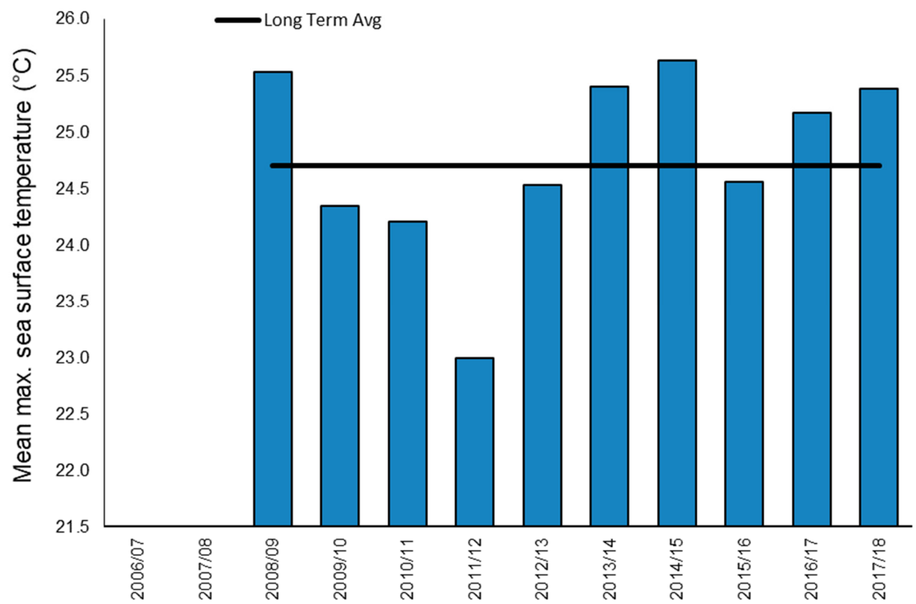


Figure 21a. Mean annual maximum sea surface temperature (°C) recorded at Hay Point 2008/09-2017/18. Twelve month year is twelve month prior to the survey. Source: QLD Department of Science, Information technology and Innovation

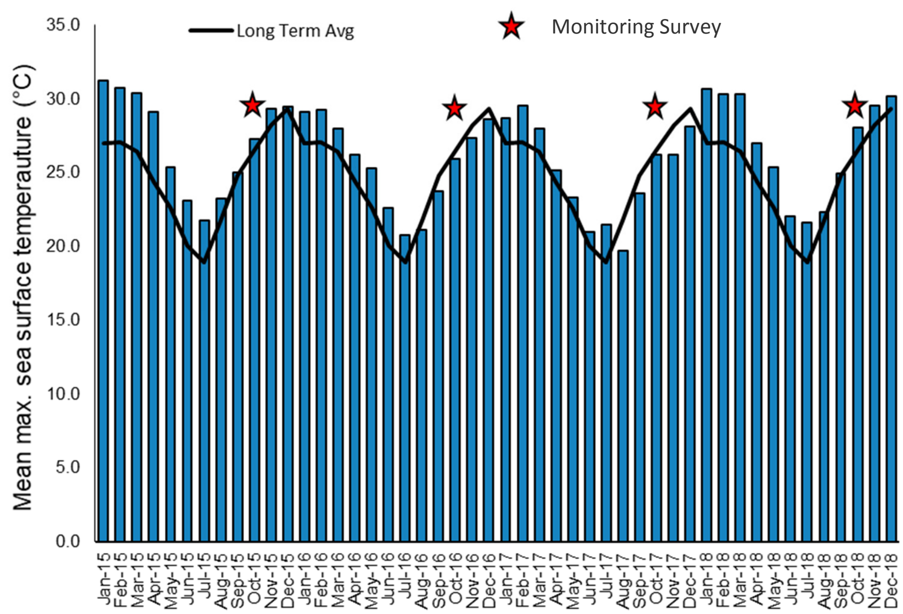


Figure 21b. Monthly maximum sea surface temperature (°C) recorded at Hay Point; January 2015 to December 2018. Source: QLD Department of Science, Information technology and Innovation

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 very close to the long-term average (20.70 MJ m^{-2}) for the region in the twelve months to the 2017/18 survey (Figure 22a). Monthly exposure was very close to the long-term average throughout the year prior to the survey (Figure 22b).

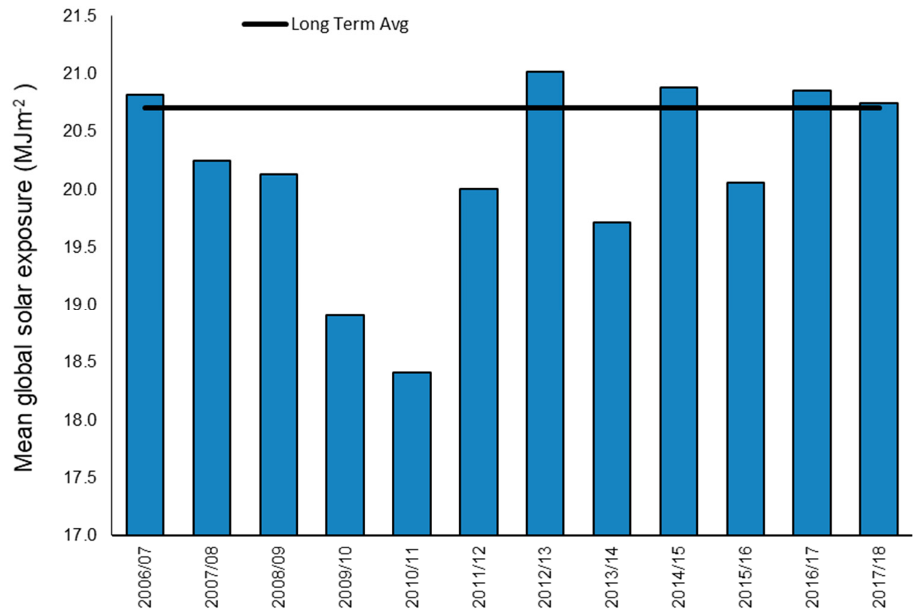


Figure 22a. Mean annual solar radiation (MJm^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) 2006/07 -2017/18. Twelve month year is twelve months prior to the survey. Source: BOM

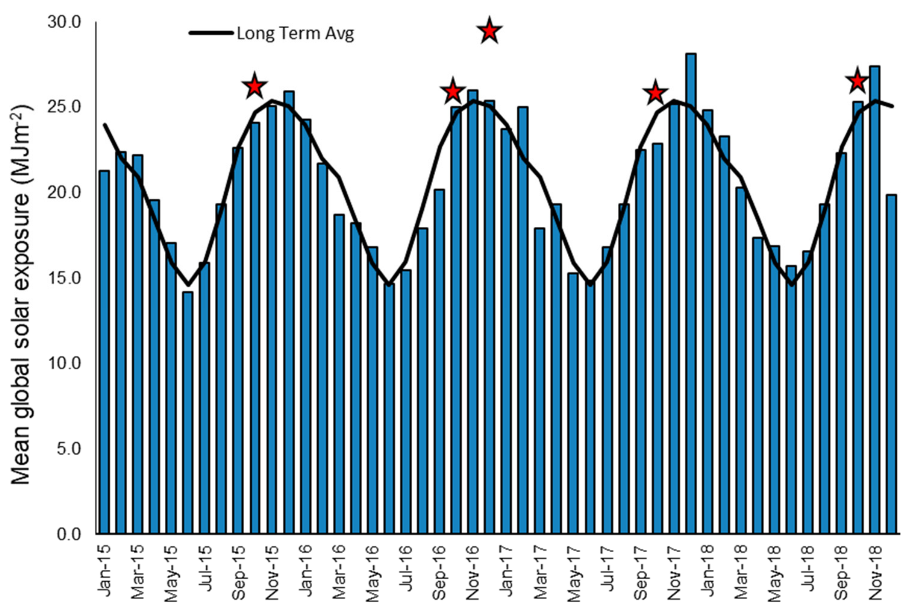


Figure 22b. Mean monthly daily global solar exposure (MJ m^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) January 2014-December 2018. Source: BOM.

Significant Wave Height

Maximum wave height is the maximum wave height in a record (26.6 minute recording period) (DSITI 2018). In the 12 months prior to the survey, the highest maximum average wave height of 1.45m was recorded in March 2018 (Figure 23). The general trend throughout the year was consistent with seasonal averages with wave heights peaking in March and April and lowest in July and August.

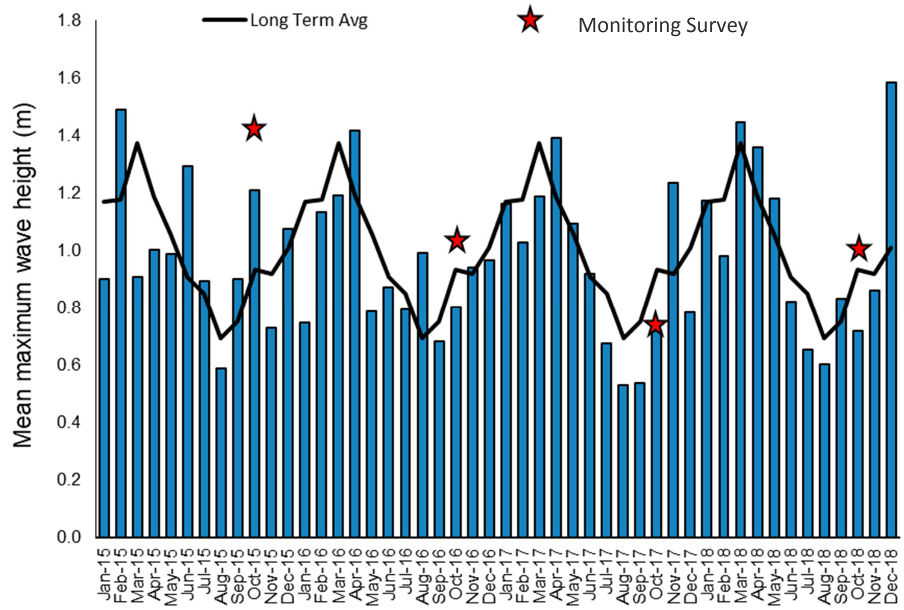


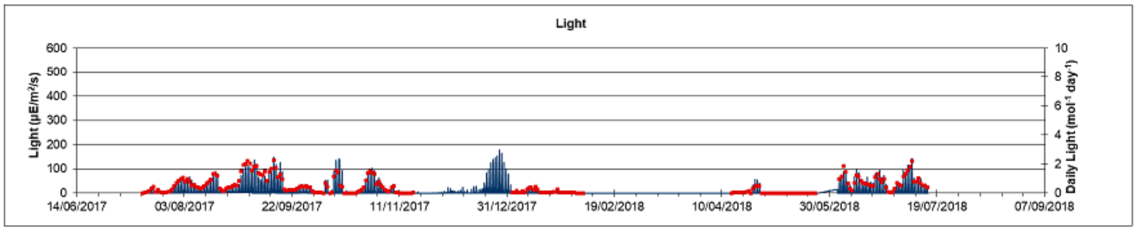
Figure 23. Mean monthly maximum wave height (m) recorded at Hay Point, January 2015-December 2018.
Source: DSITI.

Benthic daily light (Photosynthetically active radiation - PAR)

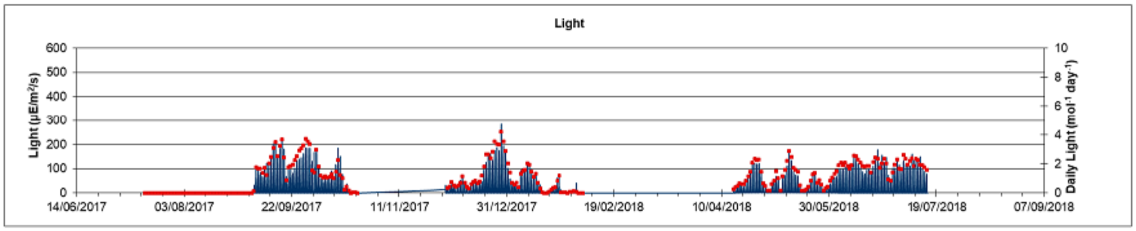
Total daily light measured as photosynthetically active radiation (PAR) is monitored as part of the Ambient Marine Water Quality Monitoring Program for the ports of Mackay and Hay Point. Locations where PAR is collected within or near coastal seagrass meadows include Victor Island, Hay Reef, Hay Point spoil ground, Round Top Island and Keswick Island (Multiparameter water quality loggers – Figure 26).

PAR showed general seasonal trends particularly at sites closer to the coast (e.g. Hay Reef, Victor Island) with higher benthic light availability from June through to November when lighter winds and fewer rainfall events occurred. 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. 2018). Off shore around Hay Point spoil ground light levels were extremely low from November through to April due to the weather conditions mentioned above in combination with the deeper water and greater light attenuation with depth (Figure 26). This period coincides (or promotes) the annual period of dormancy in the deep-water meadows off Hay Point and Mackay. Further offshore at Keswick Island the larger-sized sandy particles require greater wave energy to resuspend the sediments and light environment is more consistent throughout the year. Fine-scale patterns of PAR are primarily driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows and therefore less sediment suspension (Waltham et al. 2018).

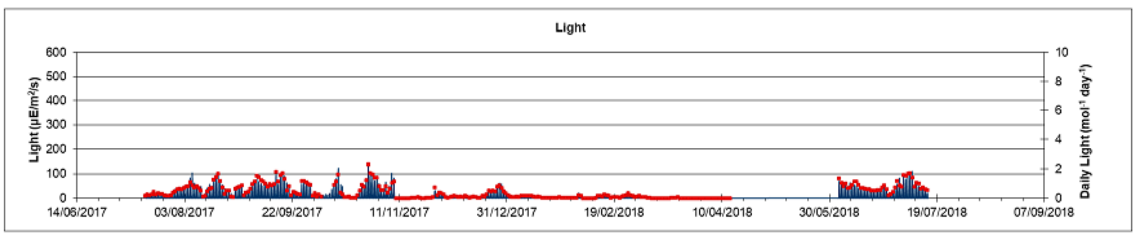
AMB2: Hay Reef



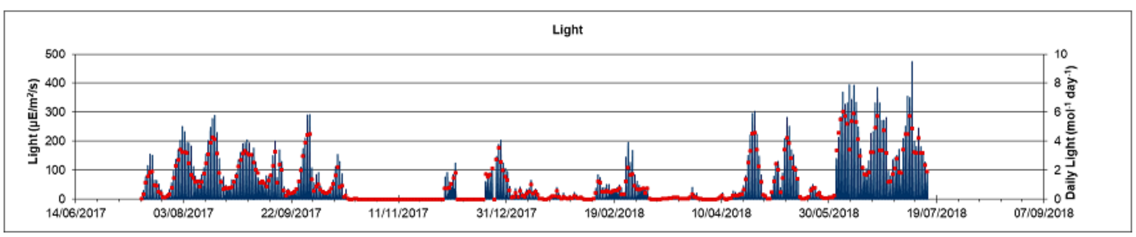
AMB 3: Round Top Island



AMB 8: Hay Point Spoil ground



AMB 10: Victor Island



AMB 12: Keswick Island

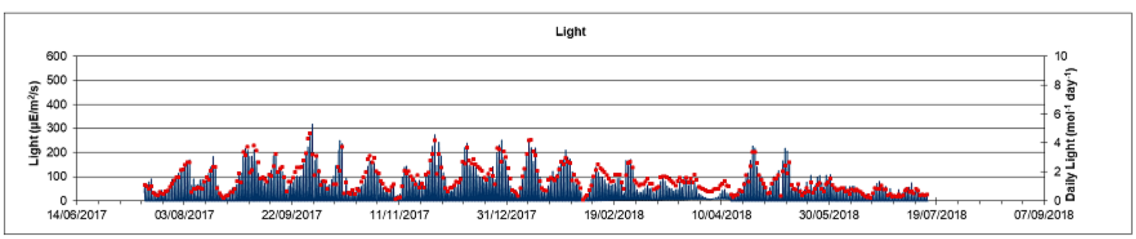


Figure 26. Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1} - red line – right axis) and continous par logging (µEinsteins m^{-2} s^{-1} – blue line – left axis) at Hay Reef, Round Top Island, Hay Point Spoil Ground, Victor Island and Keswick Island. Data presented from July 2017 to July 2018. Source: Waltham et al. 2018. Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program (July 2017 – July 2018).

4 DISCUSSION

The 2018 survey of seagrass monitoring areas 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 and more regularly since 2014. The 2018 survey was the first year that condition indicator scores were applied to monitoring meadows at the coastal Dudgeon Point site and offshore adjacent to Keswick Island and St Bees Island. It is also the second year that the condition scores have been applied to the deep-water seagrass meadows off Hay Point. The meadow assessments in 2018 showed varying levels of seagrass condition across the region with coastal seagrass in satisfactory condition, deep-water meadows remained in poor condition and meadows around offshore islands in generally good condition. These results reflect the different environmental conditions where the seagrass occur and the weather and climatic conditions that influence them. Generally, climate conditions for seagrass growth were favourable for much of the year prior to the seagrass survey in October 2018 with the region experiencing below average rainfall and river flows.

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, York et al 2018). The Hay Point deep-water meadow was scored as in poor condition in 2018, primarily because of the low biomass in seagrass meadows in the monitoring area compared to the long-term baseline average. Biomass within this meadow has been at low levels throughout all surveys in the last decade following the initial baseline mapping in 2004 where biomass was 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. In 2018 while still rated as poor the biomass score was only marginally below that of satisfactory, which suggests that the baseline conditions are likely to be appropriate given there are still three more years until the full 10 year baseline history is reached.

The *Halophila* 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). PAR levels in deep-water seagrass meadows such as the Hay Point spoil ground and near Victor Island show long periods with very low light between February and April. This is the period when the deep-water seagrasses are in their dormant stage. The levels present throughout the rest of the year are also close to the range of tolerance for these species and may explain the low biomass often found in these deep-water habitats as the seagrass are living at their margins of survival (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 compared to *H. decipiens* (though still low compared to other seagrass genera found elsewhere in the Great Barrier Reef region – Collier et al. 2016). These meadows combined were scored in good condition in 2018 and both increased their biomass and area compared to the monitoring survey conducted in 2017 (York and Rasheed 2018). These meadows are considerably further offshore than the Hay Point meadows and they are less susceptible to turbid plumes from coastal flooding and water quality. They also occur in sediments with larger sediment particles (sand) that require greater wind speeds and wave heights to resuspend and the Keswick Island meadow is on the leeward side of the island and sheltered from prevailing winds and swell. These conditions generally provide more favourable conditions for seagrass growth. PAR data collected at a location near, and at a similar depth to these meadows at Keswick Island shows a more consistent pattern of light throughout the year and overall higher levels than found in deep-water environments of Hay Point. These light conditions support the presence of structurally larger *Halophila* species and allows them to persist throughout the year as opposed to the annual lifecycle of *H. decipiens* meadows offshore from Hay Point.

The inshore monitoring area around Dudgeon Point combined three seagrass meadows dominated by *Halodule uninervis* with *Zostera muelleri* and *Halophila ovalis* also present. These meadows covered a greater area in 2018 than previously mapped, however, biomass levels were lower than average and scored satisfactory as an indicator condition. 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 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).

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 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. 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 taking advantages 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 2018. For many locations coastal seagrasses have improved (e.g., Gladstone – Chartrand et al. 2019, Abbot Point – McKenna et al. 2019), some have remained stable (e.g., Townsville - Bryant et al. 2019, Cairns - Reason et al. 2019, Weipa –McKenna et al. 2019) and at others they have declined in response to local pressures (e.g., Karumba – van de Wetering et al. 2019).

Ongoing development of seagrass condition indices

This is the second year of the new monitoring program and reporting of seagrass condition established in 2017 for Hay Point, Mackay and the Southern Whitsundays. The program as it develops 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 (HR2R) Partnership report card.

Hay Point offshore

The current survey (2018) was the second 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. The baseline long-term averages for meadow indicator conditions now has 7 years of data and will become a permanent baseline when 10 years of baseline of data is achieved in 2021. During this period, the influence of the 2004 survey will be continually reviewed to determine if this single year is having a disproportionate influence on the baseline and skewing the condition index. Recent results suggest that it is likely to be appropriate as the condition score for biomass was close to satisfactory and area and species were good or better with three more years of the baseline to go.

Coastal meadows and Keswick Island

This year saw the first condition scores for the Dudgeon Point and Keswick and St Bees Islands monitoring areas with the establishment of an interim 5-year baseline. Baseline conditions will continue to change for these locations until a permanent baselines is established in 2023 after 10 years of data collection.

Mackay offshore

The Mackay offshore seagrasses have been mapped for the second time in 2018 and an interim score for this area will not be available until 2021 after a 5-year baseline is established for all metrics.

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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 7 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 5 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 2004–2018 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 (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 2018 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 2018 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).

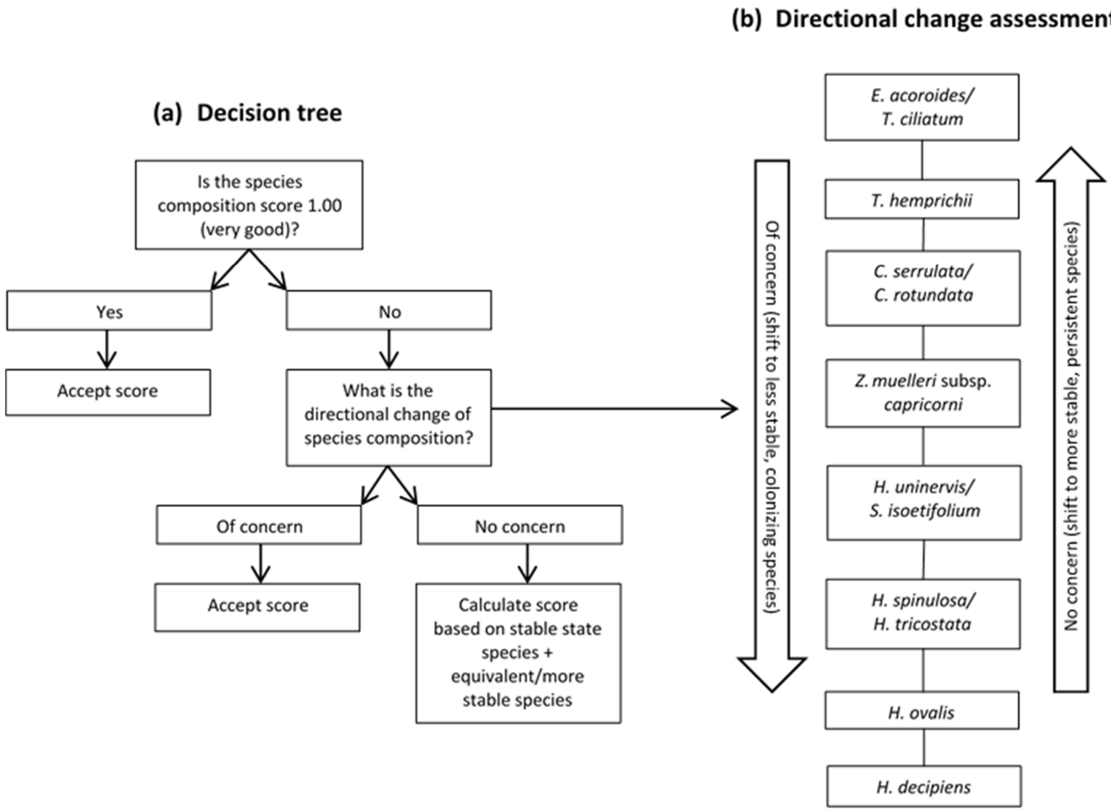

Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

Score Aggregation

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. 2014b).

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 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:

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

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 offshore area 2004, 2005, 2010, 2011, 2014, 2016, 2017 and 2018

(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**

Table A5. Seagrass community type, mean above-ground biomass and meadow area in the Dudgeon Point - Hay Point annual survey areas, 2010 – 2018.

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	
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	
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**

* 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 – 2018.

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**

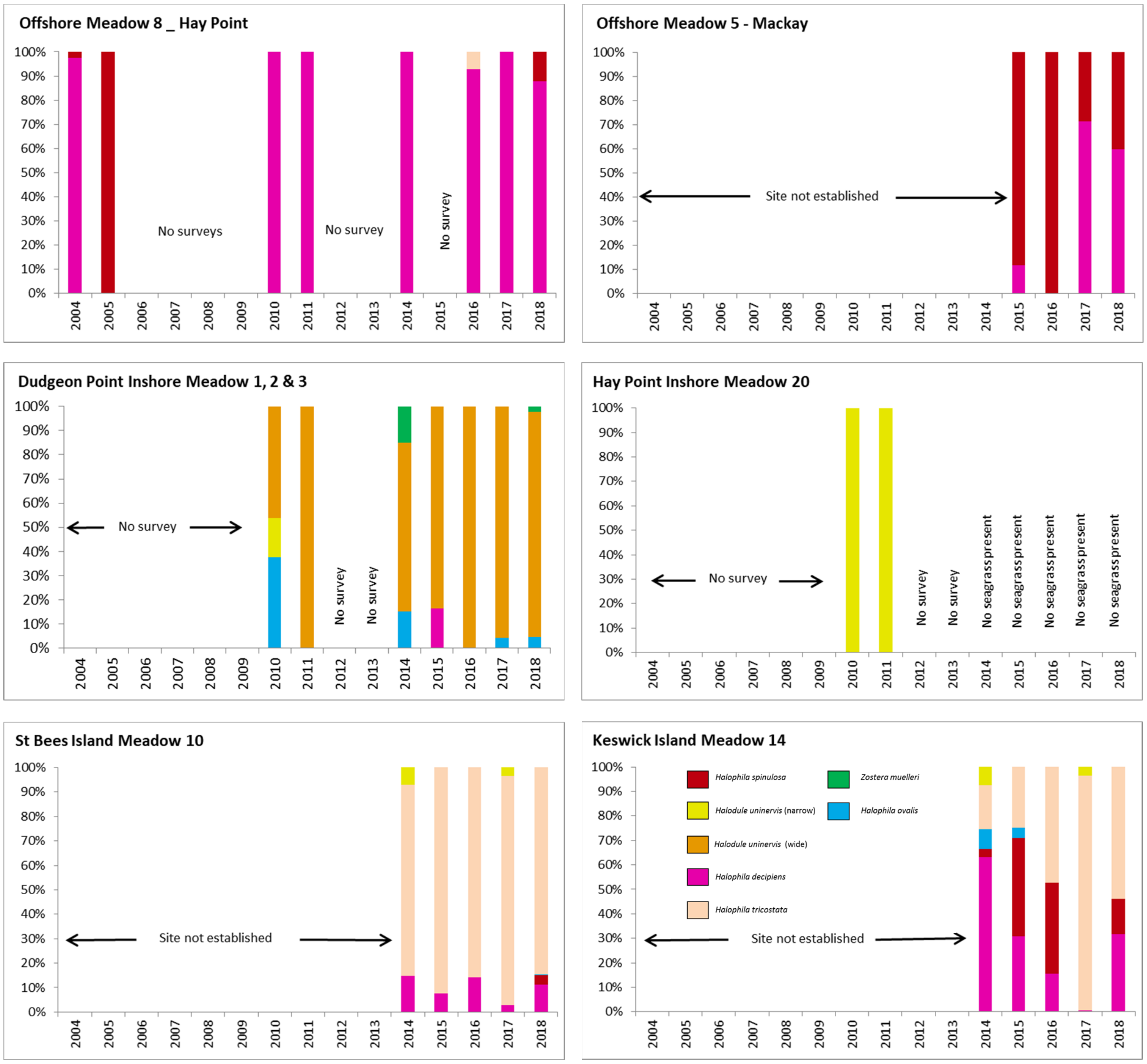

Figure A2: Species composition of monitoring meadows in the Hay Point-Mackay region, and the Keswick Island group.