ANNUAL SEAGRASS MONITORING IN THE MACKAY-HAY POINT REGION – 2021

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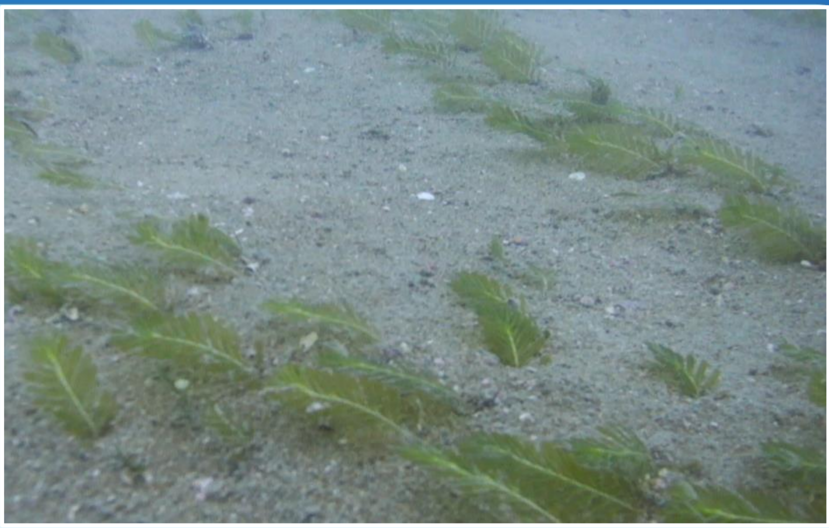

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Key Findings

OVERALL CONDITION
Hay Point and Mackay

GOOD
(Interim)

Likely causes of seagrass condition:

- *No significant large-scale adverse weather events over the last four years*

This report compiles findings of the annual Hay Point-Mackay long-term seagrass monitoring conducted in September-October 2021.

- The overall seagrass condition in 2021 in the Hay Point-Mackay region was classified as good, an improvement from satisfactory in 2020. Seagrass condition was variable among different seagrass habitats and locations.
    - Coastal meadows at Dudgeon Point shifted from satisfactory to good condition in 2020 due to an increase in meadow area.
    - The highly variable seagrass in the Hay Point offshore deep-water remained in a poor condition in 2021. Despite a large increase in the size of the meadow, this was offset by a decline in meadow biomass.
    - In contrast, the Mackay offshore monitoring area recorded the largest area and biomass of deep-water seagrass since sampling began there in 2017 and was classified as being in very good condition.
    - Meadows at offshore Islands (Keswick and St Bees combined) maintained their overall good condition for 2021 with both meadows expanding in area.
- The general improvement in most meadow scores is likely due to the overall favourable conditions for seagrass growth in the 12 months before to the survey, with no major weather or climatic events to impact seagrass health.

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.

In 2021 the overall seagrass condition throughout the region was good, an improvement from satisfactory in 2020, however, condition also varied among locations and seagrass community types. The general trend across all monitoring meadows was of an expanding footprint of seagrass (increased area) with reduced abundances (lower biomass) often occurring concurrently at some locations. The deep-water meadows offshore from Hay Point were in poor condition, while the deep-water meadows offshore from Mackay were in very good condition (Figure 1). The coastal meadow at Dudgeon Point and the meadow adjacent to Keswick Island were in good condition and the meadow adjacent to St Bees Island was satisfactory (Figure 1).

The deep-water meadows offshore from Hay Point and Mackay both underwent large increases meadow area in 2021, however, there was a contrast in the condition of their biomass with the Mackay meadow dominated by *H. spinulosa* increasing in biomass while the Hay Point meadow dominated by the highly variable *H. decipiens* declined in biomass compared to the previous year. The coastal meadow at Dudgeon Point also underwent increases in both area and biomass in 2021. The increase in the size of all of these meadows indicates sustained favourable growth conditions allowing for the spread of seagrass into new areas. The contrast in biomass responses among these meadows may reflect variability in shorter-term environmental conditions with *H. decipiens* in the Hay Point offshore meadow being less resilient than the species in the other two meadows and responding much more quickly to local variability in water quality which may have fluctuated immediately prior to the survey.

The general improved trend in seagrass condition in the Mackay-Hay Point region from poor in 2017 and 2018 following TC Debbie to good in 2021 coincides with a period in the region where no large-scale disturbances such as cyclones and floods have occurred for over four years. This has likely allowed for the meadows to build resilience in the form of stored carbohydrate reserves within plant structures and seedbanks within marine sediments to help withstand short-term adverse events in the future.

The seagrass habitats in the Hay Point-Mackay region are known to be highly variable and assemblages are dominated by colonising and opportunistic species that are adapted to surviving in low light conditions. When conditions for seagrass growth are unfavourable these colonising species, consisting of mainly *H. decipiens, H. tricostata* and *H. spinulosa,* 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 for other larger seagrass species. 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. While previous research has shown that these meadows are susceptible to impacts from large scale prolonged capital dredging (e.g., in 2006), they also had an ability to rapidly recover, and were able to persist during smaller and shorter capital and maintenance dredging activities. 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.

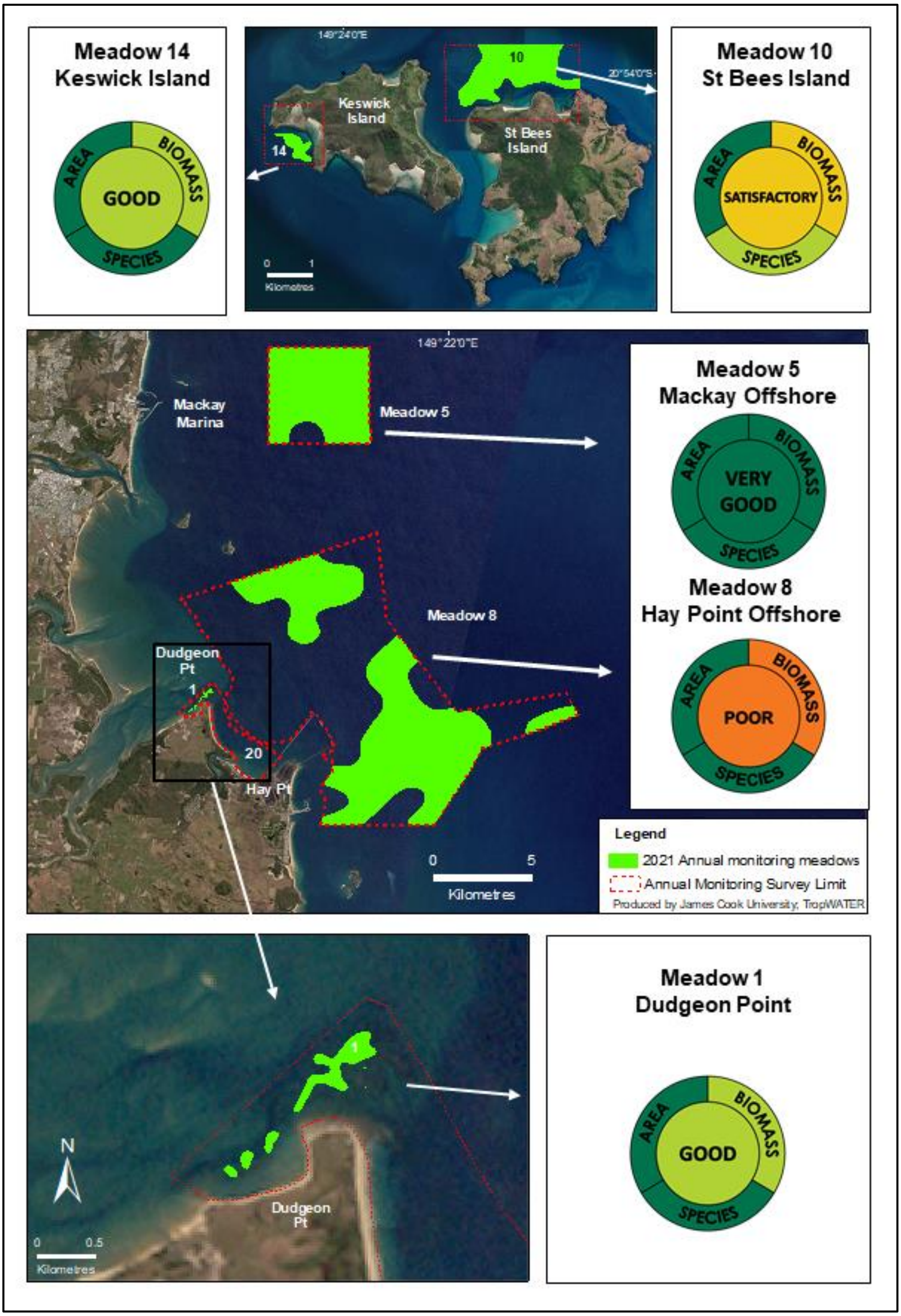

Figure 1. Seagrass meadow condition for the ports of Mackay, Hay Point, Keswick and St Bees Island 2021.

At the time of the 2021 survey, the region had experienced four-and-a-half-years with no major flooding or cyclones, allowing seagrass meadows time to recover following several consecutive years of floods, storms and cyclone impacts. The climate conditions for seagrass growth were favourable for much of the year prior to the survey with below- average rainfall and river flows and wave height and sea surface temperatures that were above the long term average (Figure 2). Monitoring at other port locations in Queensland have shown a range of results during 2021. Coastal areas to the north and south of the Hay Point-Mackay region had seagrass in good condition (e.g. Gladstone, Abbot Point, Townsville and Cairns while the estuarine habitat in Trinity inlet was in poor condition.

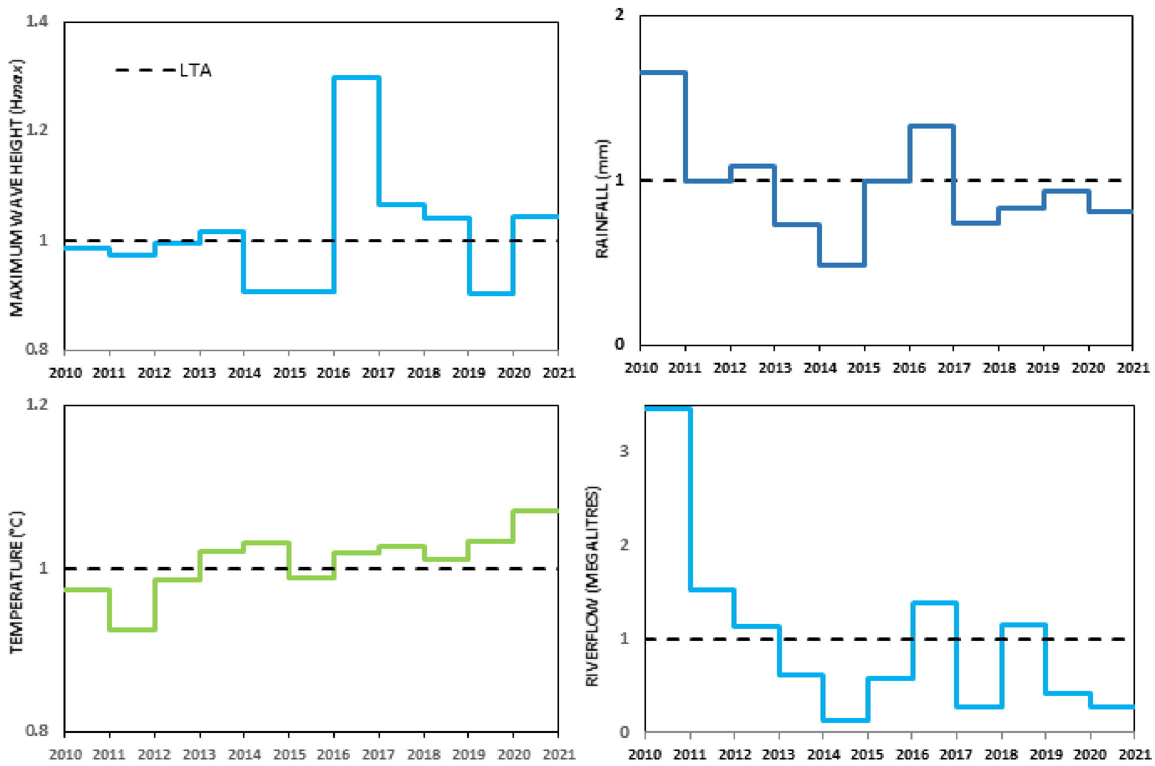

Figure 2. Recent climate trends in the Hay Point Area: change in climate variables as a proportion of the long-term average over the last 10 years (2010 – 2021). Black dotted line represents the long-term average. (See section 3.3 for detailed climate data).

Contents

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; Hayes et al. 2020), and food for grazing megaherbivores like dugongs and sea turtles (Heck et al. 2008; Scott et al. 2018; Scott et al. 2021). 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 3).

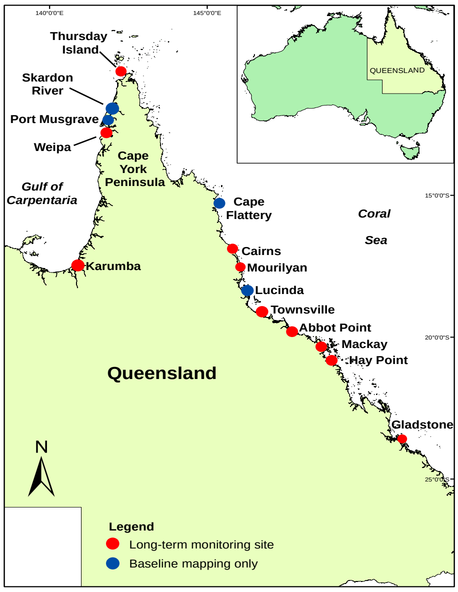

Figure 3. Location of Queensland Port Seagrass assessment sites.

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 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 (*Halodule uninervis* and *Zostera muelleri*) and the colonising *Halophila 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 re-established 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 2004 and 2012. The broad-scale survey in 2014 was used as a platform to re-establish the program, with added monitoring in the Keswick and St Bees Islands (southern Whitsunday Islands) and Mackay areas (Figure 4). 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 port marine 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 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.

This report presents the findings of the annual seagrass habitat monitoring survey conducted in September/October 2021 in the Hay Point-Mackay region. The objectives of these studies were to:

- Map seagrass distribution and determine seagrass density and community type at all 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;
- Incorporate 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.

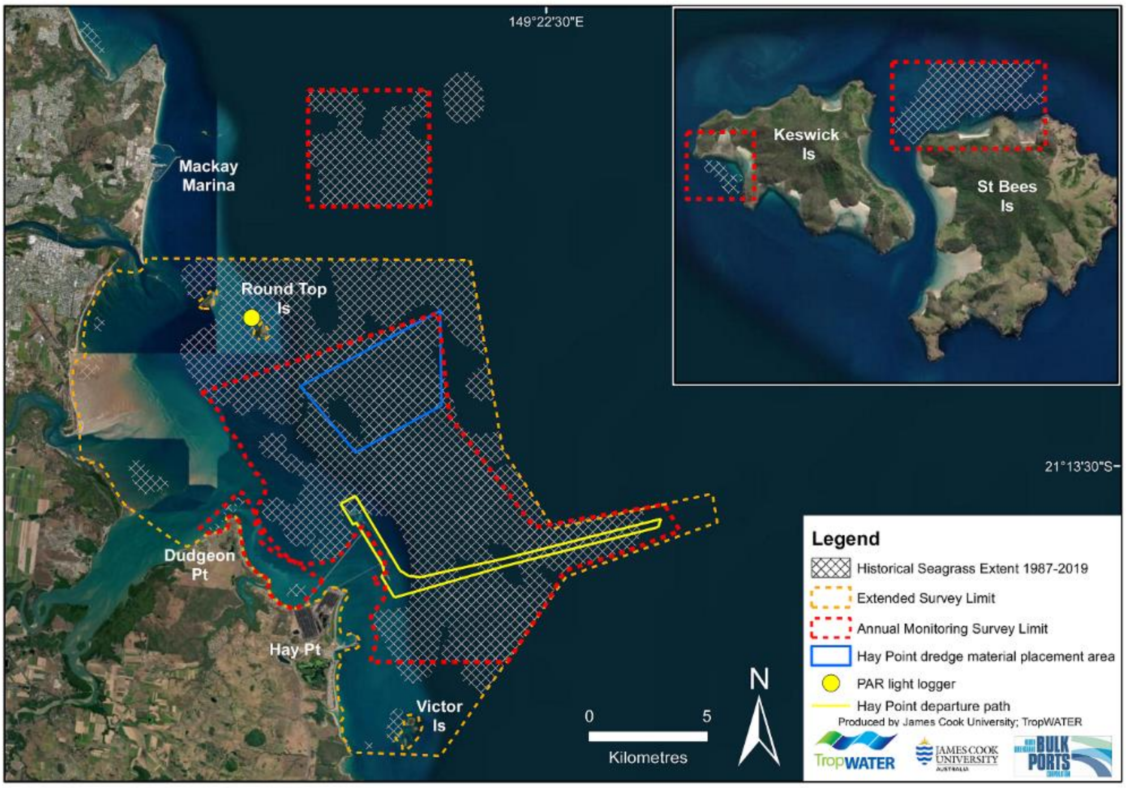

Figure 4. Location of survey limits of annual and extended seagrass monitoring areas around Mackay, Hay Point and the Keswick Island group in 2021.

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, Hay Point, Mackay 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 monitoring and an extended broad-scale survey of seagrass communities within the Hay Point-Mackay region (including Keswick and St Bees Islands) were conducted in September and October 2021 (Figure 4).

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
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 5A-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 5C-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.

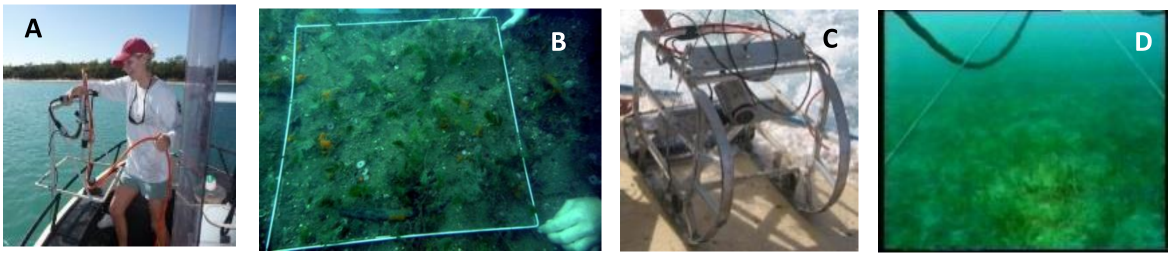

Figure 5. (A) Shallow subtidal mapping of seagrass meadows using digital camera mounted on a 0.25m^2 drop frame, (B) visual observation by free diver and (C-D) offshore underwater sled tows with digital camera.

All survey data were entered into a Geographic Information System (GIS) using ArcGIS 10.8®. 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 6).
    - 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.

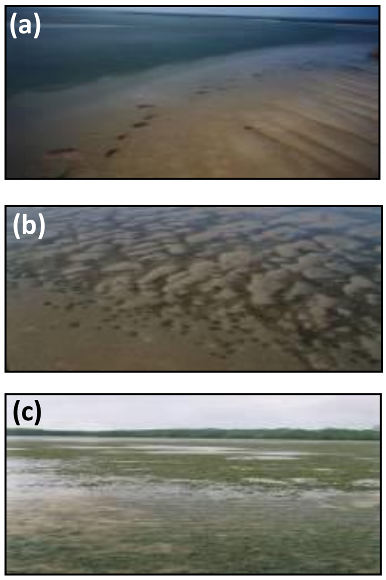

Figure 6. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

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 and Mackay 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 7 summarises the methods used to calculate seagrass condition. See Appendix 1 for full details of score calculation.

In 2021, the condition index was applied to the offshore monitoring sites at Hay Point and Mackay, and coastal monitoring meadows at Dudgeon Point, Keswick Island and St Bees Island. Scores will vary until 10 years of data become available to establish a baseline. Presently, interim scores for the Dudgeon Point, Keswick Island and St Bees Island monitoring meadows are assessed against 8 years of averaged data (2014-2020). These averages will vary annually until 10 years of data become settled in 2023. The Mackay offshore monitoring meadow was established (2017) and has been included in the condition index for the first time in 2021 with a 5-year interim baseline which will become permanent with a 10-yar baseline in 2026.

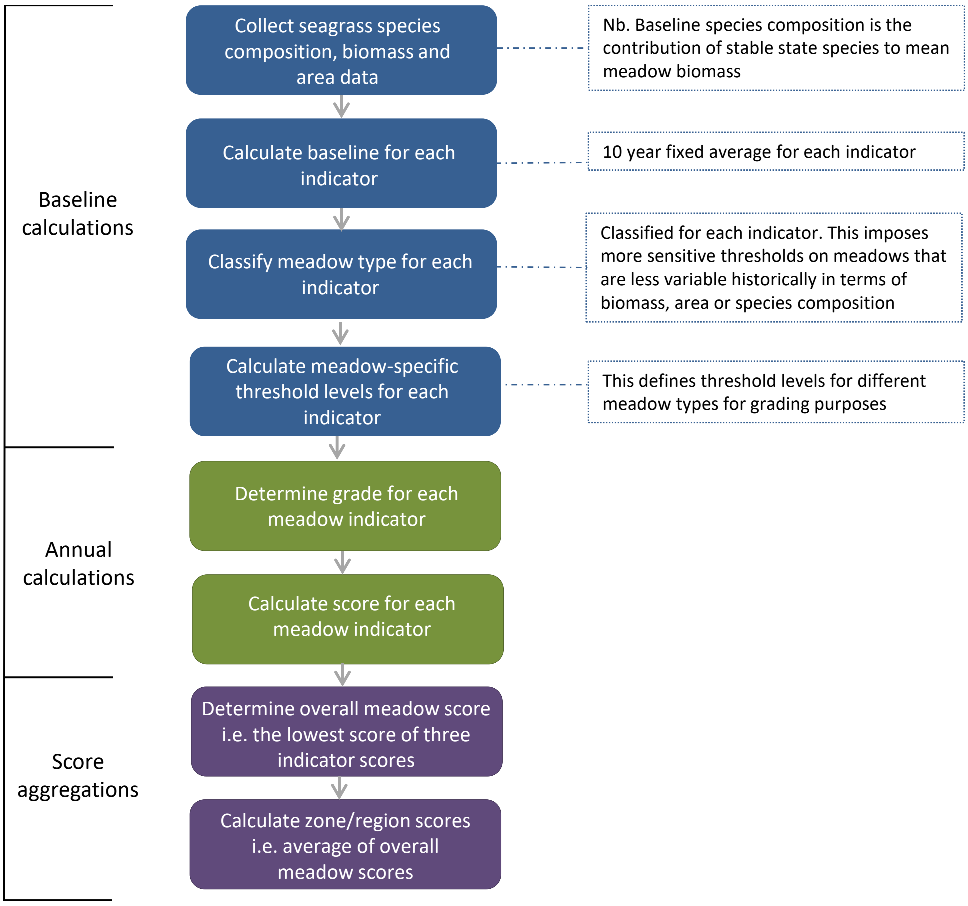

Figure 7. Flow chart to assess seagrass monitoring meadow condition.

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 Round Top Island nearby to the offshore seagrass meadows as part of the Ambient Water Quality monitoring Program at the Ports of Mackay and Hay Point. 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. 2021). Data is presented as a 7-day rolling average of total daily PAR to allow for comparison with modelled thresholds for light requirements of deep-water seagrass in the region (McKenna et al. 2015).

3 RESULTS

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

A total of 314 sites were surveyed as part of the annual monitoring survey in the Hay Point, Mackay and Keswick Island area in September and October 2021 (Figure 9). Seagrass was present at 30.8 % of all coastal sites in the survey which includes 19.0 % of sites within the Dudgeon Point annual monitoring areas, as well as 51.2 % of sites at the Keswick and St Bees Islands annual monitoring areas (Figure 9). Seagrass was present at 55.6 % of all the offshore sites in the extended survey which included 95.4 % of sites in the Mackay offshore annual monitoring area (Meadow 5) and 42.6 % of sites in the Hay Point offshore annual monitoring area (Meadow 8) (Figure 9).

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 8, Appendix 2). Six seagrass species were observed in 2021, up from five reported in 2020 (Figure 8). Deepwater assemblages offshore from Hay Point and Mackay were dominated by *Halophila decipiens* with *Halophila spinulosa* also occurring mainly in the Mackay Offshore monitoring area (Figure 10, Appendix 2; Figure A2). *Halophila tricostata* and *H. spinulosa* dominated the two meadows at Keswick and St Bees Islands with smaller amounts of *H. decipiens, H. ovalis* and *Halodule uninervis* also occurring (Figure 10), Appendix 2). *Halodule uninervis* (both wide and narrow forms) dominated the inshore meadows at Dudgeon Point with *Z. muelleri* returning to the meadow and *H. ovalis* and *H. decipiens* also occurring (Figure 10, Appendix 2).

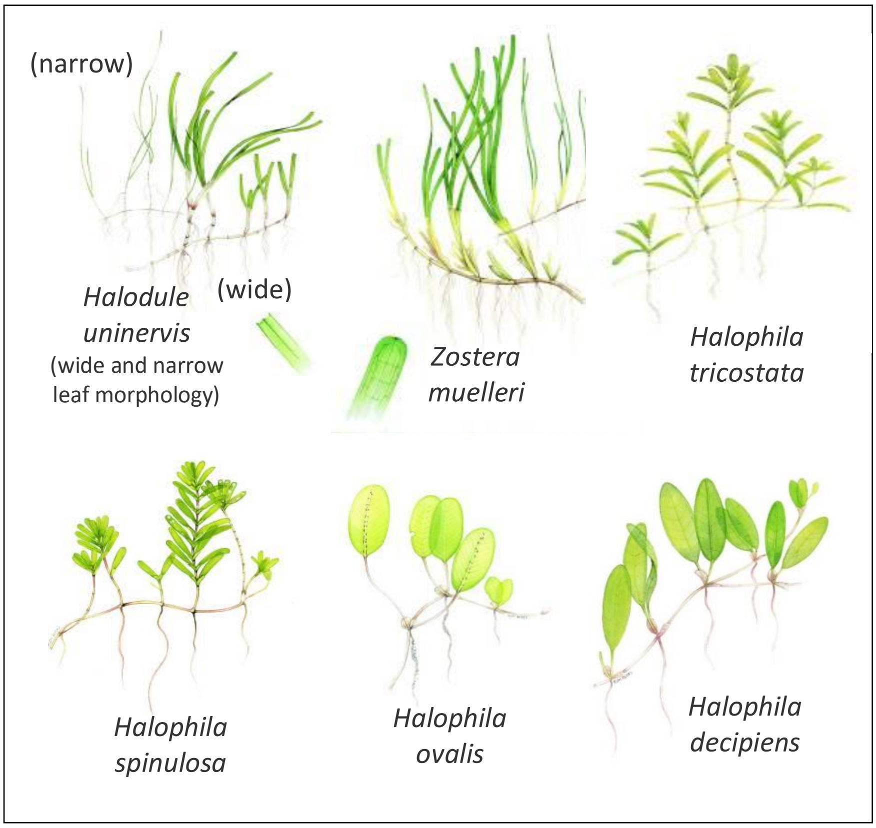

Figure 8. Seagrass species identified in the Hay Point-Mackay annual monitoring program in 2021. Leaf size varies widely within species and diagrams are not to scale.

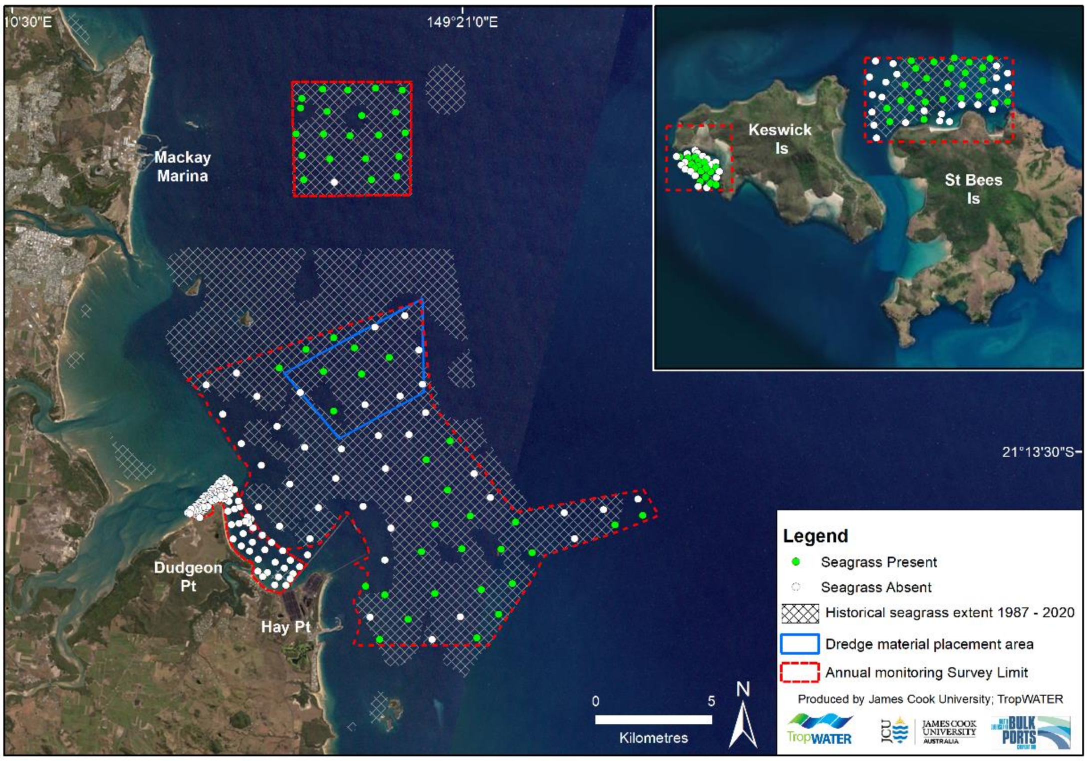

Figure 9. Location of 2021 annual and extended seagrass monitoring survey sites in the Hay Point-Mackay region.

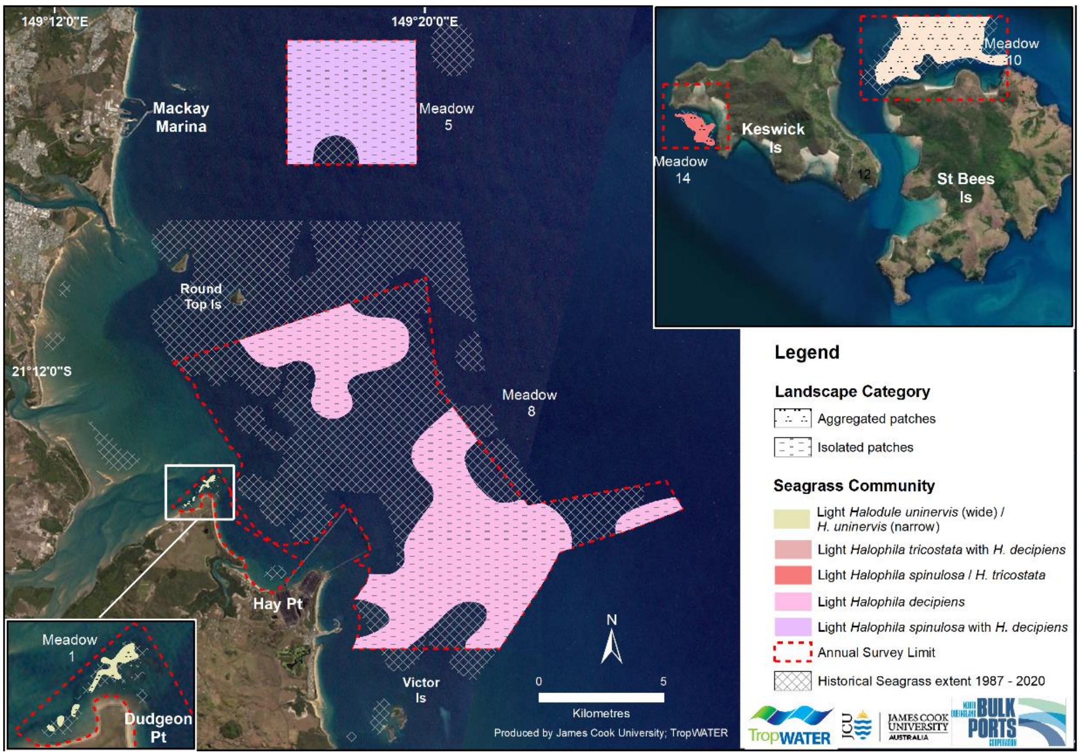

Figure 10. Location of 2021 seagrass meadows in the Hay Point region showing seagrass communities and landscape categories.

3.2 Seagrass condition in the Hay Point - Mackay region

Offshore seagrass at Hay Point and Mackay

The overall condition of offshore seagrasses in the Hay Point monitoring area scored poor in 2021 for the second consecutive year. This rating was driven by a decline in biomass of 73% from the previous year to 0.011 ± 0.006 g DW m^2 in 2021 (Figure 11, Appendix 2; Table A4). At the same time, however, the area of the meadow showed a more than seven-fold increase from 736.9 ± 258.2 ha in 2020 to 5,216.6 ± 618.2 ha in 2021 (Figure 11 & 16, Appendix 2; Table A4). The meadow was dominated by the pioneering H. decipiens, which has been the main species in this area throughout the program's history. Halophila spinulosa was also present at two sites in 2021.

The 2021 survey was the first occasion that a condition score was attributed to the meadow offshore from Mackay Harbour after five years of data collection (Figure 12). The meadow was scored in a very-good condition for all condition indices and there has been a general trend of increasing seagrass meadow area, biomass and a shift in composition to more stable species since 2017 (Figure 17). In 2021 both the meadow area and biomass were at their highest since monitoring began for this meadow. Seagrass area (2215.7 ± 213.0 ha) and biomass (0.203 ± 0.080 g DW m^2) were close to or more than double the 5-year average respectively (Figure 12; Appendix 2; Table A4). The high biomass is likely driven by a shift in the species composition with the larger bodied *H. spinulosa* becoming more prevalent in 2021 (53.5 % by weight) (Appendix 2; Figure A2).

Inshore seagrass at Dudgeon Point

The coastal intertidal monitoring meadow at Dudgeon Point improved in condition from satisfactory to good in 2021. The change in score was primarily the result of a large (82 %) increase in area to 15.7 ± 4.3 ha in 2021 (Figure 13 & 18, Appendix 2; Table A5). Biomass at the site also more than doubled to 3.01 ± 0.72 g DW m^2, and remained in good condition in (Figure 13, Appendix 2; Table A5). *Zostera muelleri* returned to the meadow at Dudgeon Point after being absent from the sampling records in 2020. *H. uninervis* (both wide and narrow leaf forms) remained the dominant species here in 2021 with both *H. ovalis* and *H. decipiens* also present (Appendix 2; Figure A2).

Keswick and St Bees Islands

The seagrass monitoring meadow adjacent to St Bees Island remained in satisfactory condition for the second consecutive year (Table 4). The area of the meadow increased by 37 % to 191.76 ± 41.8 ha in 2021, however, this was offset by a decline of 64 % in biomass to 1.04 ± 0.17 g DW m^2 in 2021 (Figure 14, Appendix 2; Table A6). Three seagrass species were found here in 2021 with the meadow dominated by *H. tricostata* (70 % by weight) with *H. decipiens* (26 %) and *H. ovalis* (4 %) also occurring (Appendix 2; Figure A2). The Keswick Island monitoring meadow remained in a good condition in 2021 for the fourth consecutive year (Figure 19; Table 4). The area of the meadow increased by 58 % to (22.5 ± 5.4 ha) changing from good to very good condition, while the biomass (1.33 ± 0.27 g DW m^2) declined by 66 % changing from very good to good condition (Figure 15, Appendix 2; Table A6). The decrease in biomass is likely due to an increase in the abundance of the small species *H. decipiens* in the newly established area of the meadow in 2021 (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 2021.

Meadow	Location	Biomass	Area	Species Composition	Overall Meadow Score
1	Dudgeon Point	0.85	0.86	0.94	0.85
5	Mackay - Offshore	0.91	0.96	1.00	0.91
8	Hay Point - Offshore	0.41	0.90	1.00	0.41
10	St Bees Island	0.65	0.89	0.66	0.65
14	Keswick Island	0.67	0.93	0.93	0.67
Overall Score for the Hay Point-Mackay region					**0.70**

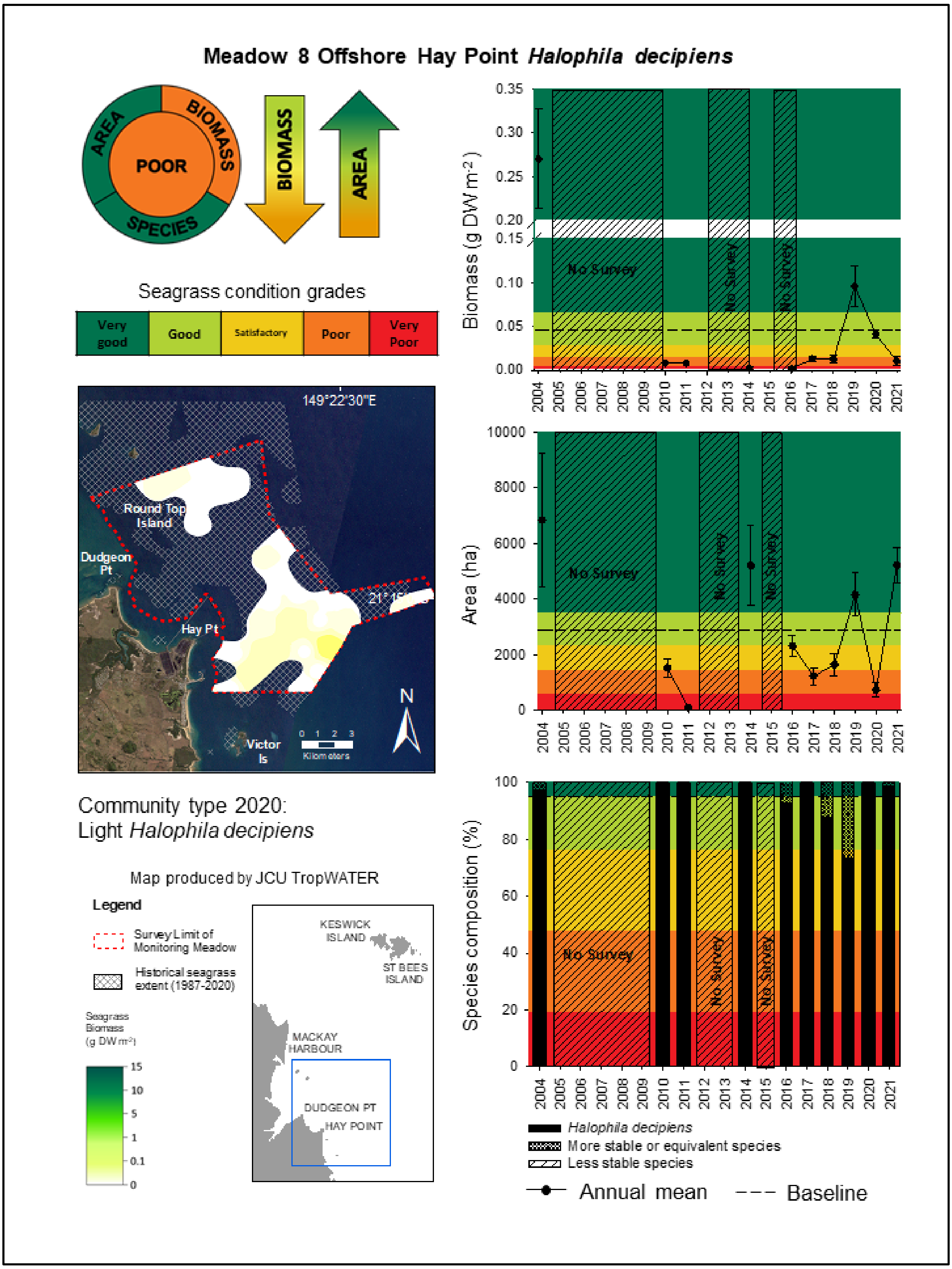

Figure 11. Changes in meadow biomass, area and species composition for seagrass in the Hay Point offshore area (Meadow 8), 2004 – 2021 (biomass error bars = SE).

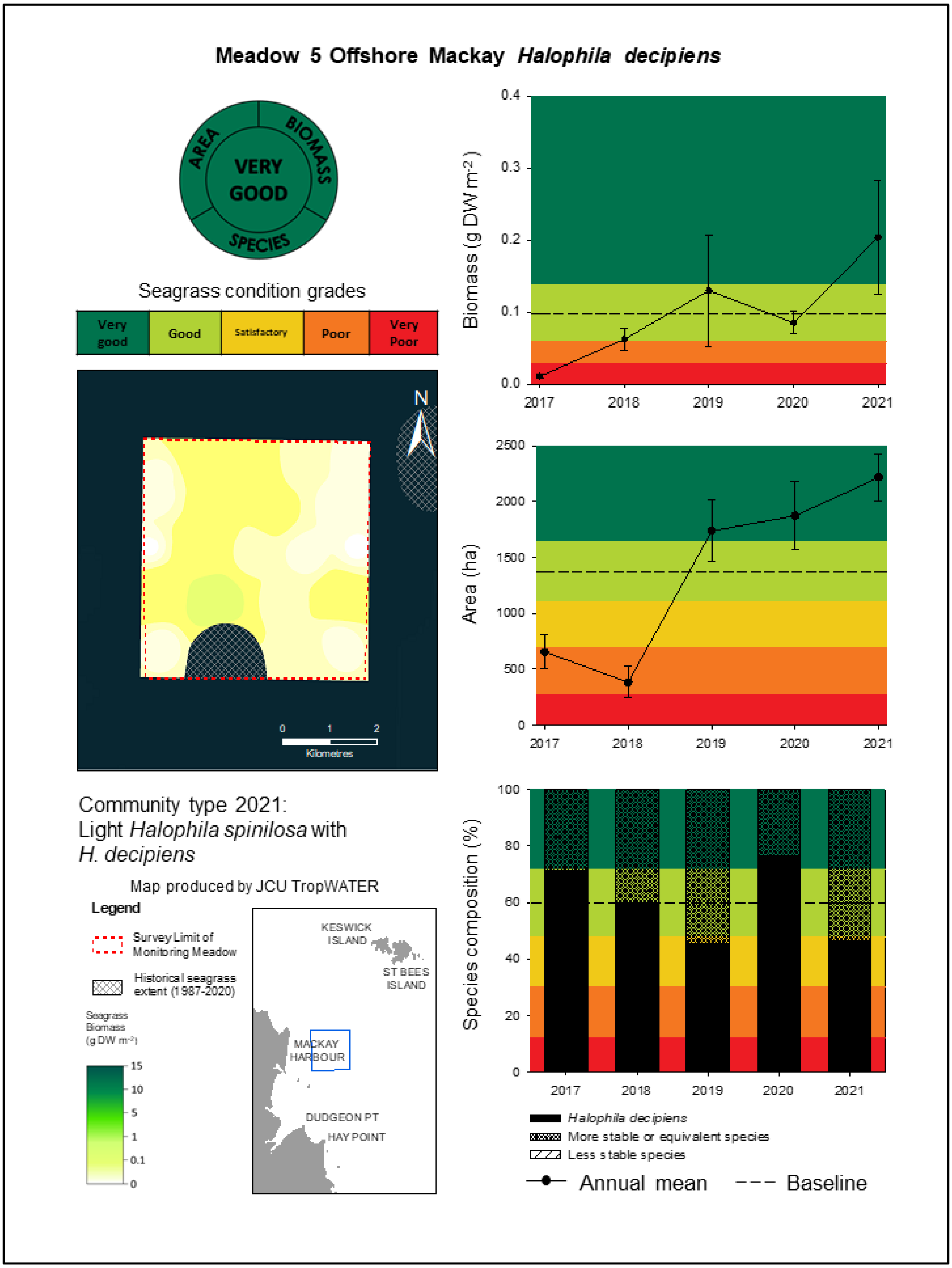

Figure 12. Changes in meadow biomass, area and species composition for seagrass in the Mackay offshore area (Meadow 5), 2017 – 2021 (biomass error bars = SE).

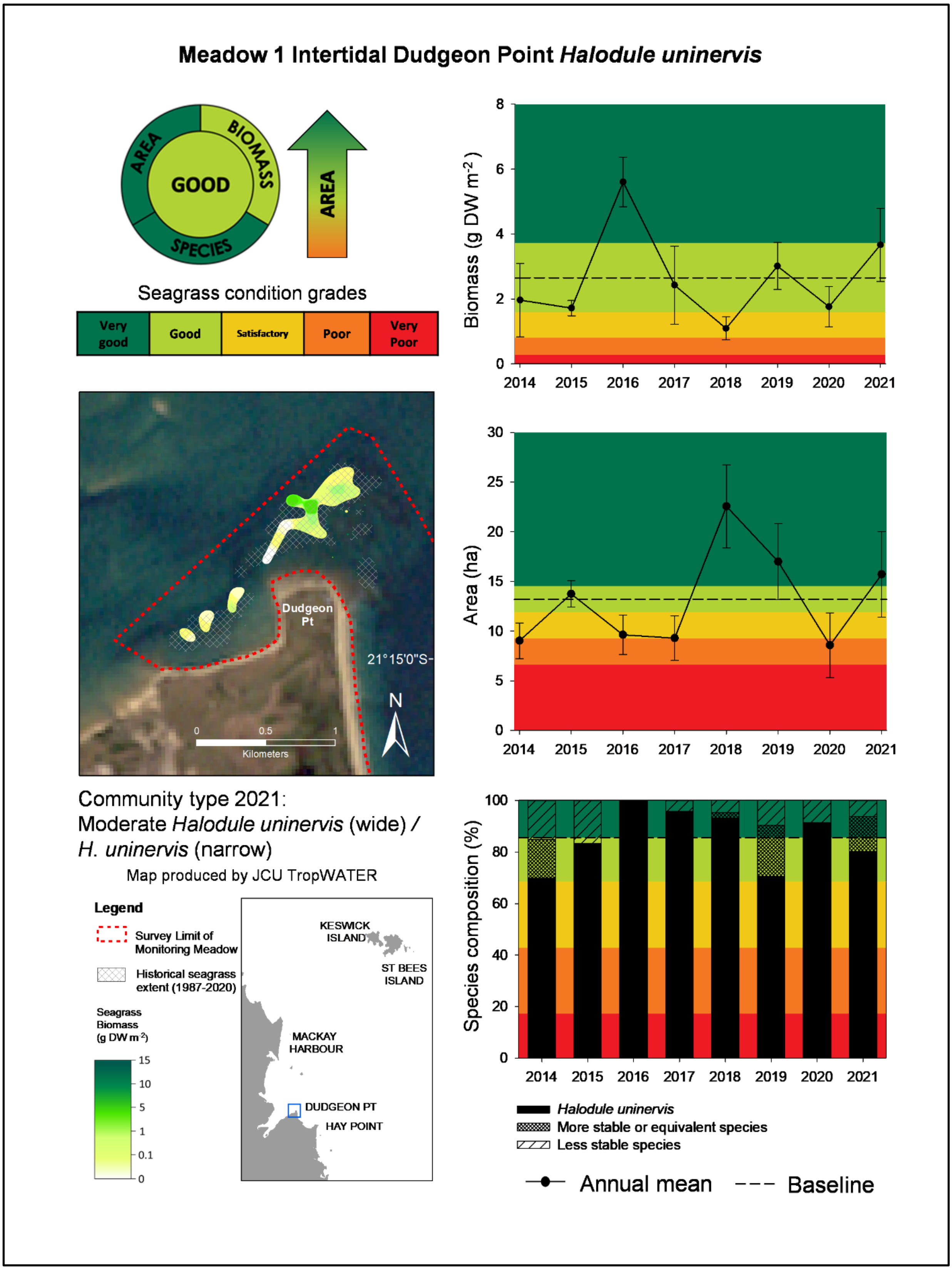

Figure 13. Changes in meadow biomass, area and species composition for seagrass in the Dudgeon Point coastal area (Meadow 1), 2014 – 2021 (biomass error bars = SE).

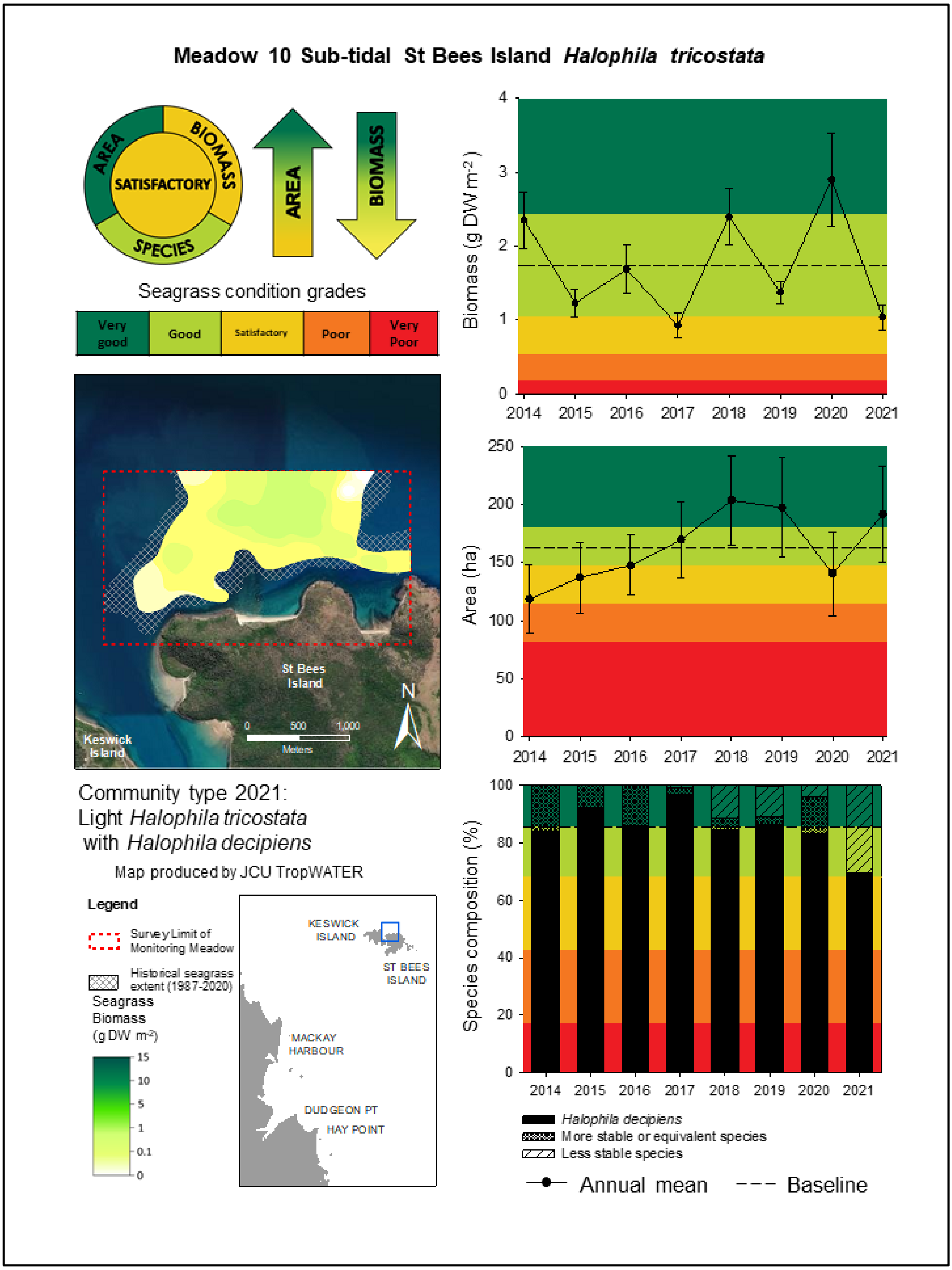

Figure 14. Changes in meadow biomass, area and species composition for seagrass in the St Bees Island coastal area (Meadow 10), 2014 – 2021 (biomass error bars = SE).

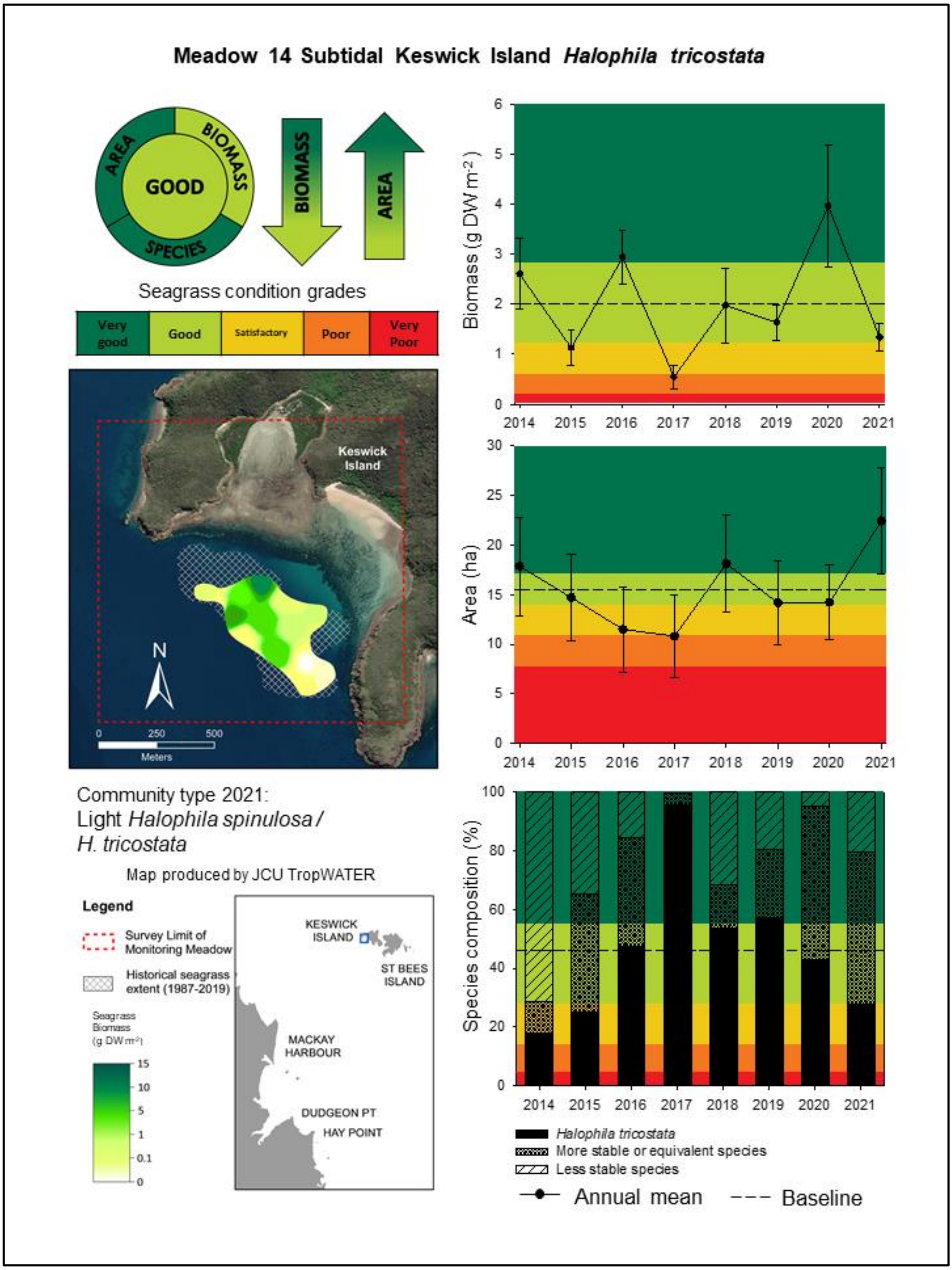

Figure 15. Changes in meadow biomass, area and species composition for seagrass in the Keswick Island coastal area (Meadow 14), 2014 – 2021 (biomass error bars = SE).

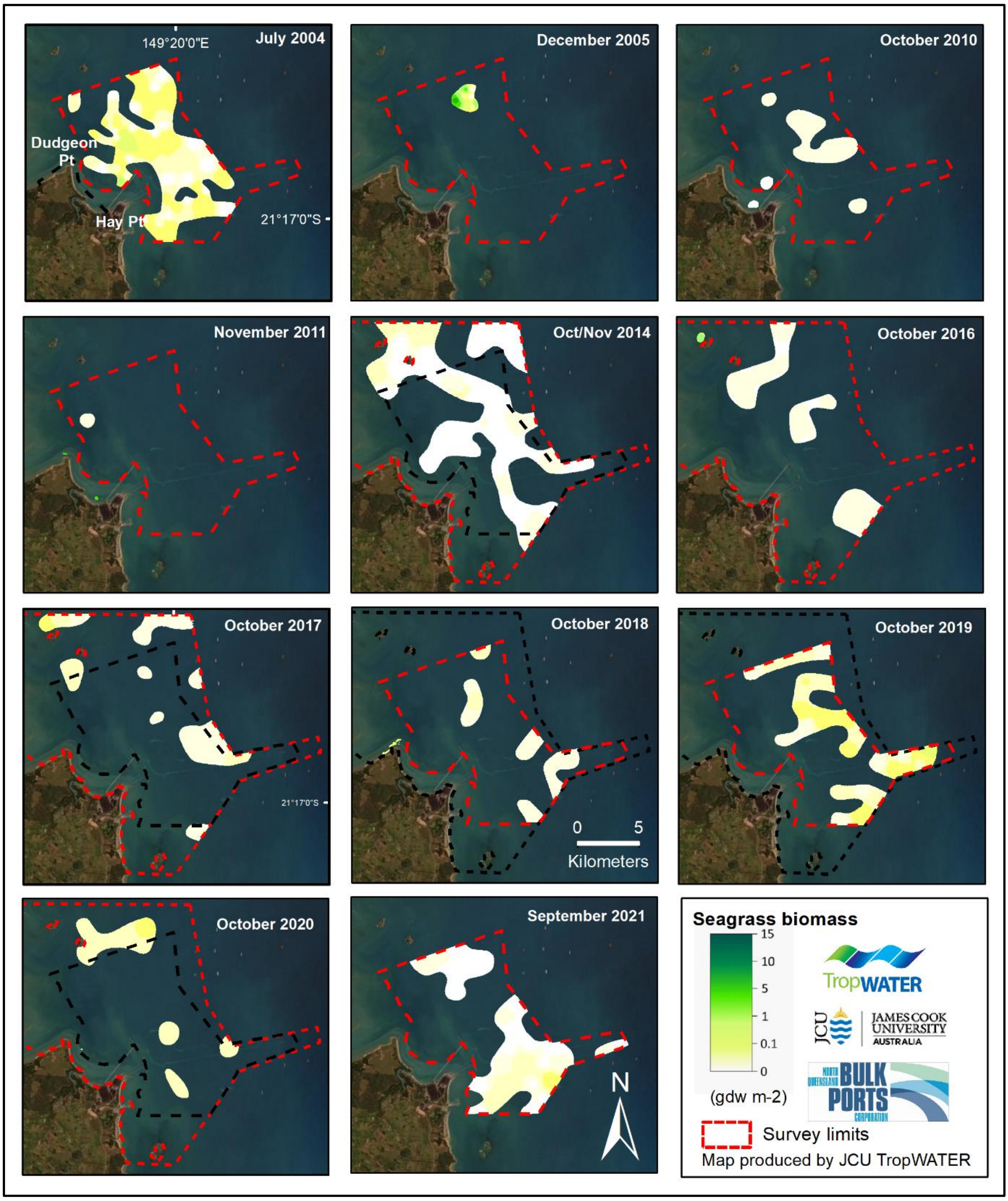

Figure 16. Seagrass biomass distribution in the Hay Point offshore monitoring area when surveys were conducted between 2004-2021.

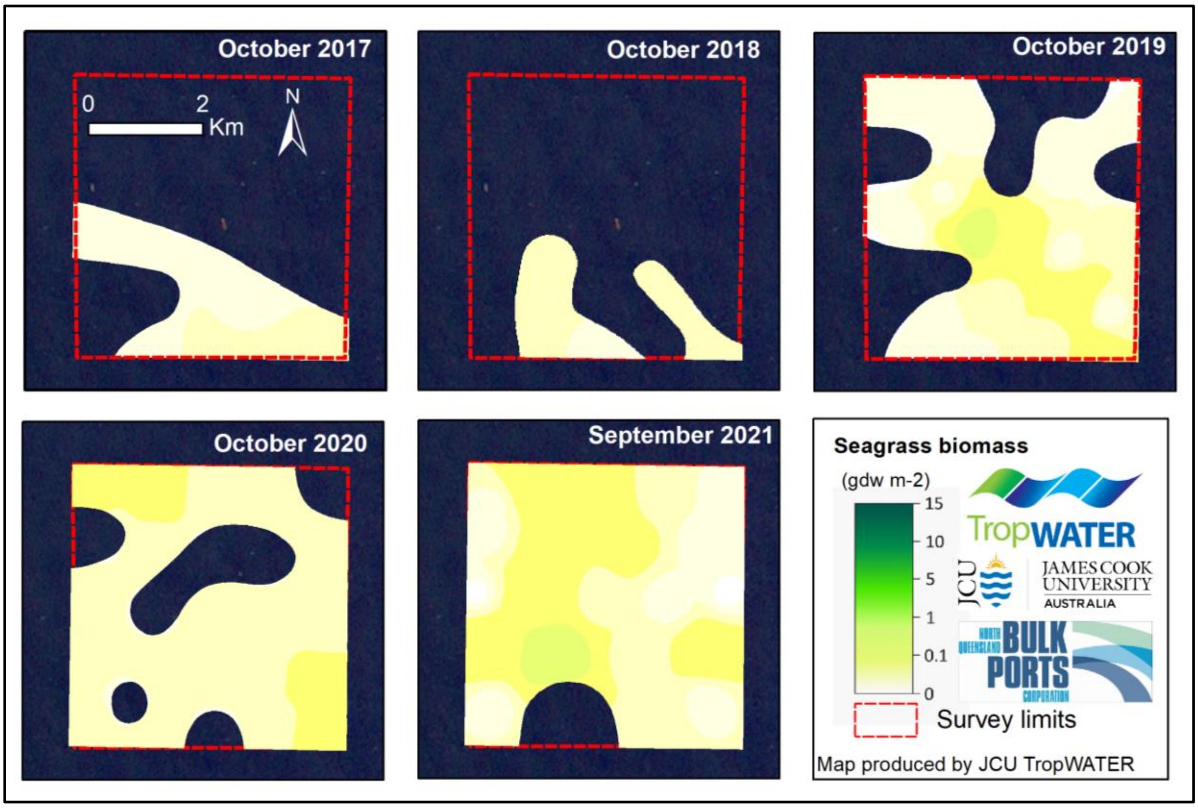

Figure 17. Seagrass biomass distribution in the Mackay offshore monitoring area when surveys were conducted between 2017-2021.

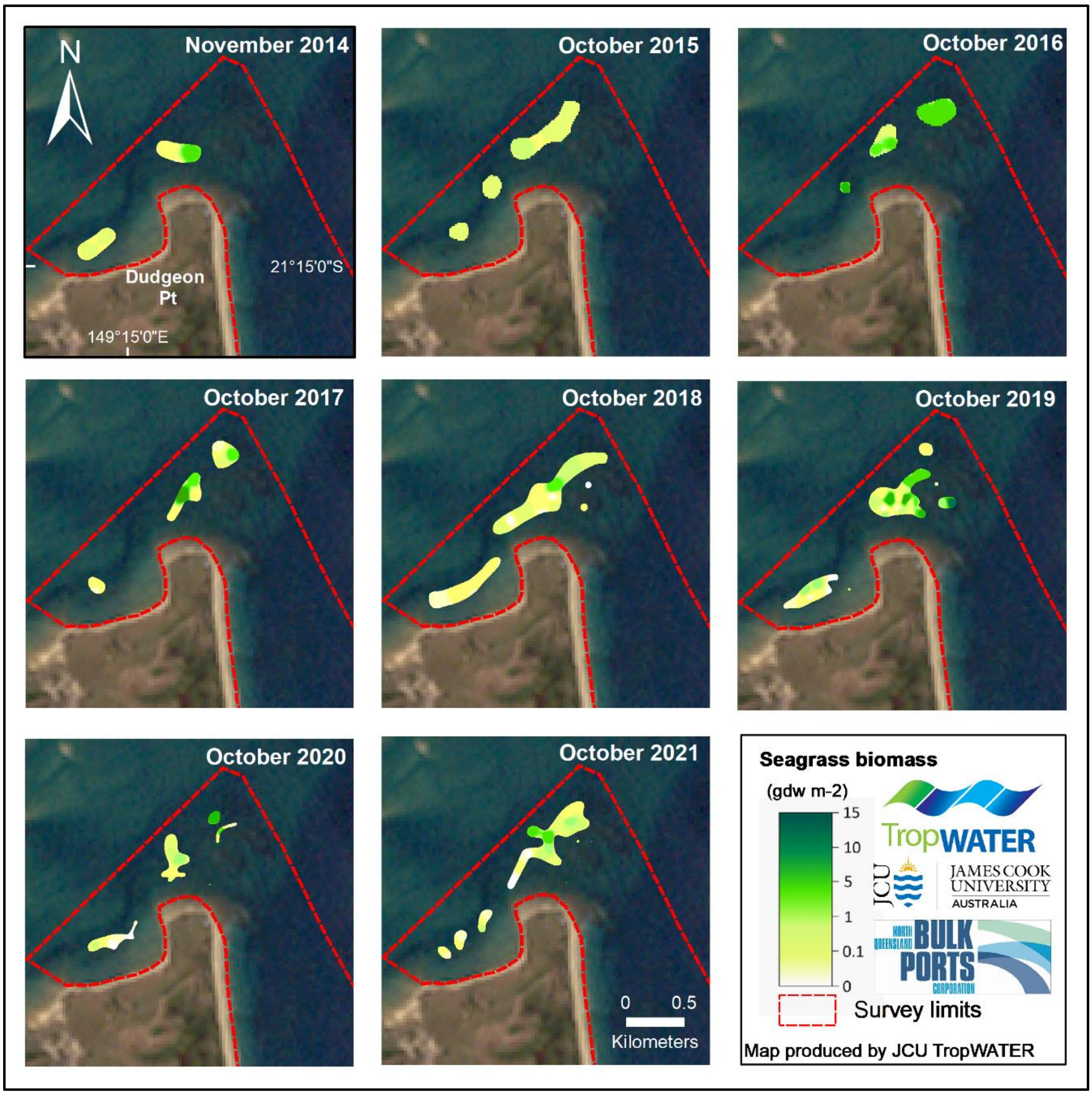

Figure 18. Seagrass biomass distribution in the Dudgeon Point to Hay Point annual monitoring area 2014 -2021.

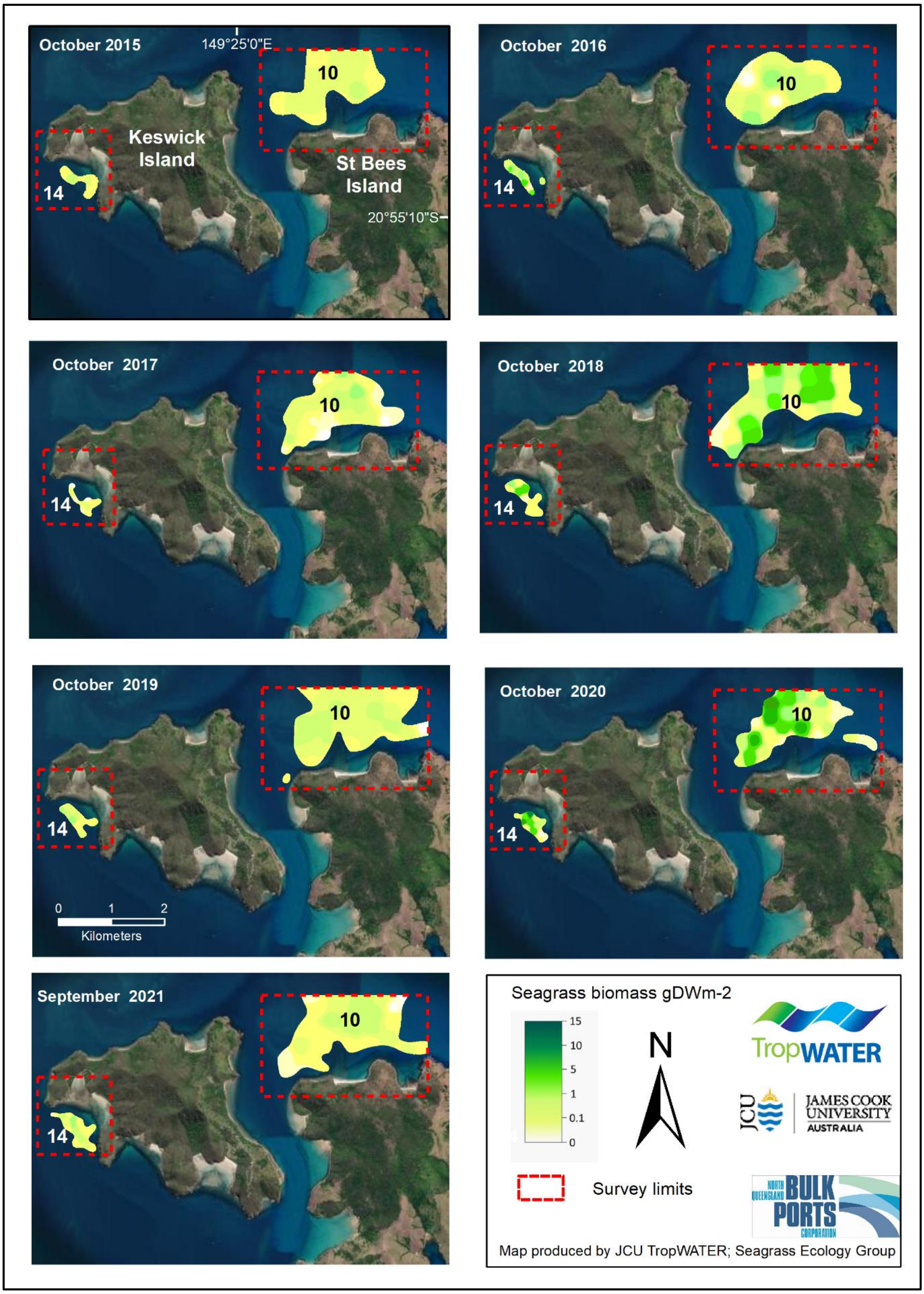

Figure 19. Seagrass biomass distribution in the annual monitoring meadows at Keswick and St Bees Islands 2015 – 2021.

3.3 Environmental conditions

Rainfall

Annual rainfall in the region was below the long term average in 2020/21 for the fourth consecutive year (Figure 20a). Throughout the year prior to the survey the majority of the rain fell from in December 2020 and January and April 2021, however, only rainfall in April and August were above the monthly long-term averages. (Figure 20b).

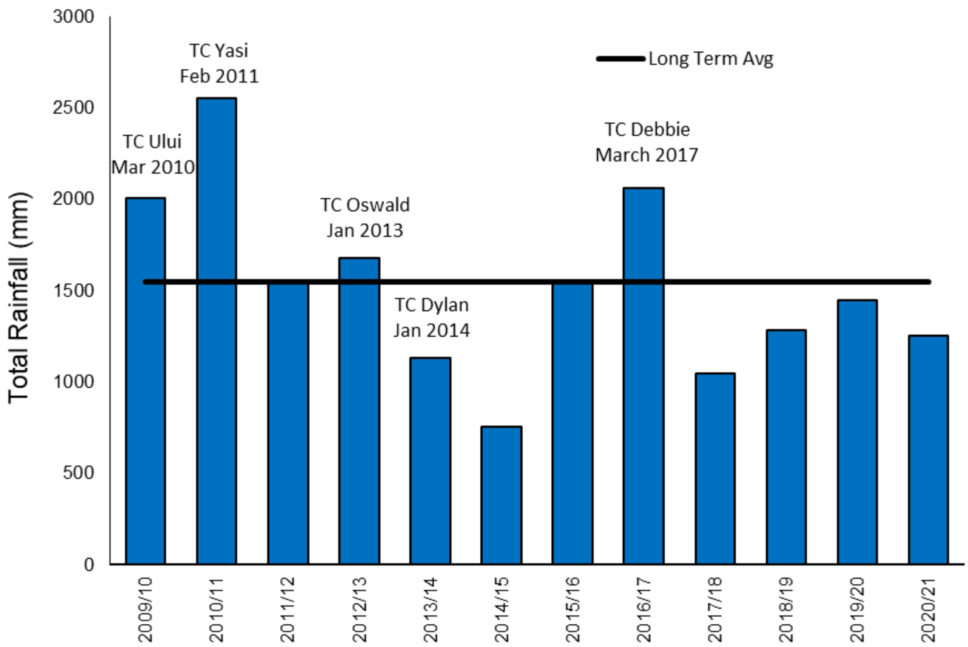

Figure 20a. Total annual rainfall (mm) recorded at Mackay Aero, 2009/10-2020/21. Twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033045.

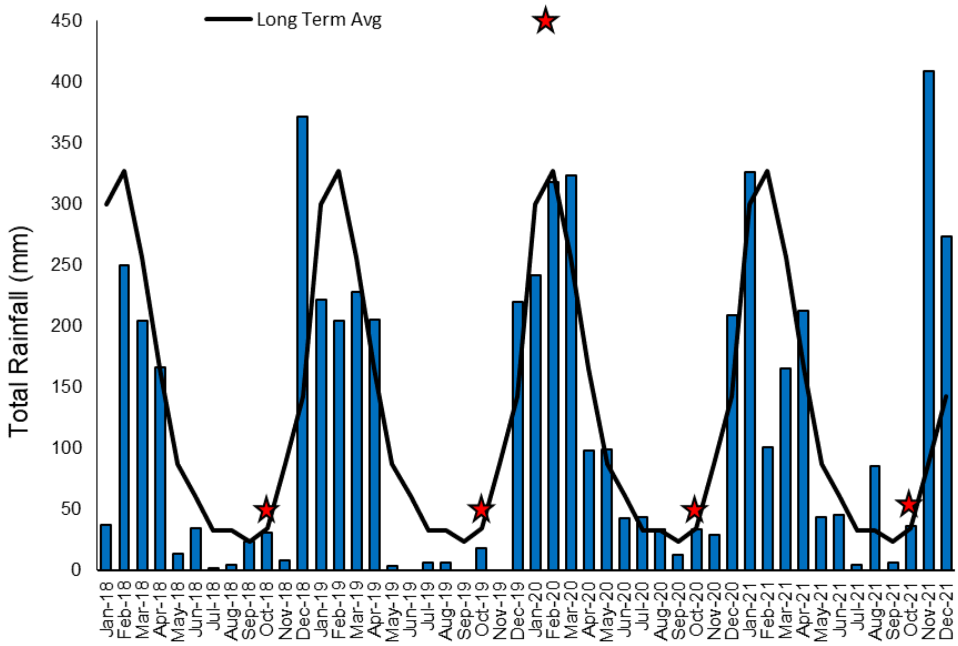

Figure 20b. Total monthly rainfall (mm) recorded at Mackay Aero, January 2018 - December 2021. Source: BOM, Station number 033045.

River flow

Annual river flow of the Pioneer River was considerably below the long-term average for the second consecutive year (Figure 21a). Monthly flow levels throughout the year were also below the long-term average with the exception of January 2021 which was close to the average (Figure 21b).

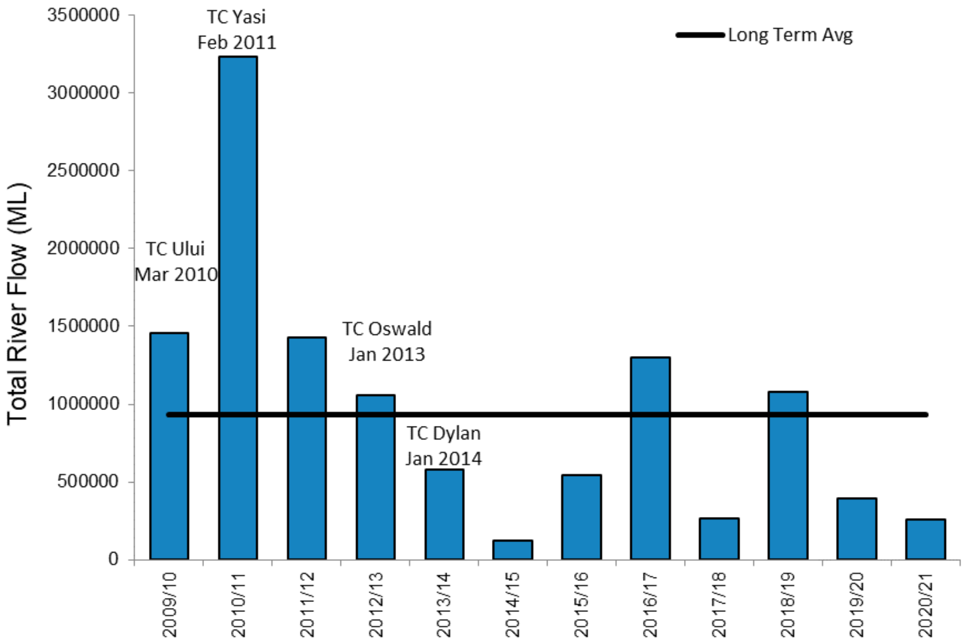

Figure 21a. Annual river flow (Mega litres) for the Pioneer River, 2009/10-2020/21. Source: Queensland Department of Natural Resources, Mines and Energy, Station number 125016A.

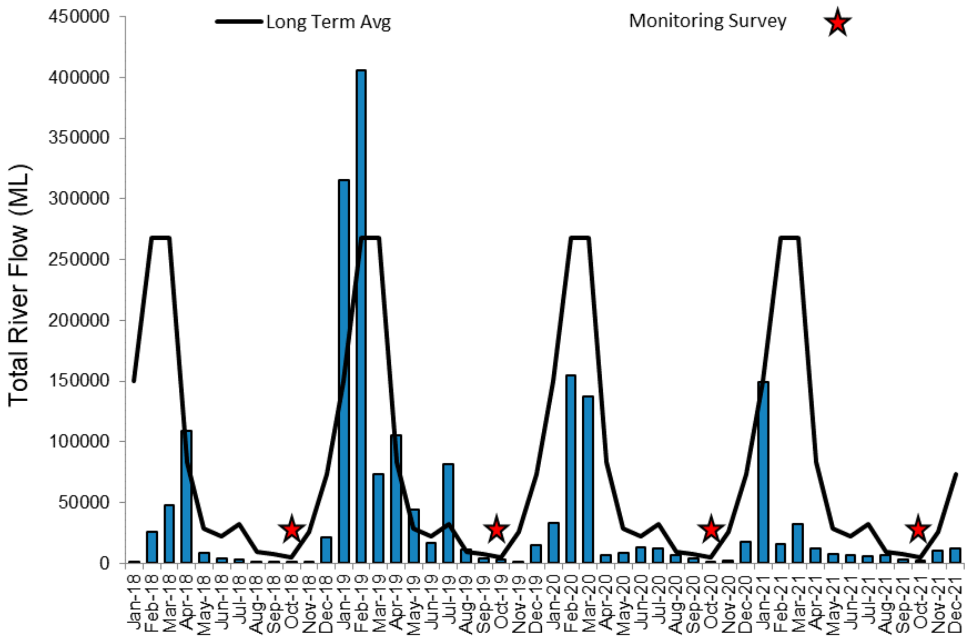

Figure 21b. Monthly river flow (Mega litres) for the Pioneer River January 2018-December 2021. Source: Queensland Department of Natural Resources, Mines and Energy, Station number 125016A.

Sea surface temperature

Sea surface temperature (SST) has been collected by the Queensland Government half hourly at Hay Point since 2008 and was available up intil the end of May 2022. The mean annual maximum daily SST of 26.65° C in 2020-21 was 1.78° C above the long-term average for this location, however, this figure is inflated due to the unavailability of data through the winter period (Figure 22a). Monthly data shows that sea surface temperature was above the long-term monthly average in February, March and April of 2021 but was close to the monthly average in November 2020 to January 2021 (Figure 22b).

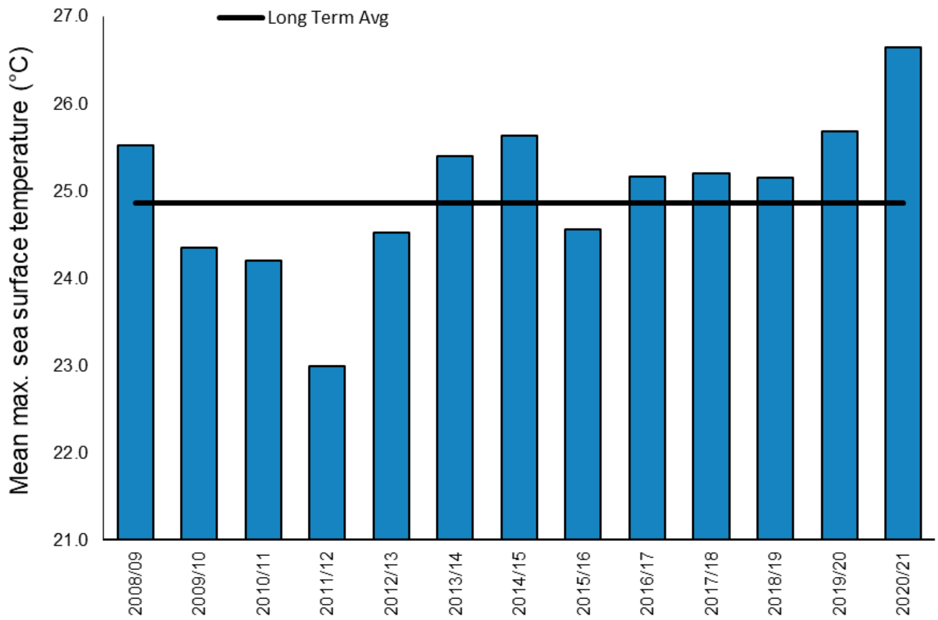

Figure 22a. Mean annual maximum sea surface temperature (°C) recorded at Hay Point 2008/09-2020/21. Source: QLD Department of Environment and Science

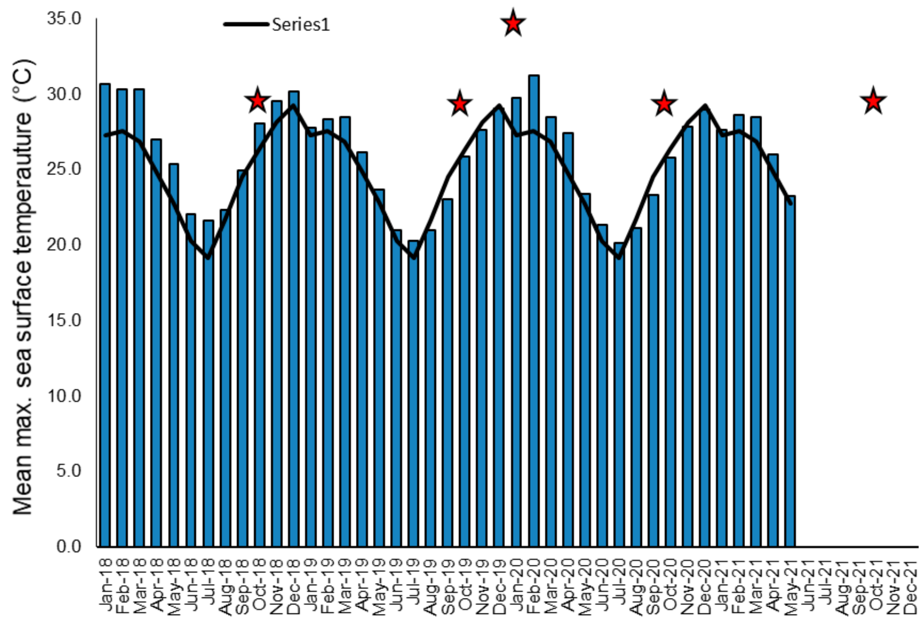

Figure 22b. Monthly maximum sea surface temperature (°C) recorded at Hay Point; January 2018 to May 2021. Source: QLD Department of Environment and Science

Daily solar radiation

Solar exposure in the Hay Point area in the twelve months to the 2020/21 survey was below the regional long-term average (20.70 MJ m^{-2}) (Figure 23a). This annual mean was mainly due to below average monthly exposure in December 2020, January and April 2021. Monthly exposure was very close to the long-term average in the five months preceding the annual survey in October 2021 (Figure 23b).

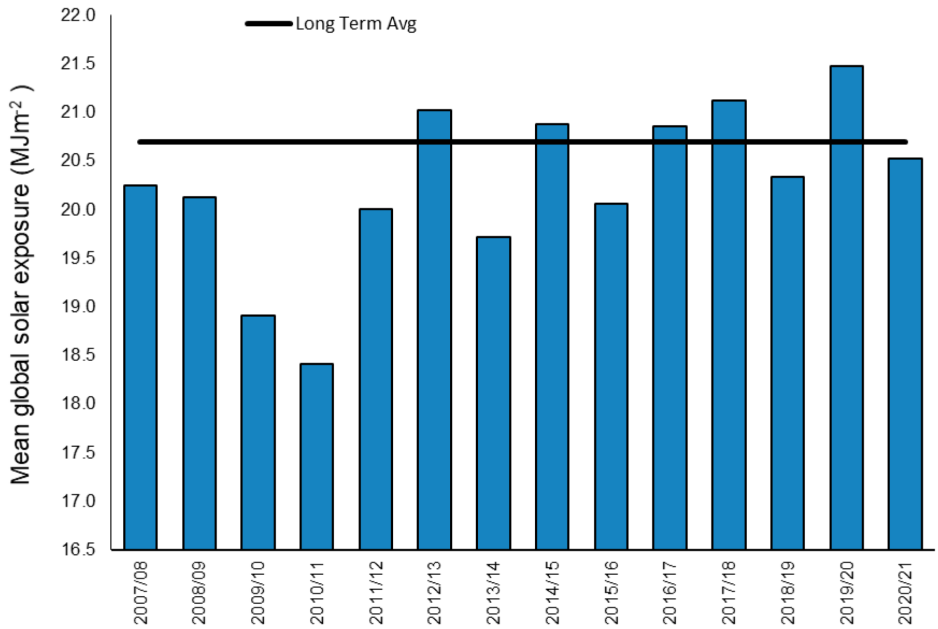

Figure 23a. Mean annual solar radiation (MJm^{-2}) recorded Mackay Aero (Station 033045) 2008/09 – 2020/21. Source: BOM

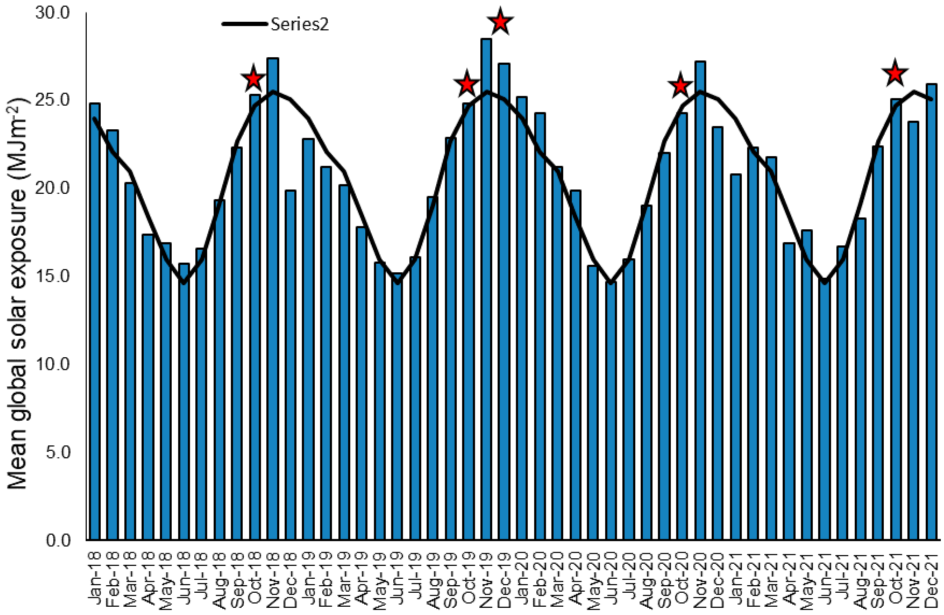

Figure 23b. Mean monthly daily global solar exposure (MJ m^{-2}) recorded at Mackay Aero (Station 033045) January 2018-December 2021. Source: BOM.

Significant wave height

Significant wave height data is only currently available for the period up to the end of May 2021, four months prior to the survey. The highest mean maximum monthly wave height of 1.30 m was recorded in February 2021, with the lowest of 0.86 recorded in March 2021 (Figure 24). The general trend in the period of recorded wave height prior to the annual survey was of monthly mean maximum wave heights close to or well below the long-term monthly averages for the area with the exception of February 2021 (Figure 24).

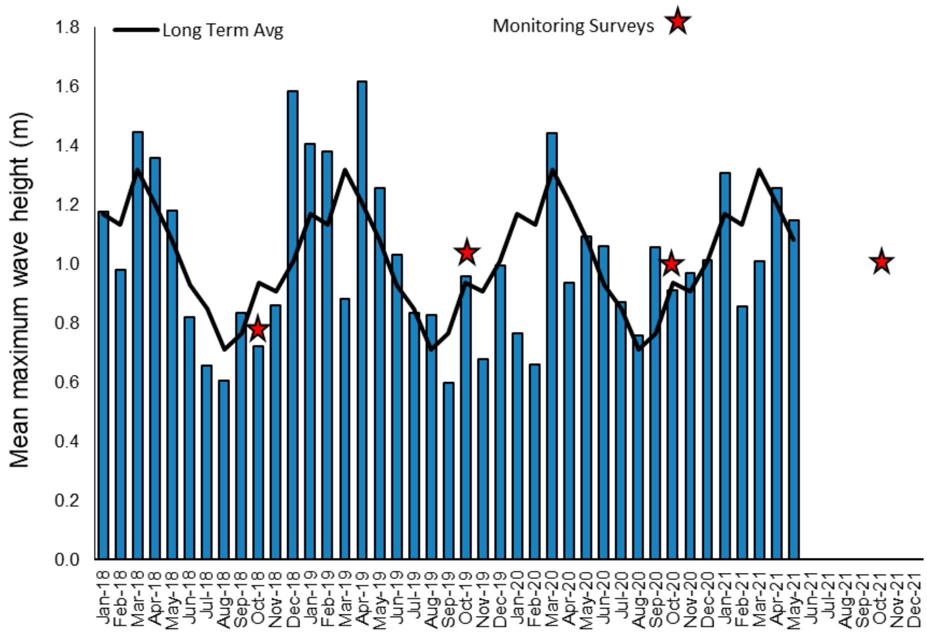

Figure 24. Mean monthly maximum wave height (m) recorded at Hay Point, January 2018-June 2021. Source: QLD Department of Environment and Science.

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. PAR was collected near and at the same depth as offshore seagrass meadows at Round Top Island (PAR light loggers - Figure 5). PAR was only available up until the end of June 2021 and showed a general seasonal trend with low benthic light availability from January through to July 2021 (Figure 25). During this period light levels are generally below the threshold for healthy growing conditions for *Halophila* species in the region (McKenna et al. 2015), and this coincides with the period where deep-water seagrass is usually in its senescent period at Hay Point (York et al. 2015).

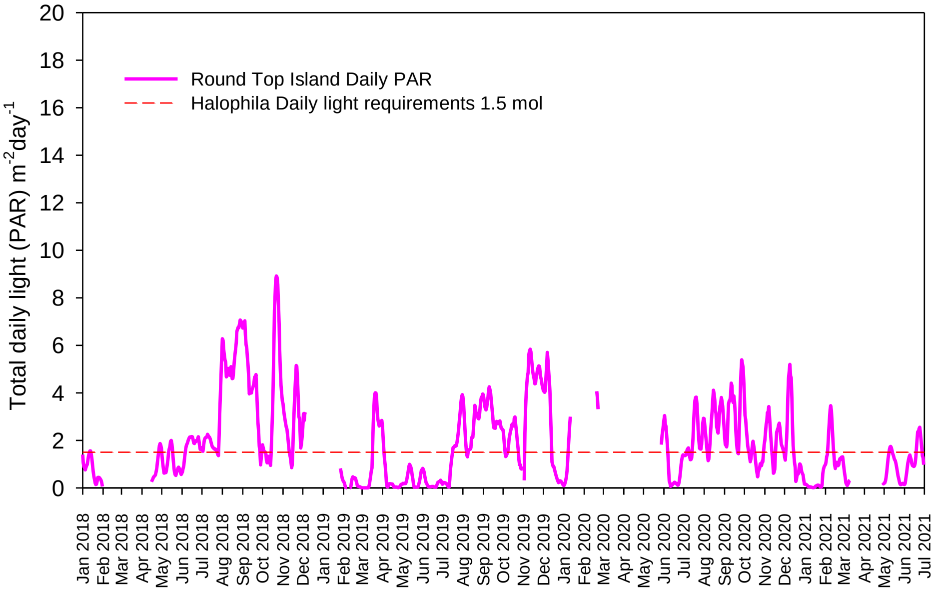

Figure 25. Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1}) at Round Top Island. Data presented from January 2018 to July 2021. Source: Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program (Waltham et al. 2021).

4 DISCUSSION

The overall condition of seagrass meadows in the Hay Point-Mackay region in 2021 was classified as good which represents an improvement from satisfactory in 2020. Seagrass condition, however, varied among monitoring locations. The general trend across all monitoring meadows was of an expanding footprint of seagrass (increased area) with reduced abundances (lower biomass) often occurring concurrently at some locations. The deep-water meadows offshore from Hay Point and Mackay both underwent large increases in meadow area in 2021, however, there was a contrast in status of their biomass with the Mackay meadow dominated by *H. spinulosa* increasing in biomass while the Hay Point meadow dominated by the highly variable *H. decipiens* underwent a large decline in biomass across its expanded footprint compared to the previous year. The coastal meadow at Dudgeon Point also increased in area and biomass in 2021. The increase in the size of all of these meadows indicates sustained favourable growth conditions allowing for the spread of seagrass into new areas. The contrast in biomass responses among these meadows may reflect variability in shorter-term environmental conditions with *H. decipiens* in the Hay Point offshore meadow being less resilient than the species in the other two meadows and responding much more quickly to local variability in water quality which may have fluctuated immediately prior to the survey (Kilminster et al. 2015).

Seagrass meadows at Keswick Island and St Bees Island remained in good and satisfactory condition respectively indicating continued favourable growing conditions in this region in 2021. At both of these locations the area of the meadows increased, however mean biomass declined from the very high values of the previous year. The general improved trend in seagrass condition in the Mackay-Hay Point region from poor in 2017 and 2018 following TC Debbie to good in 2021 coincides with a period in the region where no large-scale disturbances such as cyclones and floods have occurred for over four years. This has likely allowed for the meadows to build resilience in the form of stored carbohydrate reserves within plant structures and seedbanks within marine sediments to help withstand short-term adverse events in the future.

The seagrass habitats in the Hay Point-Mackay region are known to be highly variable and assemblages are dominated by colonising and opportunistic species (Kilminster et al. 2015) that are adapted to surviving in low light conditions (Josselyn et al. 1986, McKenna et al. 2015, Chartrand et al. 2017). When conditions for seagrass growth are unfavourable these colonising species, consisting of mainly *H. decipiens, H. tricostata* and *H. spinulosa,* 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 for other larger seagrass species (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). 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 Mackay-Hay Point long-term monitoring program is 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 Whitsunday Issac 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 2021. Coastal areas to the north and south of the Hay Point-Mackay region had seagrass in good condition (e.g. Gladstone – Smith et al. 2022; Abbot Point – York et al. 2022; Cairns Harbour - Reason et al. 2022; and Townsville – McKenna et al. 2022). In contrast the estuarine habitat in Trinity inlet was in poor condition (Reason et al. 2022). Seagrass in the Gulf of Carpentaria in Weipa and Karumba were in a good and very good condition (McKenna et al. 2021; Scott et al. 2022).

Ongoing development of seagrass condition indices

This is the fifth year of the 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, Abbot Point, Townsville, Mourilyan, Cairns, Karumba, Weipa and Thursday Island) and the information will continue to be incorporated into the Mackay Whitsunday Isaac Healthy Rivers to Reef Partnership report card.

For the Hay Point offshore seagrass the long-term averages for meadow indicator conditions have now established a permanent baseline with 10 years of data available in 2021. The Dudgeon Point and Keswick and St Bees Islands monitoring areas have now established an interim 8-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). The Mackay offshore seagrasses were monitored for the fifth time in 2021 and an interim score for this area was assigned for the first time. The interim baseline conditions will continue to change for this meadow until a 10-year baseline is settled upon in 2026.

Conclusion

Seagrasses in the Hay Point – Mackay – Keswick Island region are in good condition in 2021, however, there was considerable variability of condition among different seagrass habitat types and locations. This represents an increase in overall condition from satisfactory in 2020. Individual meadow conditions ranged from very good for the Mackay Offshore meadow; good for Keswick Island and Dudgeon Point meadows; satisfactory for St Bees Island; and poor for the Hay Point offshore meadow. The overall good condition in the Mackay-Hay Point region is sustained by the weather and climate conditions which were generally favourable for seagrass growth during the year with no major storms or floods. The good condition of seagrass in locations to the north (Abbot Point and Townsville) and south (Gladstone) indicate that local to regional scale factors have influenced the condition of the Hay Point-Mackay region in 2021.

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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 10 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 8 years of data for biomass, area and species composition (2014-20). Baseline conditions for Mackay Offshore measdow were established from annual means calculated from 5 years of data for biomass, area and species composition (2017-20).These baselines were set based on results of the Gladstone Harbour report card (Carter et al. 2015). The 2004–2020 period incorporates a range of conditions present in the Hay Point region, including El Niño and La Niña periods, and multiple extreme rainfall and river flow events. Once the monitoring program has collected over 10 years of data, the 10 year long-term average will be used in future assessments. This will be reassessed each decade.

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

Meadow Classification

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

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

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

Threshold Definition

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

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

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

Grade and score calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows for the Hay Point region (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 2021 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.

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 2021 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).

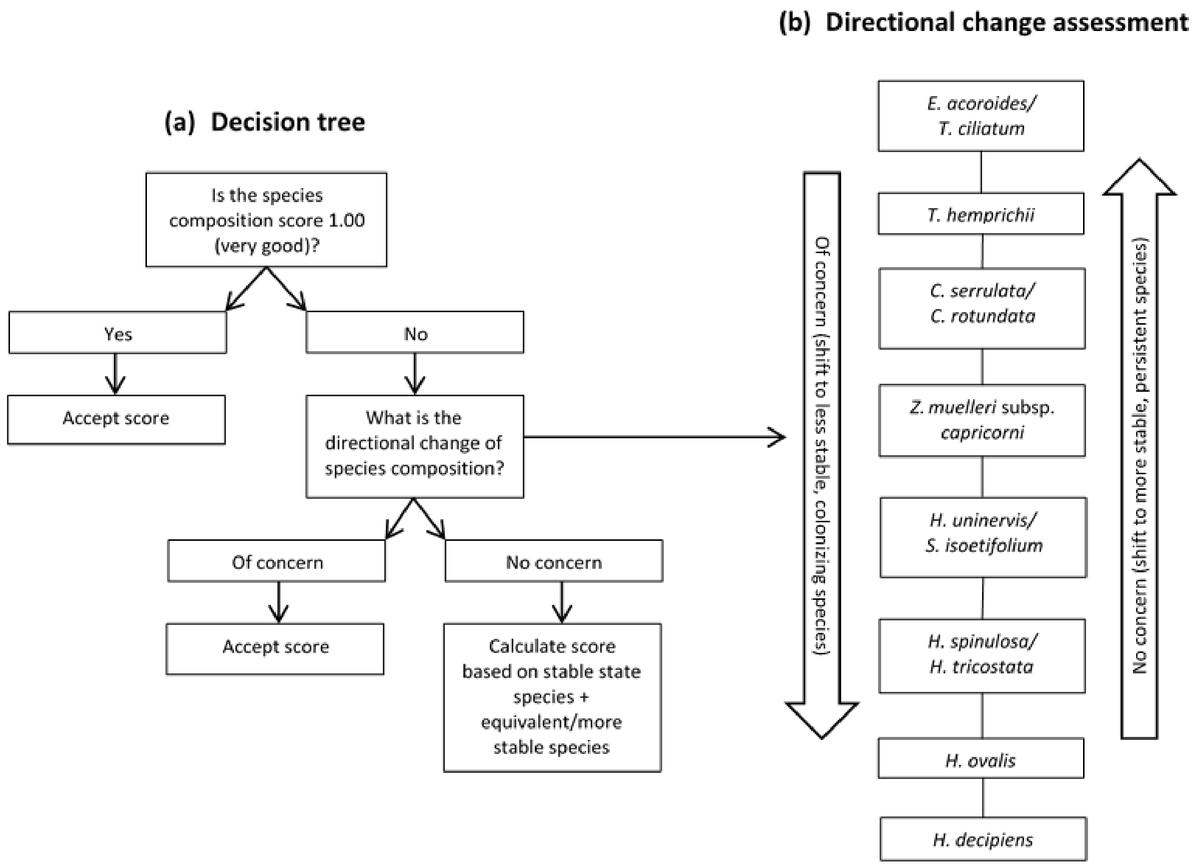

Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Hay Point.

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 2021 (current) biomass value (i.e. satisfactory).

2. Calculate the difference in areas (A_{diff}) between the 2021 area value (A_{2021}) and the area value of the lower threshold boundary for the satisfactory grade ($A_{satisfactory}$):

$$A_{diff} = A_{2020} - A_{satisfactory}$$

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 2021 ($Score_{2021}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$Score_{2021} = LA_{satisfactory} + \left(B_{prop} \times SR_{satisfactory}\right)$$

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

Appendix 2. 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 areas.

Meadow ID	Meadow location	Community type	Mean meadow biomass ($gDWm^{-2} \pm SE$)	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**
October 2020				
5	Offshore	Light *H. decipiens* with *H. spinulosa*	0.077 ± 0.0137	1871.6 ± 306.6
8	Offshore	Light *H. decipiens*	0.041 ± 0.004	736.9 ± 258.2
Total				**2608.5 ± 564.8**
September 2021				
5	Offshore	Light *H. spinulosa* with *H. decipiens*	0.203 ± 0.080	2215.7 ± 213.0
8	Offshore	Light *H. decipiens*	0.011 ± 0.006	5216.6 ± 618.2
Total				**7432.3 ± 831.2**

Table A5. Seagrass community type, mean above-ground biomass and meadow area in the Dudgeon Point - Hay Point annual survey areas, 2010 – 2021.

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	Inshore	Light *Halodule uninervis* with *H. ovalis*	Not assessed	12.2 ± 4.9
20	Inshore	Light *Halodule uninervis*	Not assessed	36.5 ± 12.2
			Total	**48.7 ± 17.1**
November 2011				
1	Inshore	Light *Halodule uninervis*	Not assessed	4.3 ± 1.9
20	Inshore	Light *Halodule uninervis*	Not assessed	6.3 ± 1.9
			Total	**10.6 ± 3.8**
October/November 2014				
1	Inshore	Light *H. uninervis* with *Z. muelleri* & *H. ovalis*	1.96 ± 1.14	9.0 ± 1.8
20	Inshore	Not present	-	-
			Total	**9.0 ± 1.8**
October 2015				
1	Inshore	Light *Halodule uninervis* (wide) with *H. decipiens*	1.72 ± 0.23	13.7 ± 1.3
20	Inshore	Not present	-	-
			Total	**13.7 ± 1.3**
October/November 2016				
1	Inshore	Moderate *Halodule uninervis* (wide)	5.60 ± 0.76	9.6 ± 2.0
20	Inshore	Not present	-	-
			Total	**9.6 ± 2.0**
October 2017				
1	Inshore	Light *Halodule uninervis* (wide)	2.42 ± 1.20	9.3 ± 2.3
20	Inshore	Not present	-	-
			Total	**9.3 ± 2.3**
October 2018				
1	Inshore	Light *H. uninervis* (wide) *with H. ovalis*	1.09 ± 0.35	22.6 ± 4.2
20	Inshore	Not present	-	-
			Total	**22.6 ± 4.2**
October 2019				
1	Inshore	Light *H. uninervis* with *Z. muelleri* /*H. decipiens*	3.01 ± 0.72	17.0 ± 3.8
20	Inshore	Light *Halodule uninervis*	0.72 ± 0.72	1.7 ± 1.1
			Total	**18.7 ± 4.9**
October 2020				
1	Inshore	Light *Halodule uninervis* with *H. uninervis*	1.76 ± 0.62	8.6 ± 3.3
20	Inshore	Not present	-	-
			Total	**8.6 ± 3.3**
September 2021				
1	Inshore	Light *Halodule uninervis* with *H. uninervis*	3.66 ± 1.12	15.7 ± 4.3
20	Inshore	Not present	-	-
			Total	**15.7 ± 4.3**

Table A6. Seagrass community type, mean above-ground biomass and meadow area in the Keswick Island and St Bees Island annual survey areas, 2014 – 2021.

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 *H. 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 *H. tricostata with H. decipiens*	1.37 ± 0.15	197.3 ± 42.9
14	Inshore	Light *H. tricostata with H. spiniulosa / H. decipiens*	1.63 ± 0.35	14.2 ± 4.2
			Total	**211.5 ± 47.1**
October 2020				
10	Inshore	Light *Halophila tricostata with H. spinulosa*	2.90 ± 0.63	140.4 ± 36.5
14	Inshore	Light *Halophila spinulosa / H. tricostata*	3.96 ± 1.23	14.2 ± 3.8
			Total	**154.6 ± 40.3**
September 2021				
10	Inshore	Light *H.tricostata with H. decipiens*	1.04 ± 0.17	191.8 ± 41.1
14	Inshore	Light *Halophila spinulosa / H. tricostata*	1.33 ± 0.27	22.5 ± 5.4
			Total	**206.0 ± 46.5**

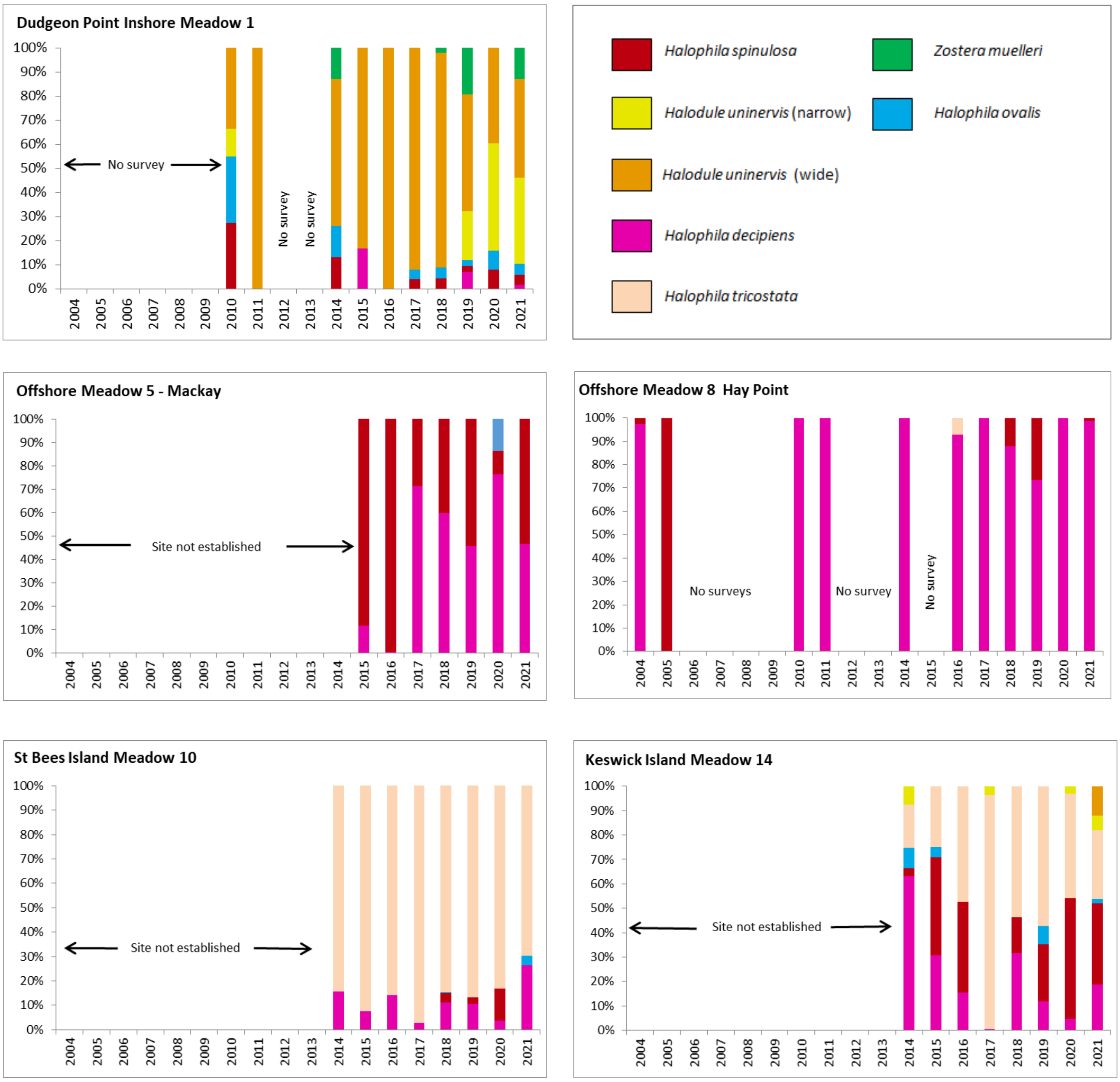

Figure A2: Species composition of monitoring meadows in the Hay Point-Mackay region, and the Keswick Island group.