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Annual Seagrass Monitoring in the Mackay – Hay Point Region 2023

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CONTENTS

1 KEY FINDINGS

Seagrass Condition 2023

Likely causes of seagrass condition:

↑ *Favourable light conditions for most of the year.*

↑ *Wave height (RMS) above long-term average in the months leading up to survey.*

- This report compiles findings of the annual Hay Point-Mackay long-term seagrass monitoring conducted in September-December 2023.
- Seagrass remained in an overall satisfactory condition in the Hay Point-Mackay region in 2023 when measured against expected baseline conditions.
- There was some variability between the different monitoring meadows and indicators.
    - All indicators for all meadows were in satisfactory or better condition in 2023 with the exception of biomass for the St Bees Island deepwater meadow.
    - The offshore Mackay deepwater meadow, was in very good condition for the second time since monitoring began at the location 7 years ago.
    - The coastal monitoring meadows around Dudgeon Point had improved from poor condition in the previous year.
    - Outside of the port limits, the offshore Keswick and St Bees Island's meadows both underwent declines in biomass during 2023.
- Seagrasses in the broader Hay Point port limits (monitored every 3 years) found similar seagrass distribution to previous surveys of this extent and a substantial area of offshore and inshore seagrasses in addition to the annually monitored meadows.
- A detailed survey of the Half Tide Tug Harbour found the seafloor was dominated by mostly bare unvegetated sediment with a small (~1 ha) seagrass meadow in the northwestern corner.
- The maintenance of seagrasses in a satisfactory condition in 2023 occurred in the absence of any exceptional climate or weather events that were likely to have had a major impact on seagrasses. Based on their condition, seagrasses in Hay Point/Mackay were likely to have a reasonable level of resilience in the coming year to future stressors and impacts.

2 IN BRIEF

A long-term seagrass monitoring program and strategy was developed for the Mackay-Hay Point area following a broad-scale extended survey of the region in 2014 and incorporates seagrass monitoring information that has been collected dating back to 2004 for the Hay Point. This annual monitoring strategy 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 (Figure 1). Seagrass meadows in these areas represent the range of different seagrass community types found in the Mackay-Hay Point region.

In addition to the annually monitored seagrass meadows an extended survey of seagrasses in the broader Hay Point port limits was also conducted in 2023 as part of scheduled three yearly assessments of seagrasses in the broader region. A detailed seagrass survey of the Half Tide Tug Harbour region was also included in the 2023 seagrass assessments and will be included in the standard annual monitoring area moving forward.

Overall seagrass condition of the Hay Point monitoring region was satisfactory in 2023 compared with expected baseline conditions. This maintained the overall condition of seagrasses from the previous year. There was some variability in condition between different meadows and indicators. The inshore Dudgeon Point coastal meadows increased in area in 2023, recovering from poor condition the previous year. The offshore deep-water Hay Point meadow (Meadow 8) continued to be highly variable from year to year in biomass, area and footprint and was in an overall satisfactory condition in 2023, while the Mackay meadow (Meadow 5) was in very good condition. Outside of the port limits the deepwater seagrass meadows at Keswick and St Bees Islands had declined in biomass in 2023, with the St Bees Island seagrasses (Meadow 10) declining to be the only meadow in poor condition in the monitoring program in 2023.

In the broader Hay Point port limits substantial areas of seagrass were mapped in both coastal and offshore areas of the port in addition to the annually monitored meadows (Figure 1). Area of seagrasses in this broader survey footprint was larger than the previous two broadscale surveys (2020 and 2017) and was a good indication of healthy seagrasses in the broader port region.

The additional survey area in the Half Tide Tug Harbour (HTTH) area found the majority of the seafloor dominated by open substrate with a small area (~1ha) of the seagrass species *Halophila decipiens.* This is the lowest light requiring species found in the Mackay/Hay Point monitoring region and is typically highly variable in its presence from year to year.

In 2023 environmental conditions were generally close to their long-term averages. Light levels (benthic PAR) recorded near offshore meadow areas were generally above the growth requirements for *Halophila* leading up to the 2023 survey and explain why the highly variable *Halophila* spp. were able to increase in distribution in the region. While there was significant amounts of rainfall and river flow in January 2023, this was seven months before the annual monitoring survey and unlikely to have impacted the seed bank and the standing biomass of the fast-growing *Halophila* and *Halodule* species that were mapped during the 2023 survey. Studies have found that during the wet season, or after a significant climate event (i.e. Cyclone) *Halophila* seed banks prevail, providing a source of propagules for re-colonisation following the unfavourable growing conditions (Chartrand et al. 2021; Hovey et al. 2015). Significant wave height measured in offshore waters was higher than average in 2023. It is possible that this could have resulted in negative physical impacts on Hay Point and Keswick & St Bees deepwater seagrass through direct removal and burial. These meadows (the meadows that had declines) grow in and occupy areas where the sediment typically has higher proportions of mud, silt and clay compared to the area offshore from Mackay (offshore meadow that didn't decline) that is dominated by more sandy/rubbly sediment. Fine sediments appear to have a greater negative effect on shoot density in *Halophila* species, compared to coarser sandy sediments (Benham et al. 2019). Increased deposition of

sediment (via higher RMS wave shear stress) on small seagrass species like the *Halophila* genus can lead to abrasion of leaves, removal of plants and limited recruitment and growth because of the stability of surface sediments etc. (Benham et al. 2019). The higher RMS values seen throughout 2023 could have led to some loss of above-ground seagrass biomass in these offshore meadows that occupy more silty sediment.

Seagrass monitoring in other locations of the Queensland coast have found similar results in 2023 with seagrasses to the north in the Bowen/Abbot Point region in satisfactory condition and to the south shallow coastal seagrasses in the Clairview region and Gladstone were in a good condition in 2023. For full details of the Queensland ports seagrass monitoring program see: https://www.tropwater.com/themes/seagrass-habitats

The condition of seagrasses in the Mackay - Hay Point region in 2023 meant they were likely to have a reasonable level of resilience in the coming year to future stressors and impacts.

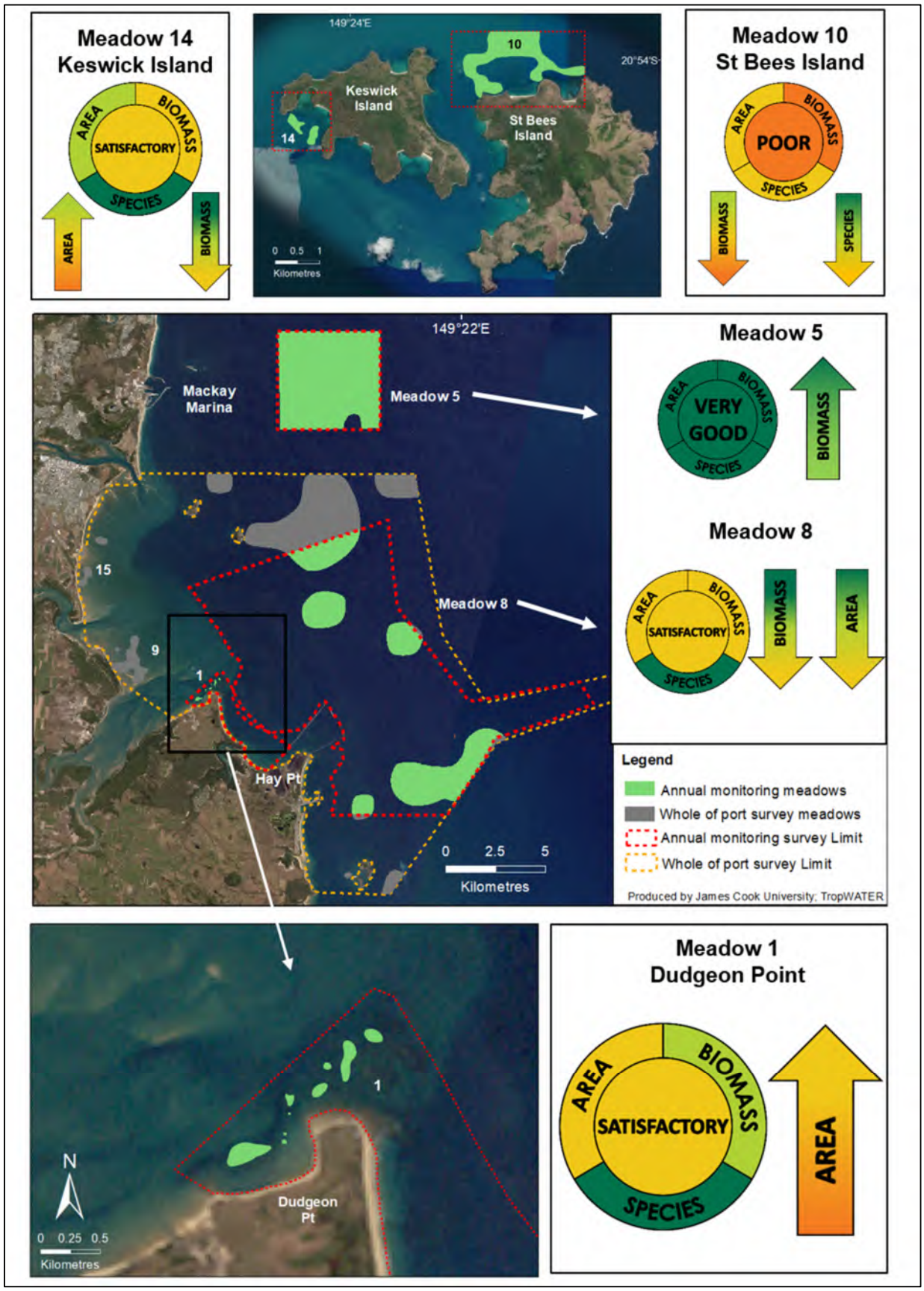

Figure 1. Seagrass meadow condition for the ports of Mackay, Hay Point, Keswick and St Bees Island 2023.

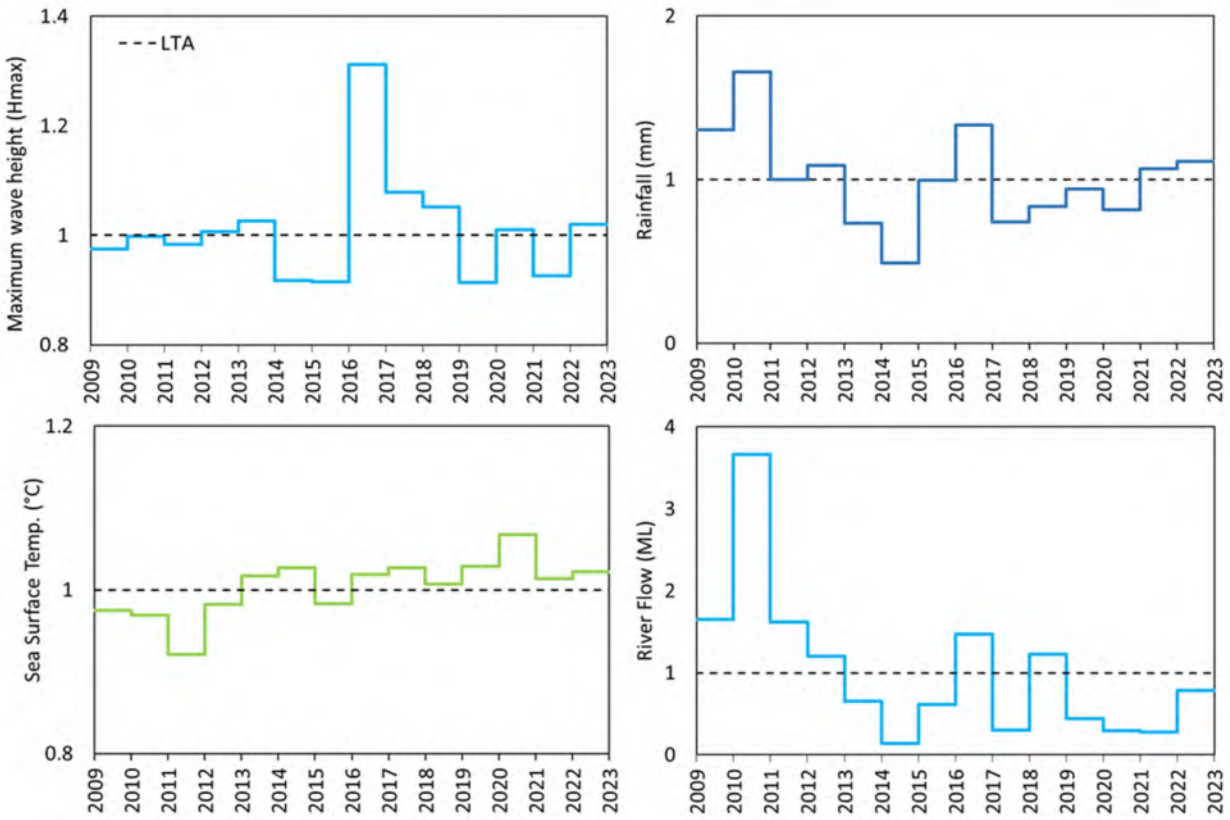

Figure 2. Recent climate trends in the Hay Point and Mackay Area: change in climate variables as a proportion of the long-term average (LTA) over the last 14 years (2009 – 2023). Black dotted line represents the long-term average (LTA). See section 6.2 for detailed climate data.

3 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).

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 are used to provide a network of seagrass monitoring locations throughout the state (Figure 3).

3.1 Queensland Ports Seagrass Monitoring Program

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/

Figure 3. Location of Queensland Port Seagrass assessment sites.

3.2 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, 2017 and 2020), 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. There was also a change in approach to annual monitoring of the highly variable offshore seagrasses at Hay Point, from focusing on the fixed blocks to a more expansive meadow scale assessment based on the 2004 survey limit to incorporate change in seagrass area to the assessment (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.

In 2023, an extended broad-scale survey of the Hay Point port limits area was conducted as part of regular three yearly assessments of the broader port area in conjunction with the annual monitoring program (Figure 4). The previous broad-scale survey was in 2020. This report presents the findings of the annual seagrass

habitat monitoring survey conducted in September/December 2023 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.
- Conduct additional assessments of seagrasses within the Half Tide Tug Harbour area.
- Discuss the implications of monitoring results for overall health of the Mackay-Hay Point marine environment and provide advice to relevant management agencies.

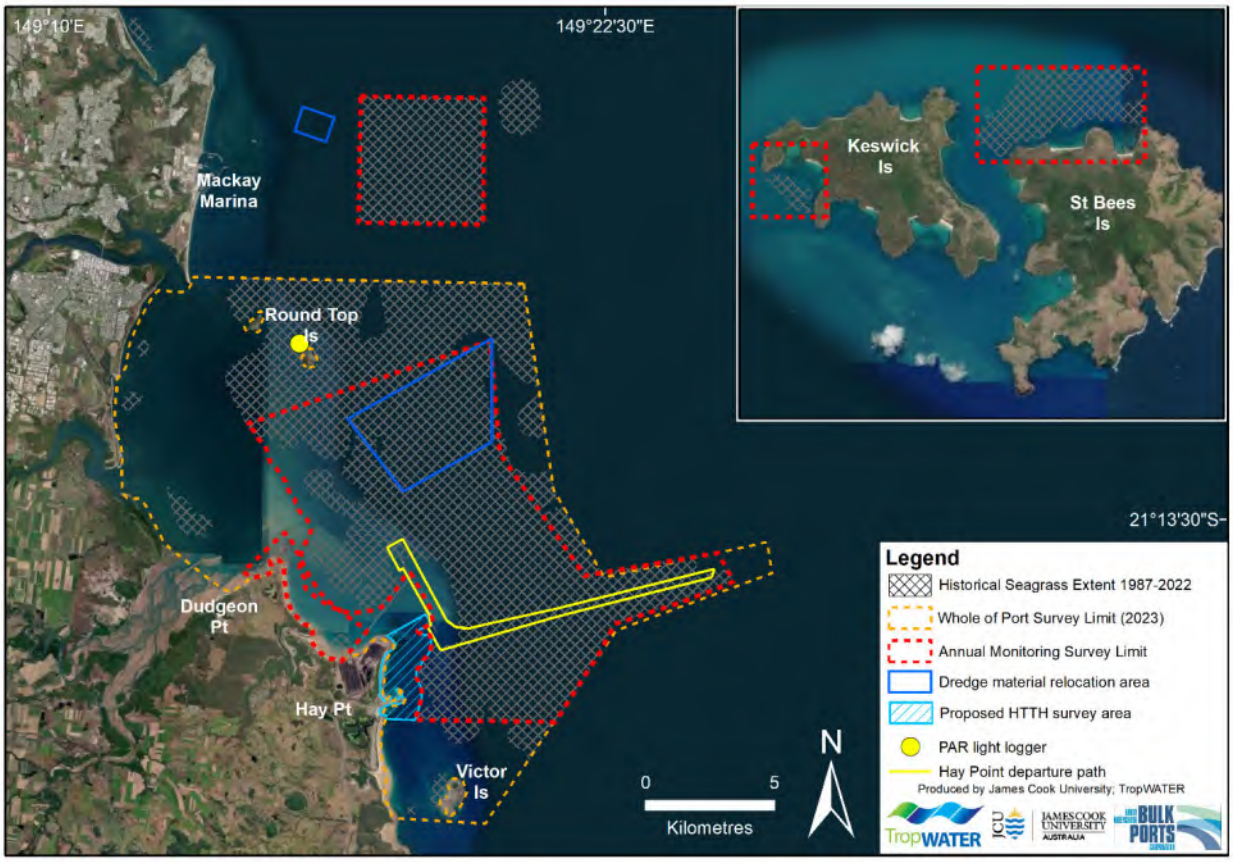

Figure 4. Location of survey limits of annual and extended seagrass monitoring areas around Mackay, Hay Point and the Keswick Island group in 2023 and the newly added seagrass assessment area at the Half Tide Tug Harbour (HTTH).

4 METHODS

4.1 Sampling Approach

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 of seagrass communities within the Hay Point-Mackay region (including Keswick and St Bees Islands) were conducted in September and December 2023 (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, Clairview, 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.

NQBP have recently amended their environmental approvals for the Half Tide Tug Harbour (HTTH) to increase the area approved for maintenance dredging (Figure 4). As part of this NQBP have committed to annual seagrass monitoring in and around (200m buffer) the new maintenance dredging area and this area was surveyed for seagrass in 2023. To align with the current seagrass condition monitoring and reporting approach, the HTTH survey area extended from the HTTH to the Hay Point Terminal jetty (southern jetty) (Figure 5). This inshore area will be incorporated into the existing seagrass program and form an additional inshore monitoring area, similar to the existing inshore monitoring area between Hay Point Terminal 'northern' jetty and Dudgeon Point (Figure 4).

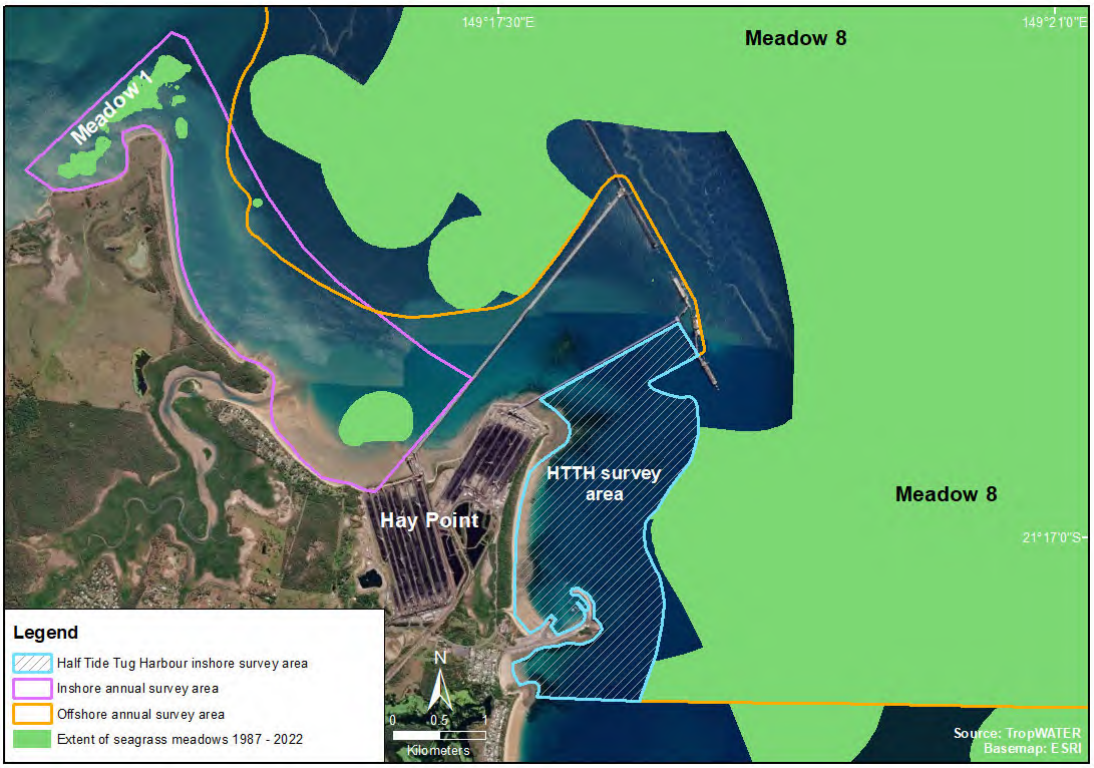

Figure 5. Half tide Tug Harbour inshore monitoring area 2023

4.2 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:

- Intertidal areas: Walking at low tide.
- Subtidal inshore areas <8m below MSL: Boat based underwater digital camera mounted on a drop frame.
- 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 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 timeframes 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.

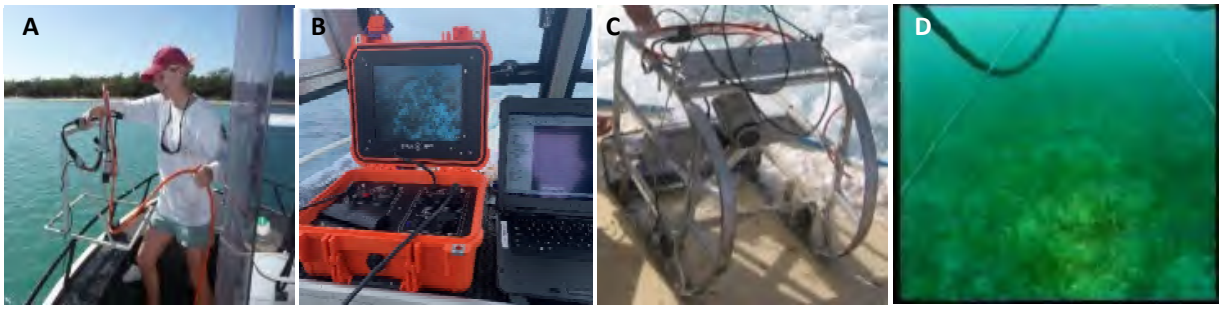

Figure 6. (**A-B**) Shallow subtidal assessments of seagrass meadows using digital camera mounted on a 0.25m^2 drop frame, and (**C-D**) offshore underwater sled tows with digital camera.

4.3 Habitat mapping and Geographic Information System

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.

- *Seagrass 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.

- *Seagrass 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 ± standard error (SE), meadow area (hectares) ± reliability estimate (R) (Table 3), number of sites within the meadow, seagrass species present, meadow density and community type (Tables 1 & 2), meadow landscape category (Figure 7).
  - Sampling method and any relevant comments.

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

Table 1. Nomenclature for Queensland seagrass community types.

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

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

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

Isolated seagrass patches

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

Aggregated seagrass patches

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

Continuous seagrass cover

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

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

Seagrass meadow boundaries were determined from a combination of techniques. Exposed inshore boundaries were guided by recent satellite imagery of the region (Source: ESRI; Google Earth). Subtidal

boundaries were interpreted from a combination of subtidal survey sites and the distance between sites, field notes, depth contours and recent satellite imagery.

Meadow area was measured using the calculate geometry function in ArcGIS®. Meadows were assigned a mapping precision estimate (in metres) based on mapping methods used for that meadow (Table 3). Mapping precision ranged from ≤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.

4.4 Seagrass meadow condition index

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline (see Carter et al. 2023 for full details). Seagrass condition for each indicator in Hay Point-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 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% (Carter et al. 2023).

4.5 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 (Cartwright et al. 2022). 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).

5 RESULTS

5.1 Seagrass in the Hay Point, Mackay, and Keswick Island long term monitoring areas

The 2023 annual monitoring survey in the Hay Point, Mackay, and Keswick Island area, surveyed a total of 512 sites (Figure 9). The survey was conducted during September through to December and seagrass was present at 27% of the coastal and offshores survey sites. The coastal areas of Keswick Island, St Bees Island and Dudgeon Point had seagrass present at 40% of the sites. The offshore survey area, which includes the Mackay offshore annual monitoring area (Meadow 5) and the Hay Point offshore annual monitoring area (Meadow 8) had seagrass present at 40 % of sites (Figure 9).

Five seagrass species were observed in 2023, and the species were typical of those found in coastal and offshore areas in Hay Point/ Mackay and more broadly in central Queensland (Figure 8; A1). The inshore meadows at Dudgeon Point were dominated by *Halodule uninervis* (wide and narrow) with a smaller amount of *Halophila ovalis* and *Halophila decipiens* (Figure 8; 10; A1). The two meadows at Keswick and St Bees Islands were dominated by *Halophila tricostata* with smaller amounts of *Halophila spinulosa*, *Halophila decipiens, H. ovalis* and *H. uninervis* also occurring (Figure 8; 10; Table A1). Deepwater seagrass assemblages offshore from Hay Point and Mackay were dominated by *H. decipiens* and *H. spinulosa* (Figure 8; 10; A1). The dominating species within the annual long-term monitoring boundaries for Meadow 8 was *H. decipiens*, while *H. spinulosa* dominated the community of the larger whole of port boundary for Meadow 8 largely due to an increase in *H. spinulosa* closer to the northern boundary.

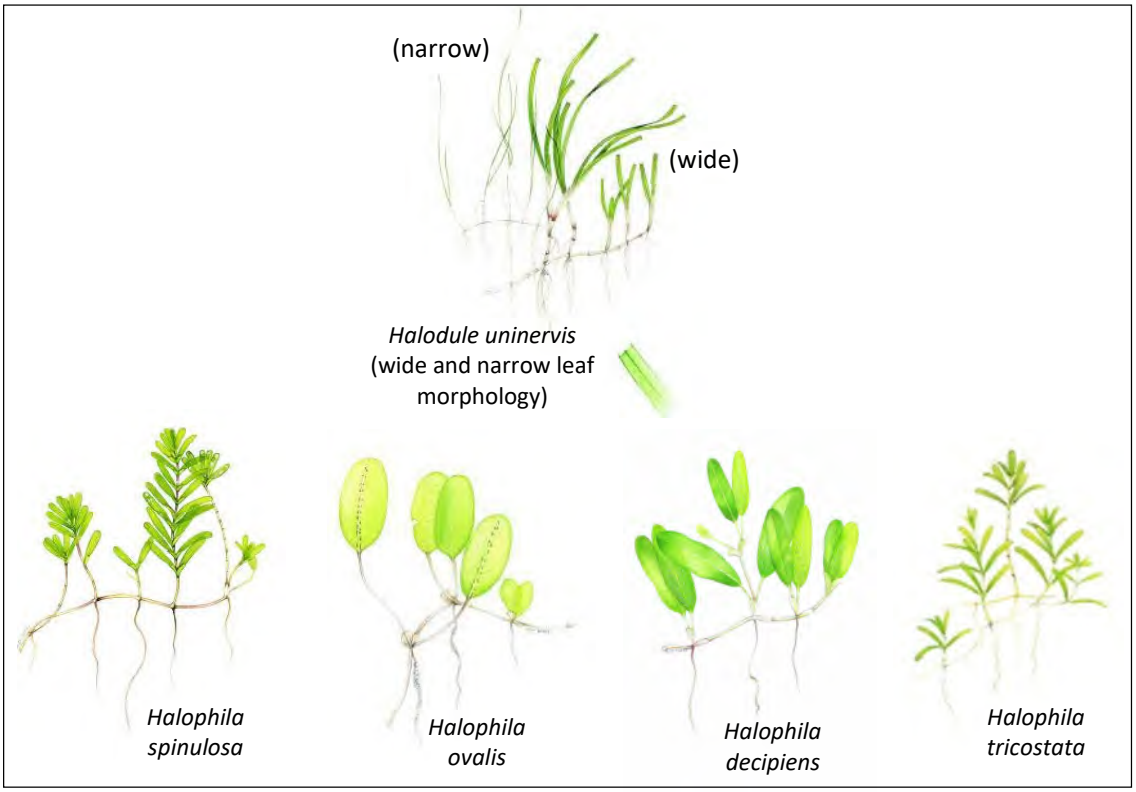

Figure 8. Seagrass species identified in the Hay Point-Mackay annual monitoring program in 2023. Leaf size varies widely within species and diagrams are not to scale.

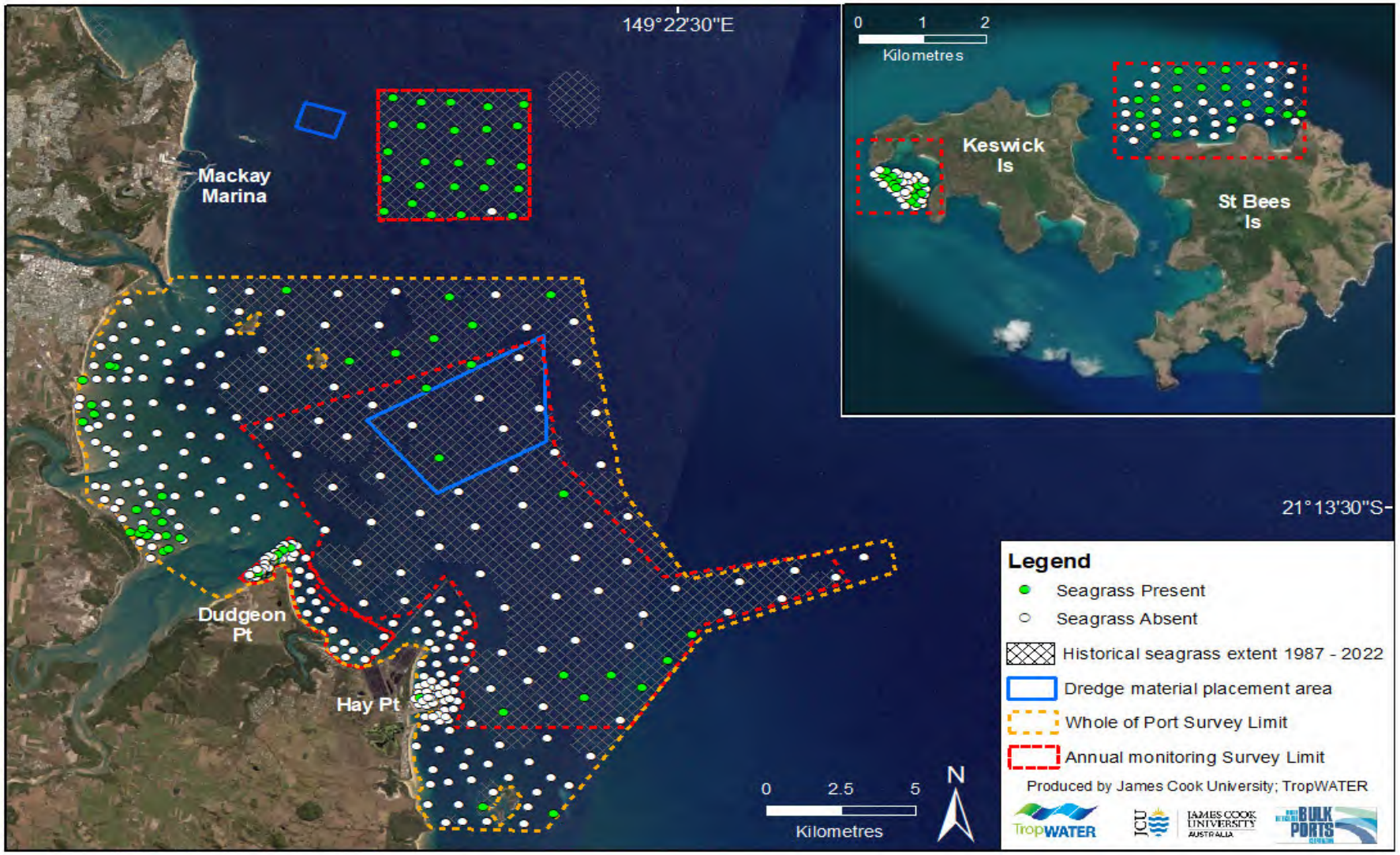

Figure 9. Location of 2023 annual and extended seagrass monitoring survey sites in the Hay Point-Mackay region.

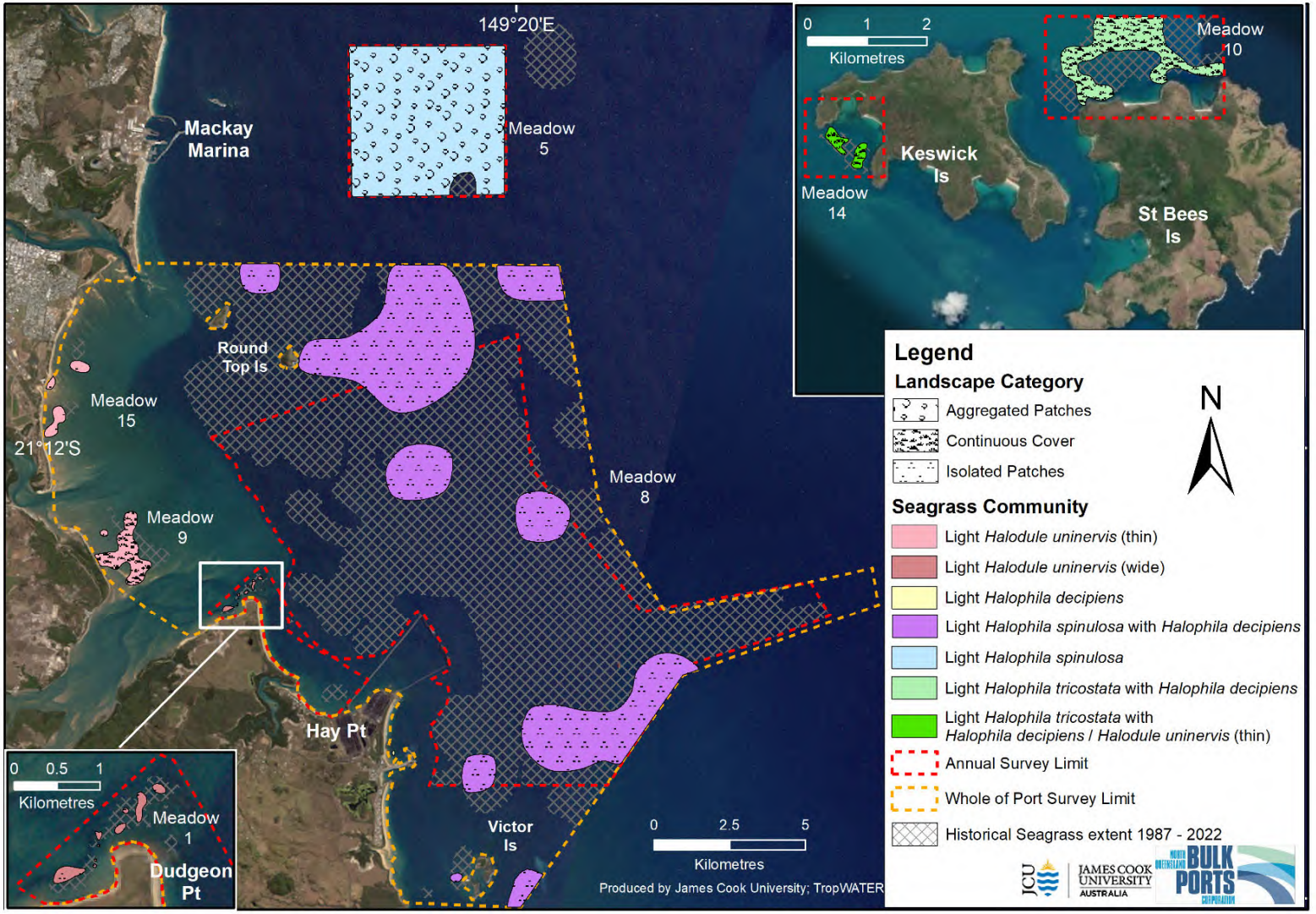

Figure 10. Location of 2023 seagrass meadows in the Hay Point region showing seagrass communities and landscape categories.

5.2 Seagrass condition in the Hay Point - Mackay region

5.2.1 Offshore seagrass at Hay Point and Mackay

The offshore deep-water Hay Point meadow (Meadow 8) continued to be highly variable from year to year in biomass, area and footprint and was in an overall satisfactory condition in 2023 (Table 4; Figure 11). In 2023 this *Halophila* meadow covered 3527 ± 647 ha in the area (Figure 11; Appendix A1). The biomass and area of the meadow were classed as satisfactory in 2023, while species composition remained in a very good state.

This meadow is dominated by the pioneering *H. decipiens*, which has been the main species in this area throughout the program's history, along with small amounts of *Halophila spinulosa* (Figure11; Figure A1).

The Offshore Mackay meadow (Meadow 5) improved in overall condition in 2023 from good to a very good condition (Table 4; Figure 12). After seven years of continuous data collection, this is the third year that a condition score has been calculated for this meadow. Biomass was the highest recorded in 2023 and improved from 0.09 ± 0.02 g DW m^2 in 2022 to 0.3 ± 0.1 g DW m^2 (Figure 12; Table A1). Seagrass was present at all but one survey site within the survey boundary, and area (2274.78 ± 205.77 ha) reduced slightly from the previous year which had the highest recorded since monitoring began in 2017 (Figure 12; Table A1). The species composition in this meadow was dominated by *H. spinulosa,* with a further shift in 2023 to *H. spinulosa* becoming more dominant (Table A1; Figure A1).

5.2.2 Inshore seagrass at Dudgeon Point

The Dudgeon Point coastal intertidal monitoring meadow (Meadow 1) improved from a poor condition to a satisfactory condition in 2023 (Table 4; Table A2). The main driver behind the improvement was an increase in area (Figure 13; Table A2). This meadow is made up of multiple small, isolated patches of seagrass dominated by *H. uninervis,* both wide and narrow leaf forms, with a small amount of *H. ovalis* and *H. decipiens*. The species composition of this meadow remained in a very good condition for the eighth year in a row, however the *Z. muelleri* that was present in 2021 has not been recorded in the last two surveys (Figure 13; Figure A1). Biomass remained in a good condition for the fifth year in a row with little change, most likely due to the persistence of the *H. uninervis* in this area (Figure 13). The footprint of this meadow is largely dictated by rock formations, pools and deeper channels that form a majority of the landscape around Dudgeon Point.

5.2.3 Keswick and St Bees Islands

The St Bees Island seagrass monitoring meadow (10) dropped to a poor condition after being satisfactory for three consecutive years (Table 4; Figure 14). Biomass of this meadow dropped from a good to a poor condition, with a 79% reduction since 2022 (Figure 14; Table A3). The species composition of this meadow dropped to satisfactory from a good condition due to an increase in the presence of *H. decipiens* in the meadow (Figure 14; Figure A1). The Keswick Island subtidal monitoring meadow (14) improved to a satisfactory condition in 2023 (Table 4; Figure 15). The area of this meadow improved by 42% to 14.6 ± 6.6 ha, changing from a poor to a good condition (Table 4; Figure 15). However, there was a concurrent 62% decrease in biomass (1.1 ± 1.08 g DW m^2) in the meadow which downgraded this indicator from very good to satisfactory (Figure 15, Table A3). The species composition of the meadow remained in a very good condition with a small increase in less dominant species like *Halophila decipiens* (Figure 15; Figure A1).

Table 4. Condition scores for the seagrass indicators (biomass, area and species composition) for the Hay Point-Mackay monitoring meadow in 2023.

Meadow #	Location	Biomass	Area	Species Composition	Overall Meadow Score
1	Dudgeon Point	0.76	0.56	0.96	0.56
5	Mackay - Offshore	1.00	0.97	1.00	0.97
8	Hay Point - Offshore	0.62	0.57	1.00	0.57
10	St Bees Island	0.40	0.57	0.60	0.40
14	Keswick Island	0.62	0.69	0.90	0.62
Overall Score for the Hay Point-Mackay region					0.62

= very good condition = good condition = satisfactory condition

= poor condition = very poor condition

5.2.4 Half Tide Tug Harbour

Marine plant assessments in the Half Tide Tug Harbour (HTTH) area revealed predominantly 'open substrate' with the majority of the area devoid of marine plants or visible habitat forming benthic macroinvertebrates. However, some sites contained seagrass and more complex habitats formed by macroalgae (McKenna & Van De Wetering 2024). Notably, a small meadow of *Halophila decipiens*, covering approximately 1.03 hectares was mapped in the south-west corner of the survey area and within the HTTH (Figure 16). This meadow featured a sparse distribution of *H. decipiens*, interspersed with macroalgae.

The HTTH survey area also contained two distinct functional groups of algae: macroalgae and turf mat algae. Turf mat algae appeared as a 'fuzz' over rocks and rubble, particularly along rock walls, while macroalgae primarily occurred on shoreline reefs or rocks. Algal coverage at surveyed sites ranged from minimal (~5%) to complete (100%) for turf mat algae at some sites along the rock wall. The total area of complex macroalgal habitats was estimated at around 2.06 hectares (see McKenna and Van De Wetering 2024)

5.2.5 Hay Point Whole of Port Survey Area

The 2023 whole of Hay Point port limits survey included additional monitoring areas to the north and south of the annually monitored regions (Figure 1; Figure 10). The survey found additional extensive offshore areas of seagrass in the vicinity of Round Top Island, extending the distribution of Meadow 8 assessed in the annual program to a total area 3,527 ± 647 ha. There were also additional smaller offshore seagrasses in the vicinity of Victor Island to the south (Figure 10). These deeper water offshore meadow areas were dominated by *Halophila spinulosa* and also contained *Halophila decipiens*.

The coastal area between Dungeon Point and the Pioneer River had a collection of inshore seagrass meadows made up of a light cover *Halodule uninervis* (thin leaf variety) (Meadows 9 & 15) with a combined area of 218.3 ha (Figure 10).

Area of seagrasses within this extended footprint was greater than for the two previous surveys that covered this extent in 2020 and 2017, for both the inshore shallow and offshore deeper water seagrasses.

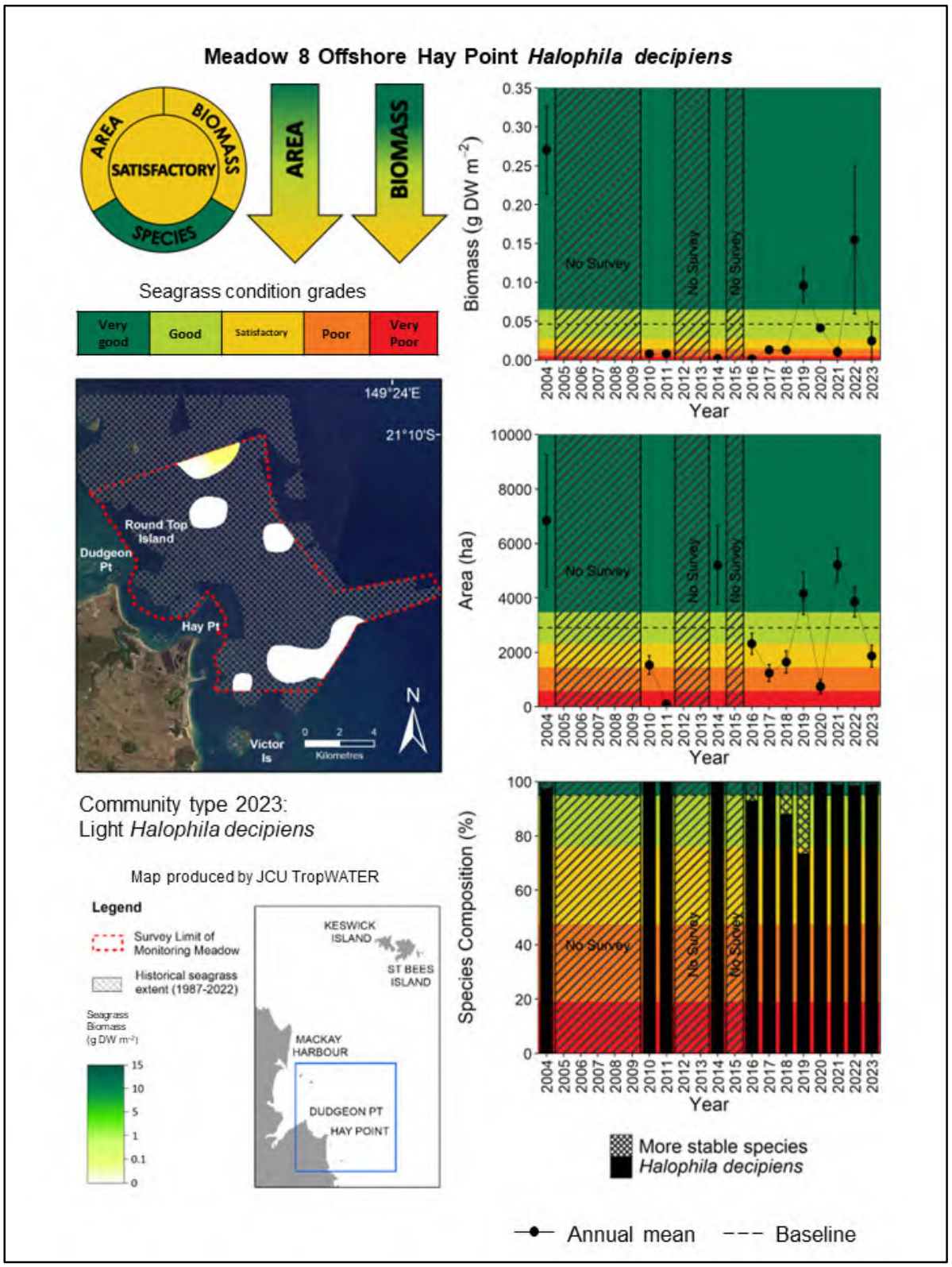

Figure 11. Changes in meadow biomass, area and species composition for seagrass in the Hay Point offshore area (Meadow 8), 2004 – 2023 (biomass error bars = SE).

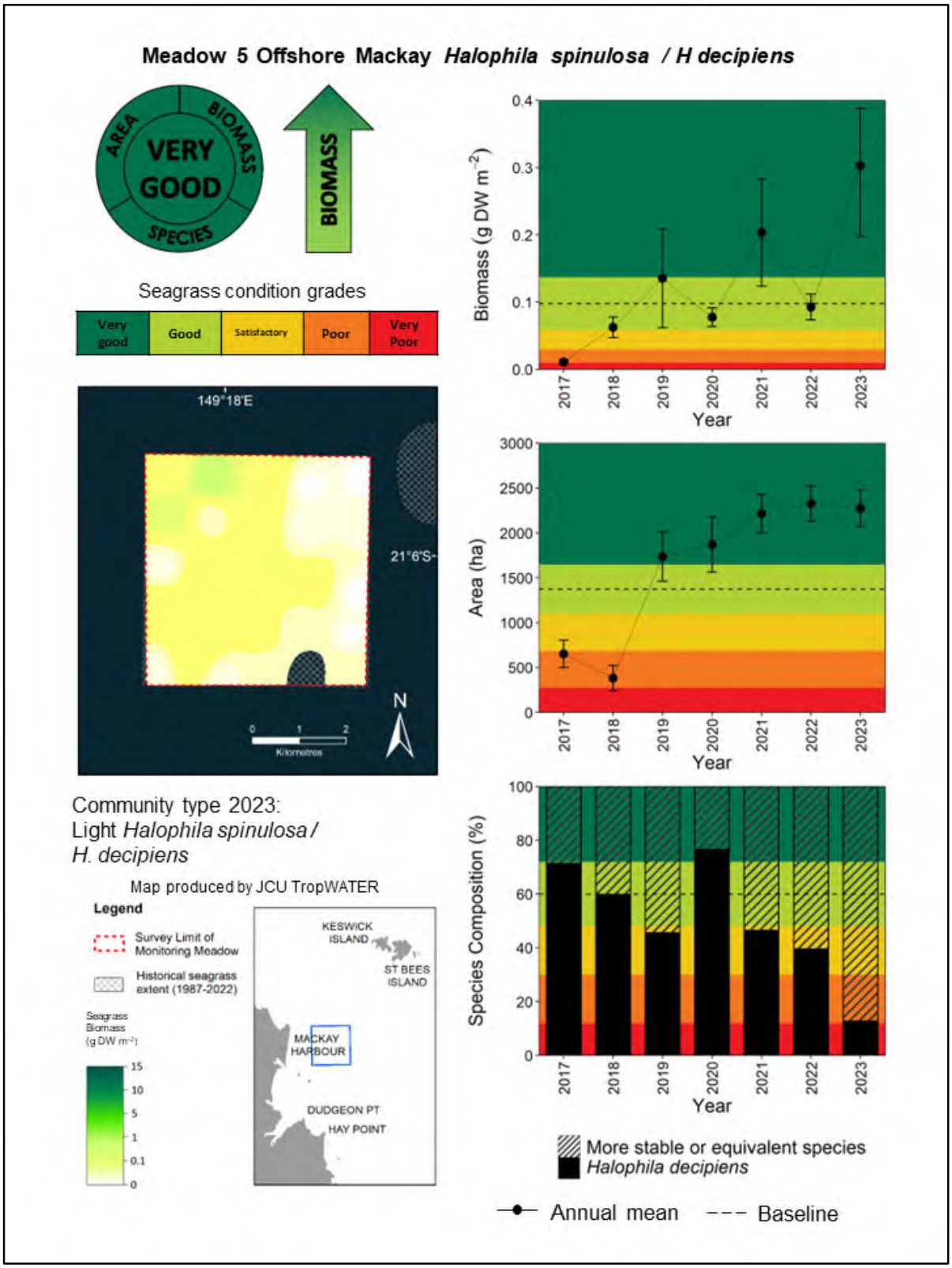

Figure 12. Changes in meadow biomass, area and species composition for seagrass in the Mackay offshore area (Meadow 5), 2017 – 2023 (biomass error bars = SE).

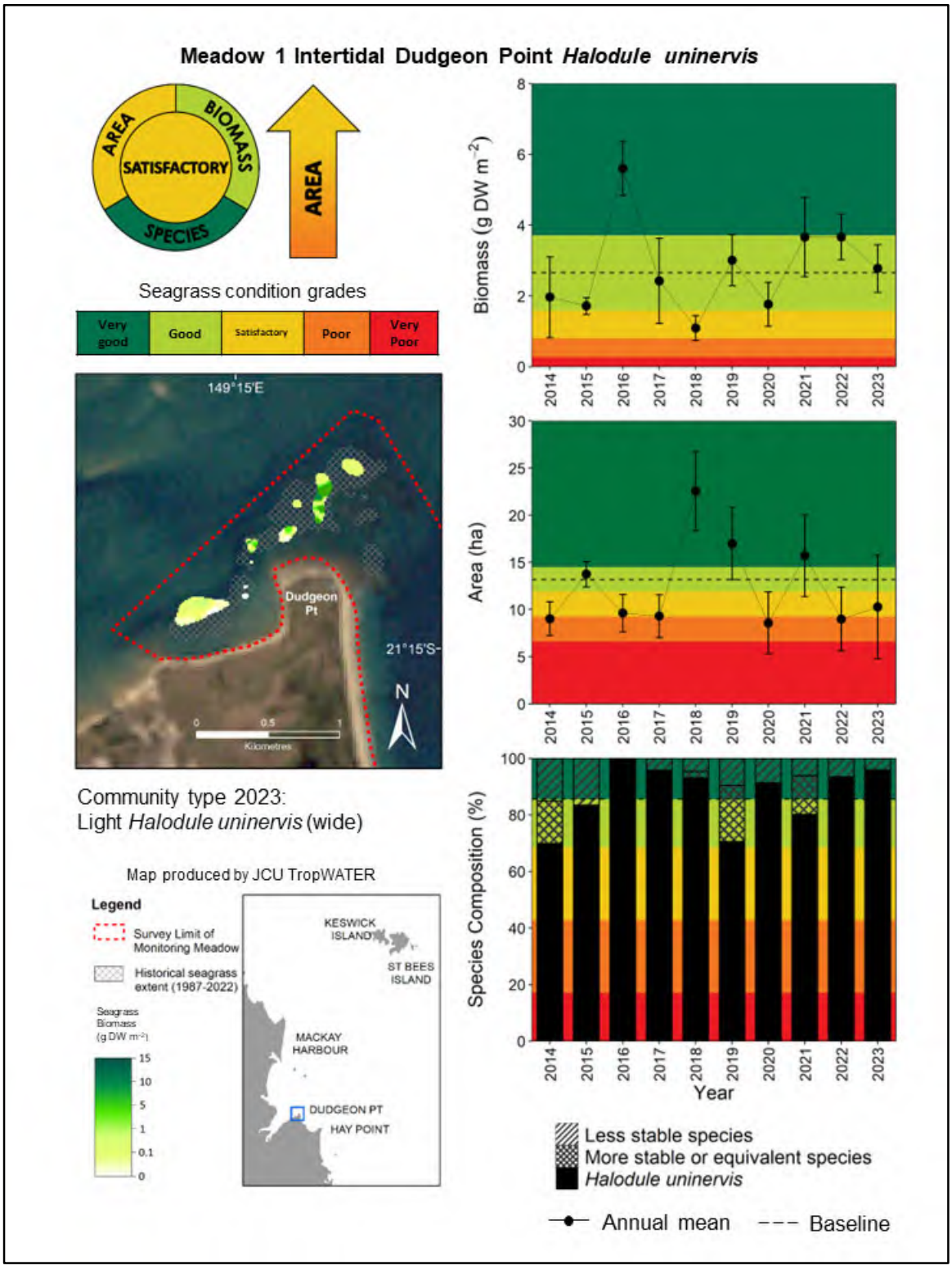

Figure 13. Changes in meadow biomass, area and species composition for seagrass in the Dudgeon Point coastal area (Meadow 1), 2014 – 2023 (biomass error bars = SE).

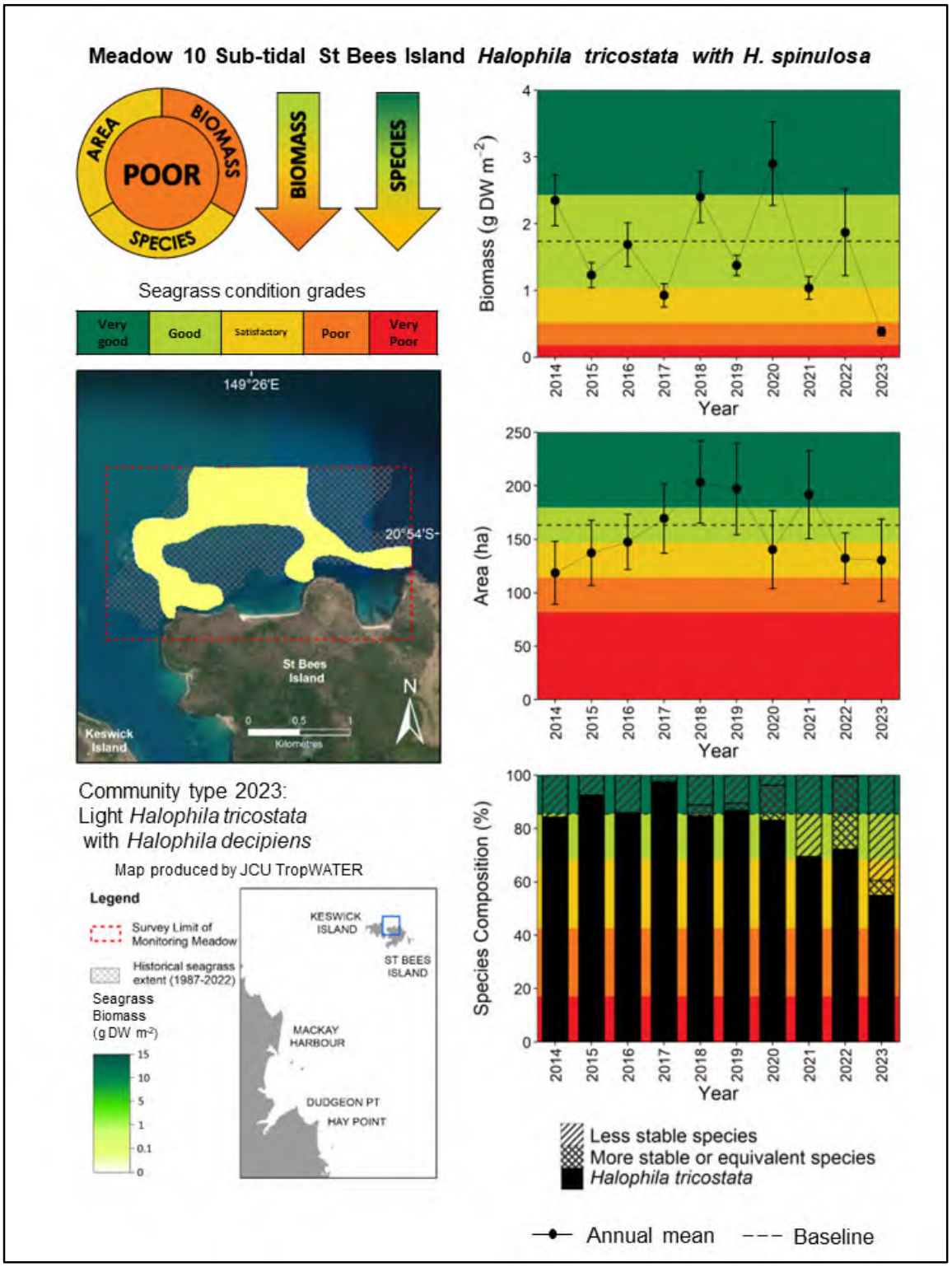

Figure 14. Changes in meadow biomass, area and species composition for seagrass in the St Bees Island coastal area (Meadow 10), 2014 – 2023 (biomass error bars = SE).

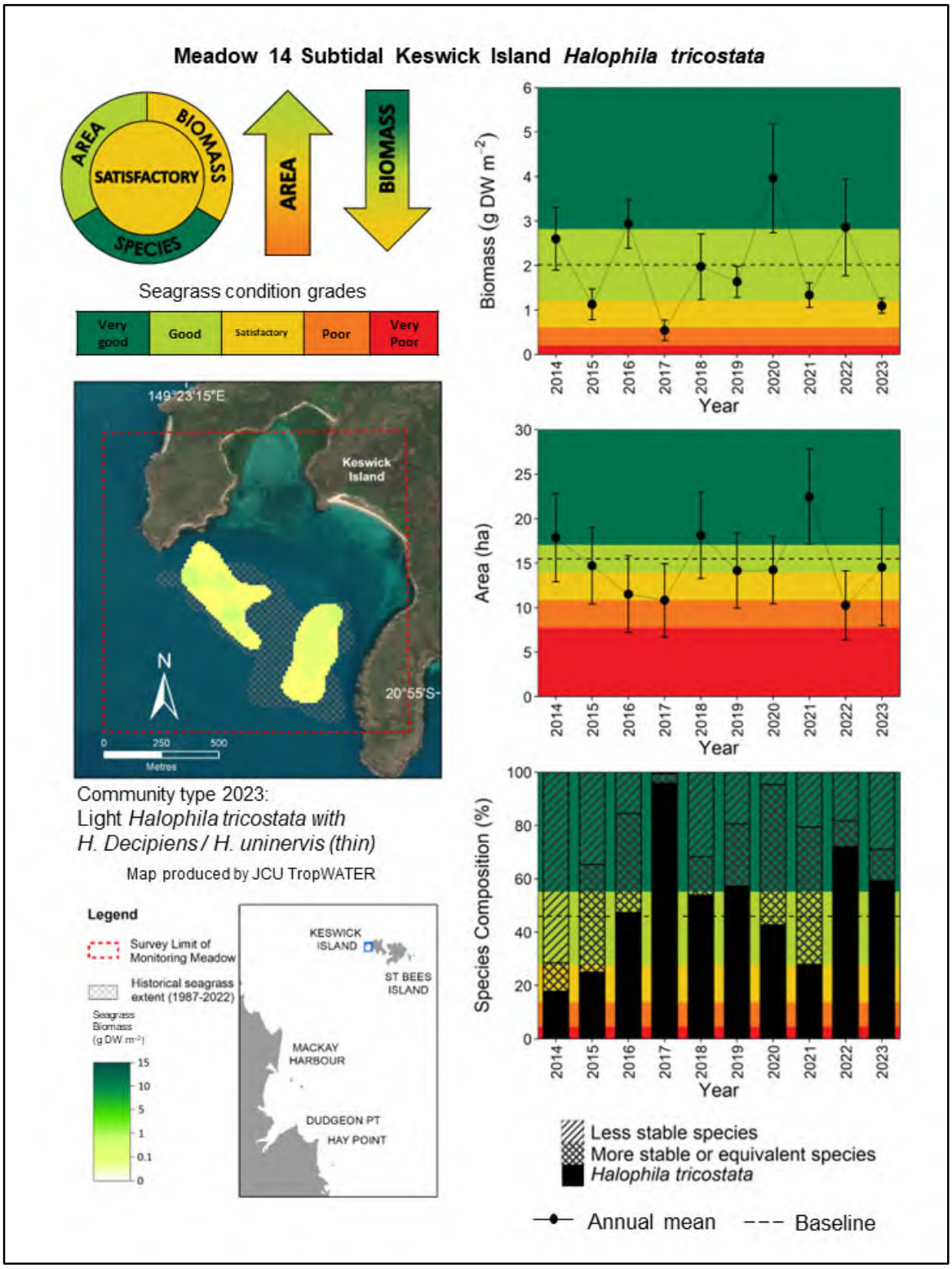

Figure 15. Changes in meadow biomass, area and species composition for seagrass in the Keswick Island coastal area (Meadow 14), 2014 – 2023 (biomass error bars = SE).

Figure 16. Location and extended seagrass monitoring survey sites in the 2023 Half Tide Tug Harbour Hay Point-Mackay region.

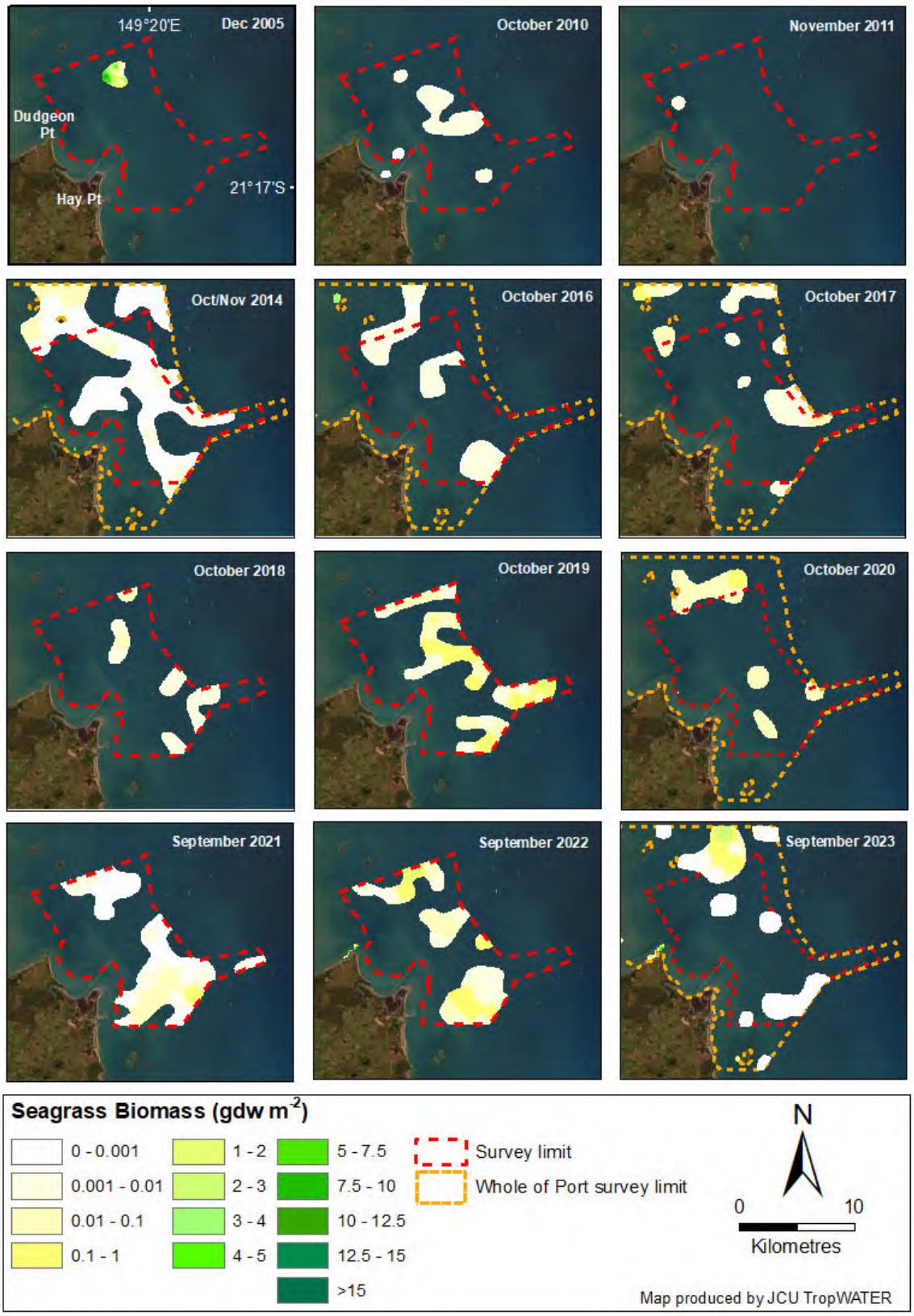

Figure 17. Seagrass biomass distribution in the Hay Point offshore monitoring area when surveys were conducted between 2005-2023.

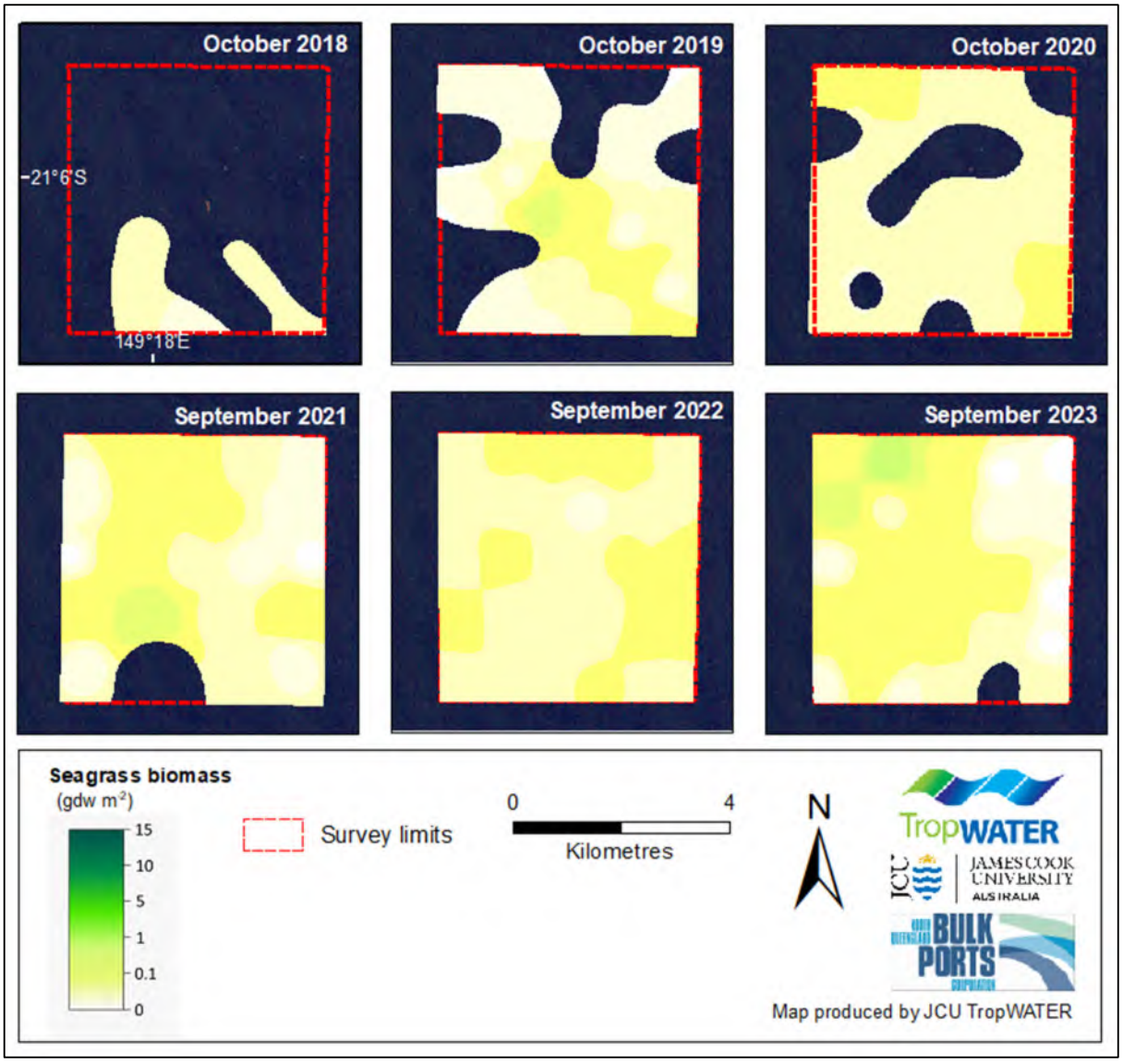

Figure 18. Seagrass biomass distribution in the Mackay offshore monitoring area when surveys were conducted between 2018-2023.

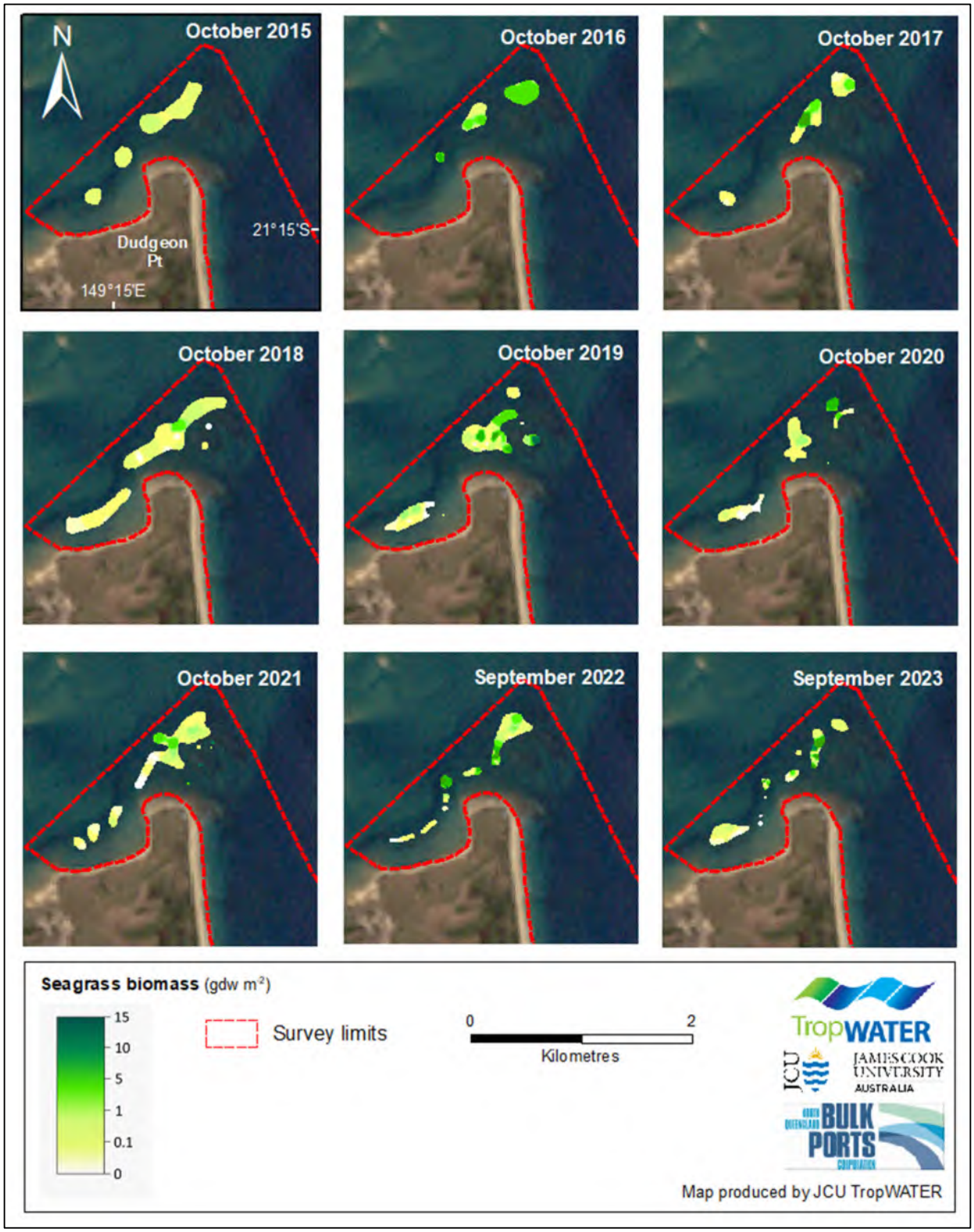

Figure 19. Seagrass biomass distribution in the Dudgeon Point to Hay Point annual monitoring area, 2015 - 2023.

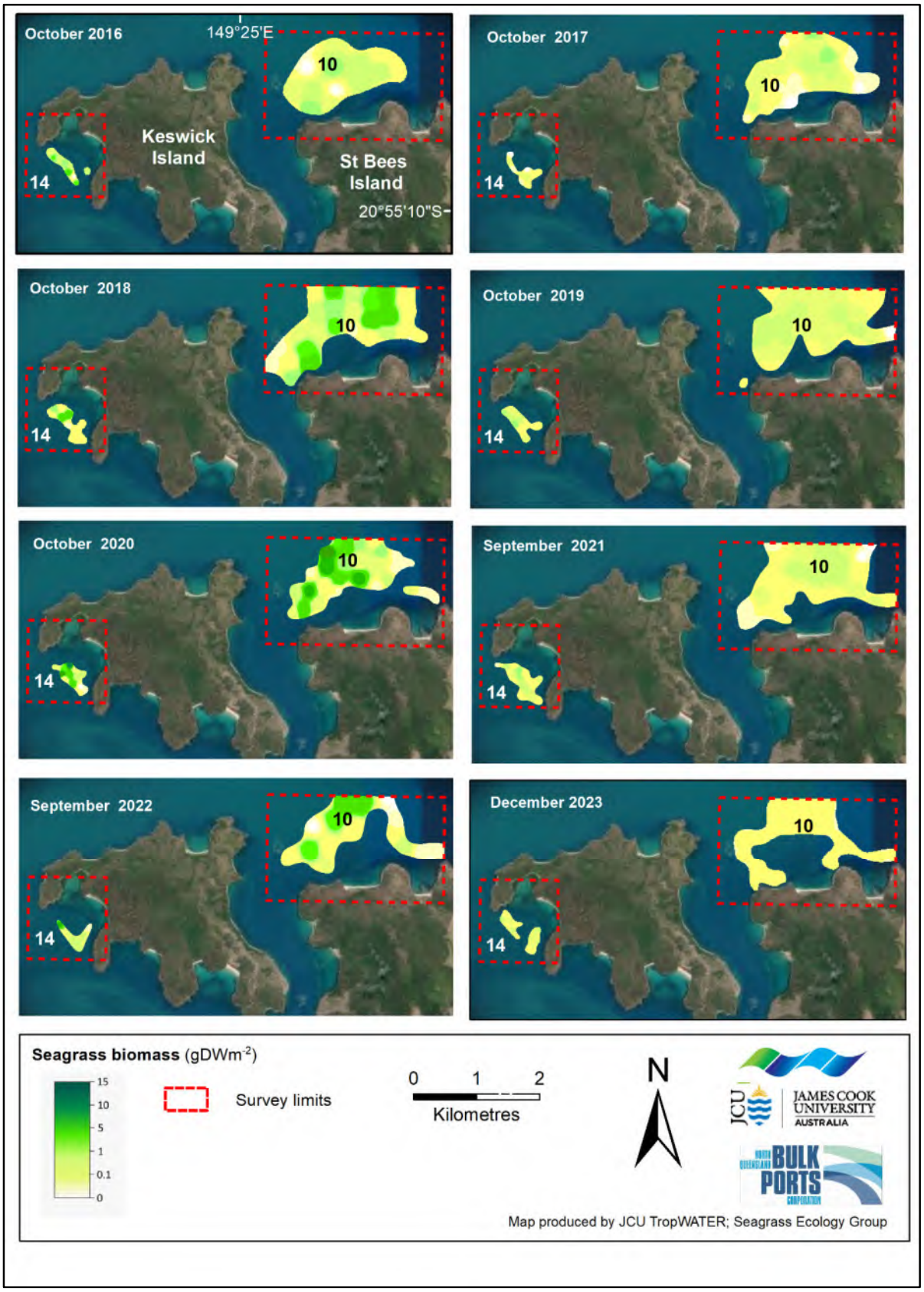

Figure 20. Seagrass biomass distribution in the annual monitoring meadows at Keswick and St Bees Islands 2015 – 2023.

5.3 Environmental data

5.3.1 Rainfall

In the 12 months prior to the 2023 survey annual rainfall in the region was 1711 mm and above the long term average (1594 mm) for the second year in a row (Figure 21a). The majority of rainfall for the year occurred in January 2023 (Figure 21b) Rainfall in January and July 2023 exceeded the respective monlthy long term averages (Figure 21b).

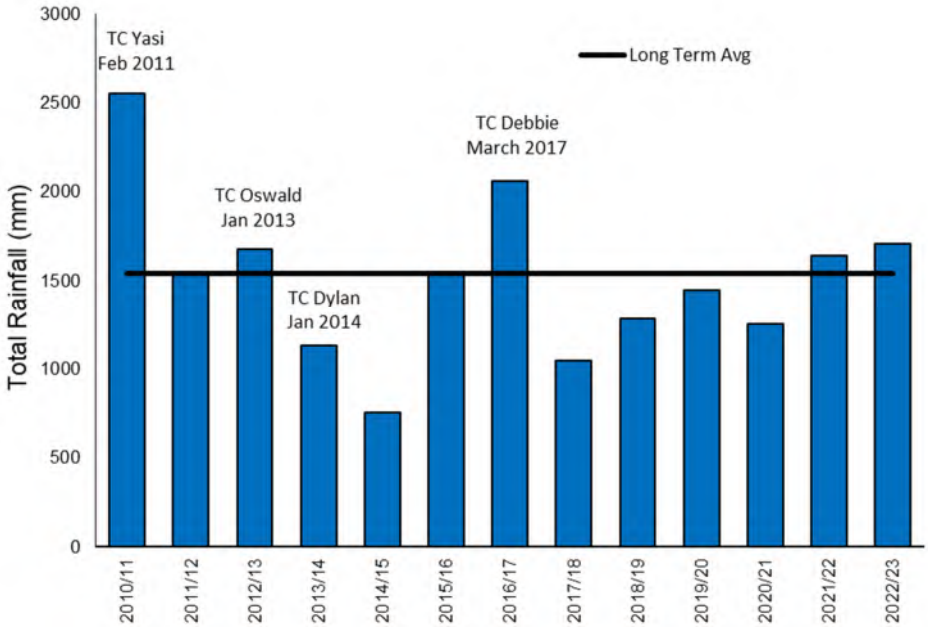

Figure 21a. Total annual rainfall (mm) recorded at Mackay Aero, 2010/11-2022/23. Twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033045.

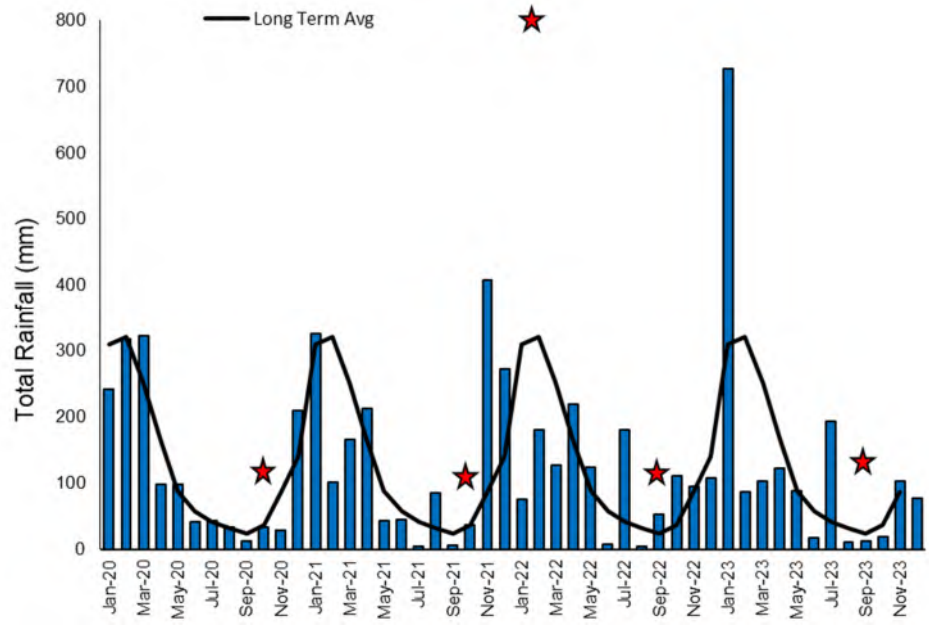

Figure 21b. Total monthly rainfall (mm) recorded at Mackay Aero, January 2020 – December 2023. Source: BOM, Station number 033045.

5.3.2 River flow

For the fourth year in a row annual river flow of the Pioneer River was below the long-term average. There was however an increase in river flow in 2022/23 compared to the previous three years (Figure 22a). This was largely due to significant amounts of flow in January 2023 that exceeded the long-term monthly average. River flow for the rest of the year was below long-term monthly averages (Figure 22b).

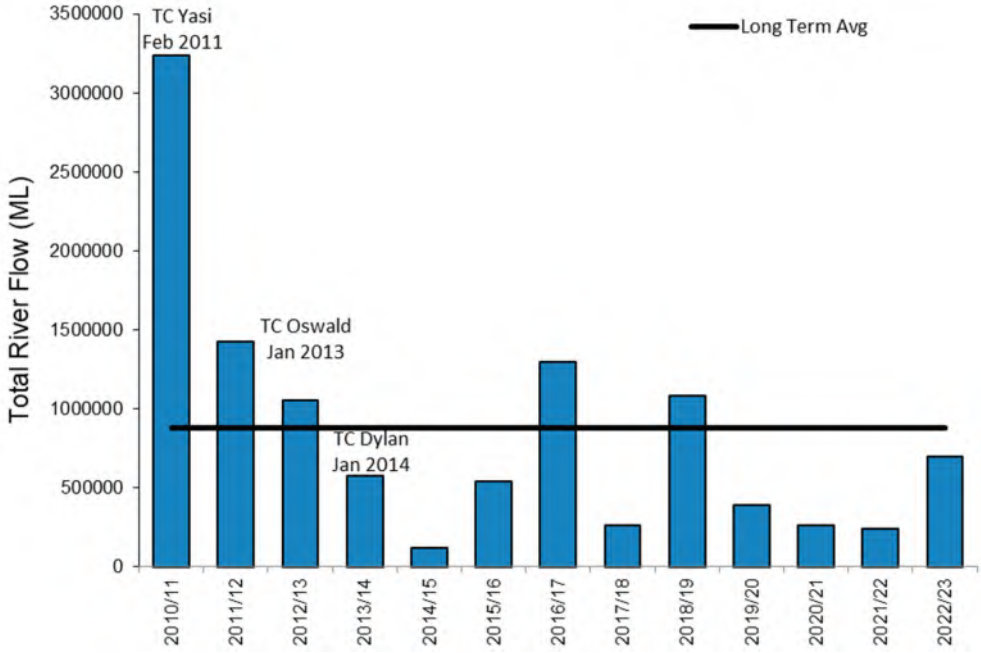

Figure 22a. Annual river flow (Mega litres) for the Pioneer River, 2010/11-2022/23. Source: Queensland Department of Natural Resources, Mines and Energy, Station number 125016A.

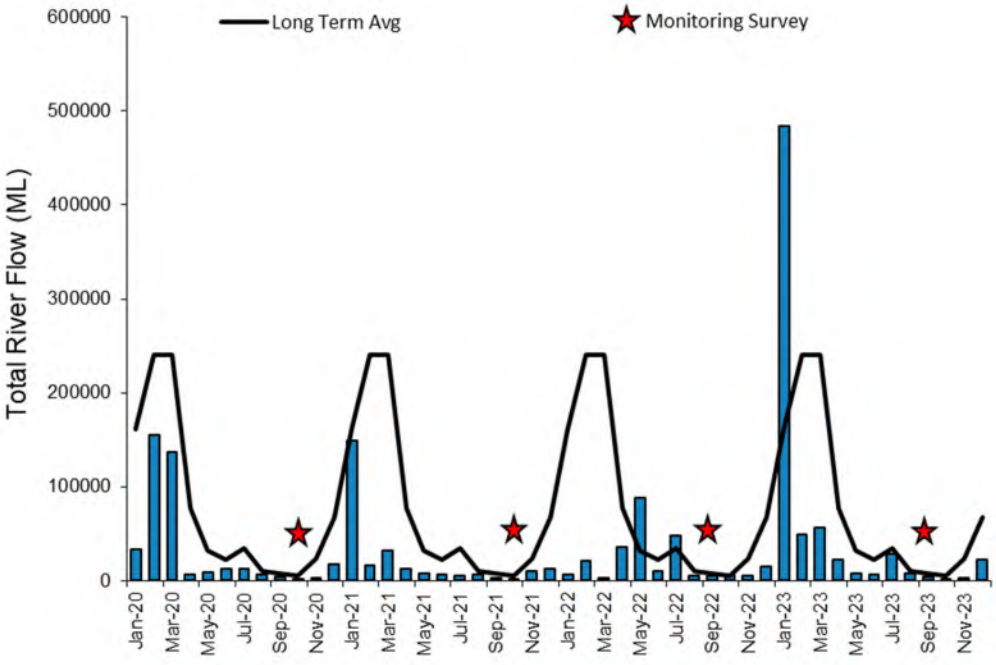

Figure 22b. Monthly river flow (Mega litres) for the Pioneer River January 2020-December 2023. Source: Queensland Department of Natural Resources, Mines and Energy, Station number 125016A.

5.3.3 Sea surface temperature

In 2022-23 the mean annual maximum daily SST (25.5°C) was above the long-term average (24.97°C) for this location (Figure 23a). Monthly data shows that sea surface temperature was above the long-term monthly average for the majority of 2023 with May and September being the only exceptions (Figure 23b).

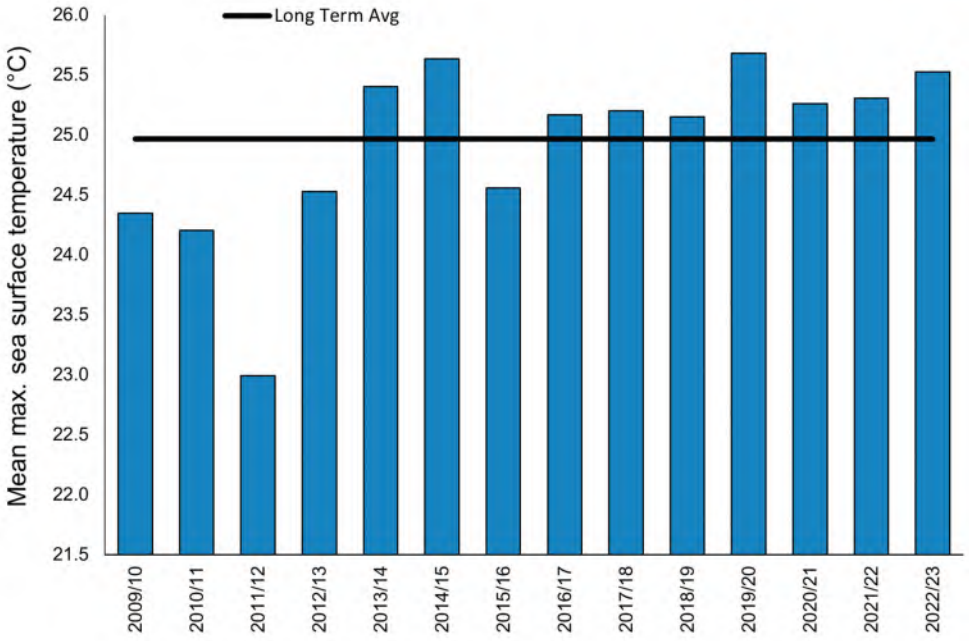

Figure 23a. Mean annual maximum sea surface temperature (°C) recorded at Hay Point 2009/10 - 2022/23. Source: QLD Department of Environment and Science.

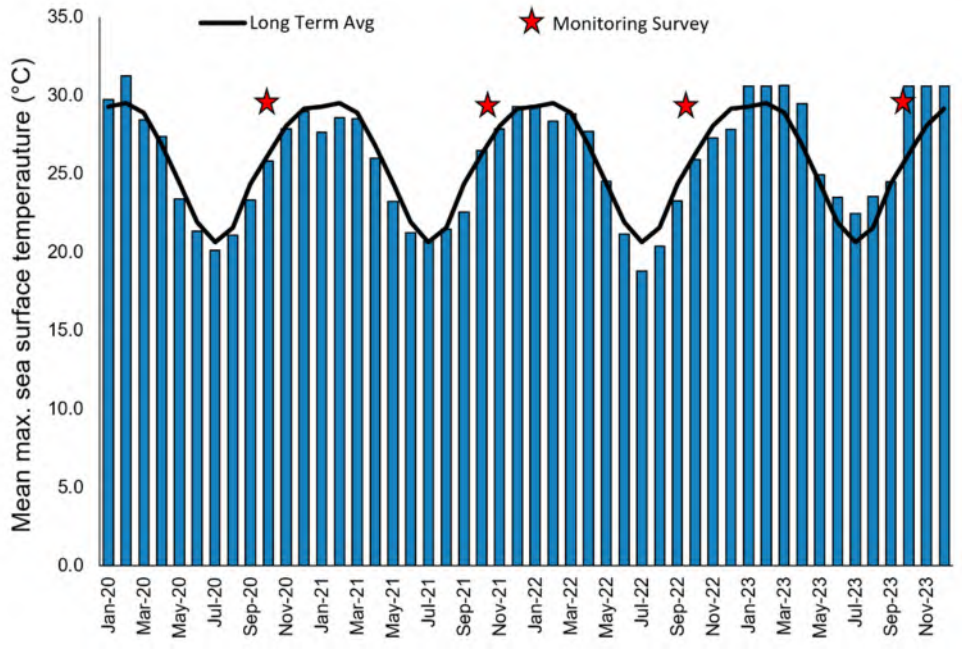

Figure 23b. Monthly maximum sea surface temperature (°C) recorded at Hay Point; January 2020 to December 2023. Source: QLD Department of Environment and Science.

5.3.4 Daily solar radiation

Solar exposure in the Hay Point area in the twelve months leading up to the 2022/23 survey (20.86 MJ m^{-2}) was just above the regional long-term average (20.73 MJ m^{-2}) (Figure 24a). Exposure was close to that of the long-term average for July and August, the two months leading up to the survey in September 2023 (Figure 24b.) During the 2022/23 survey period, the monthly exposure in March had the biggest increase comparable to the long-term average (Figure 24b).

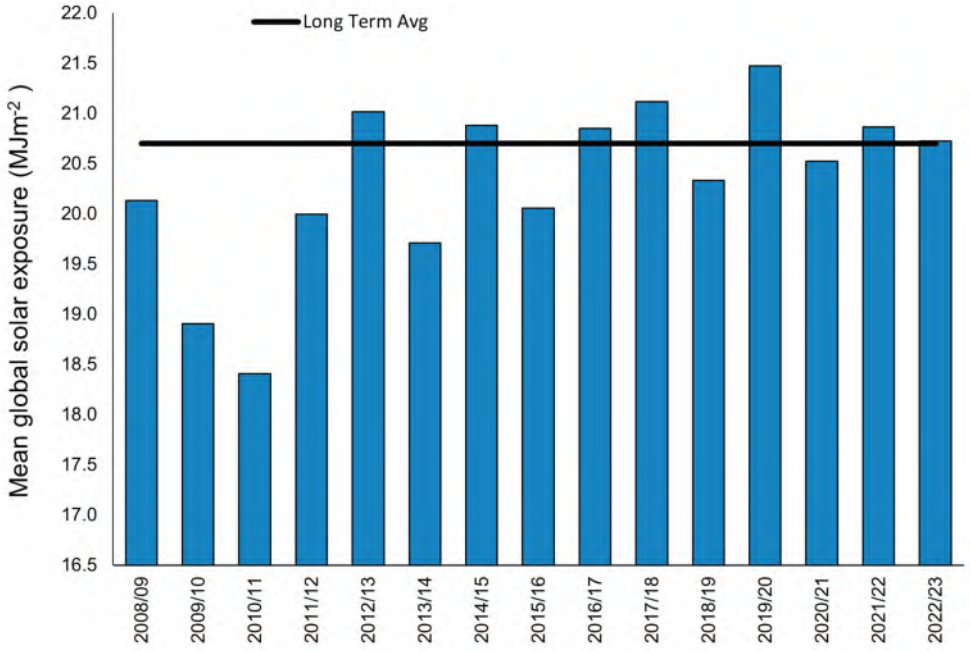

Figure 24a. Mean annual solar radiation (MJm-2) recorded Mackay Aero (Station 033045) 2008/09 – 2022/23. Source: BOM.

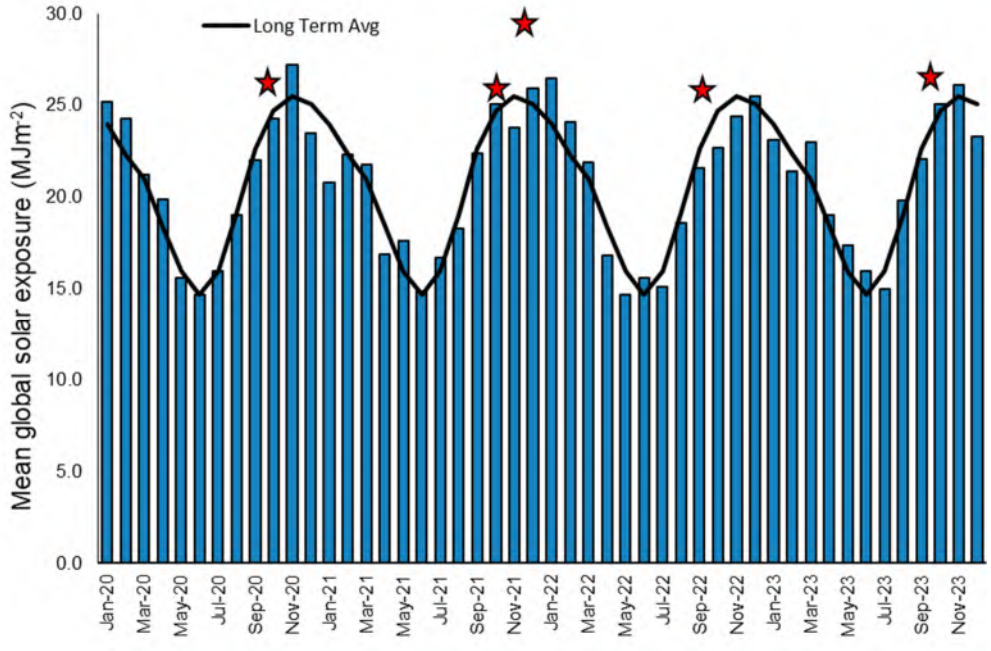

Figure 24b. Mean monthly daily global solar exposure (MJ m-2) recorded at Mackay Aero (Station 033045) January 2020-December 2023. Source: BOM.

5.3.5 Significant wave height

For eight months of the 2022/23 survey period the wave height was above the long-term average monthly mean, including the 2 months leading up to the 2023 survey (Figure 25). In 2023, February had the highest mean maximum monthly wave height of 1.44m, with the lowest of 0.75 recorded in June (Figure 25).

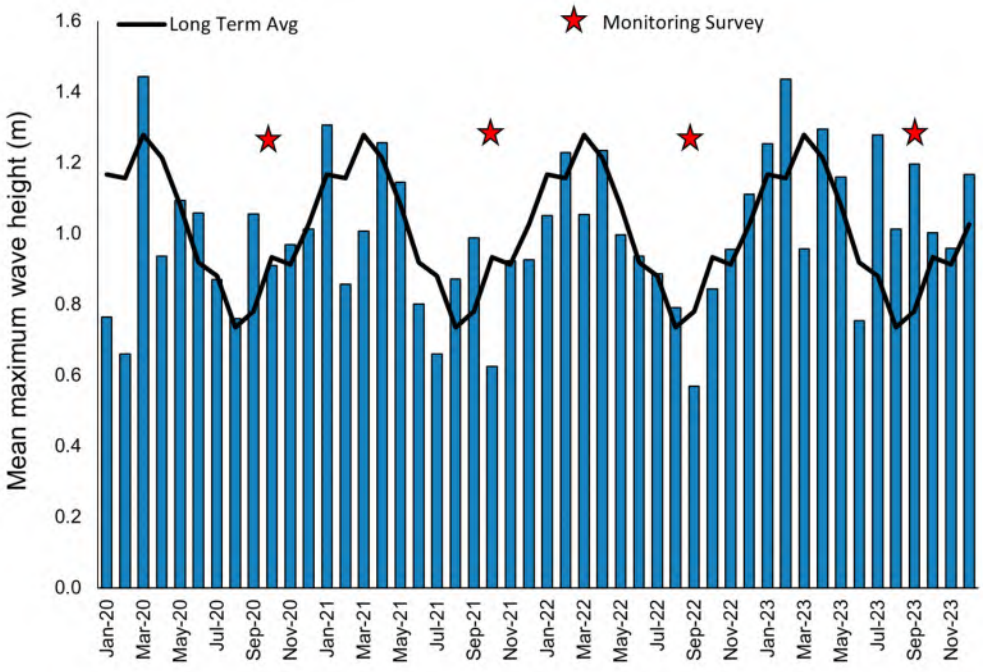

Figure 25. Mean monthly maximum wave height (m) recorded at Hay Point, January 2020-December 2023. Source: QLD Department of Environment and Science.

5.3.6 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. During the 12-month period leading up to the 2023 survey, PAR at this site was above the seagrass growth requirements for deep water *Halophila* species for most of the year (Figure 26). Benthic light levels over the past two years have been substantially higher than the preceding two years (Figure 26). The lowest light in 2023 coincided with wet season months between January and May.

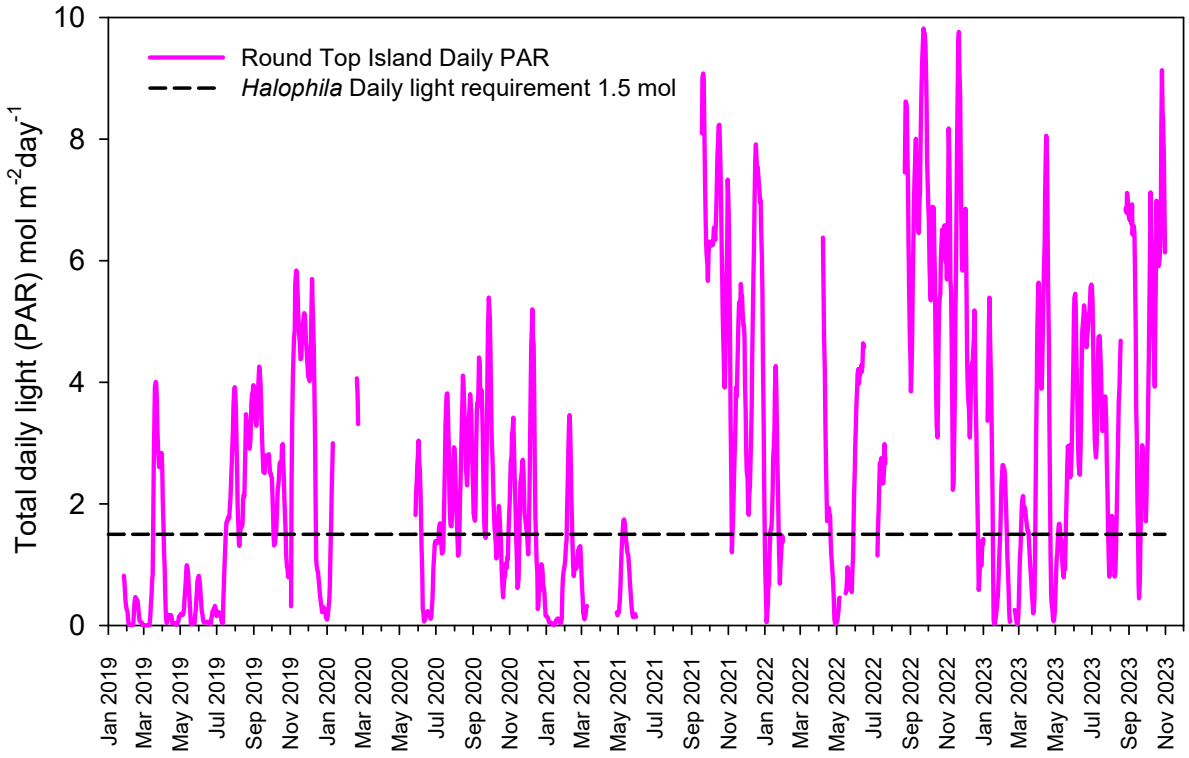

Figure 26. Daily photosynthetically active radiation (PAR; mol photons m^{-2} day^{-1} over a 7-day rolling average) at Round Top Island. Data presented from January 2019 to Oct 2023. Source: Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program.

6 DISCUSSION

Seagrasses in the Hay Point-Mackay region in 2023 were generally in a healthy state compared to historical baseline conditions. The annual monitoring meadows maintained the overall satisfactory condition from the previous year and the largest area of seagrass mapped across the whole of the port survey since 2014. There was some variability in the condition trends among different meadows and indicators. The inshore Dudgeon Point coastal meadows increased in area in 2023, recovering from a poor condition the previous year to satisfactory in 2023. The Mackay offshore meadow (Meadow 5) was in very good condition for the second time in seven years of monitoring and the Hay Point offshore seagrass (Meadow 8) was in satisfactory condition. Outside of the port limits the deep-water seagrass meadows at Keswick and St Bees Islands had declined in biomass in 2023, with the St Bees Island seagrasses (Meadow 10) declining to be the only meadow in poor condition in the monitoring program in 2023.

In the broader Hay Point port limits substantial areas of seagrass were mapped in both coastal and offshore areas of the port in addition to the annually monitored meadows. These areas are assessed every third year in the program to give an update of the broader seagrass status within the port of Hay Point. Area of seagrass in this additional survey footprint was larger than the previous two broadscale surveys (2020 and 2017) and was a good indication of healthy seagrasses in the broader port region. In particular, an increase in the presence of *Halophila spinulosa*, a species with higher biomass and resilience than *H. ovalis* and *H. decipiens* (Kilminster et al. 2015) was observed in meadows offshore from Mackay and to the north of the Hay Point offshore annual monitoring area.

The additional survey area in the Half Tide Tug Harbour area found the majority of the seafloor dominated by open substrate with a small area (~1 ha) of the seagrass species *Halophila decipiens.* This is the lowest light requiring species found in the Mackay/Hay Point monitoring region and is typically highly variable in its presence from year to year (Chartrand et al 2017). Previous surveys in recent years have found no seagrass in the area in October 2020 (York et al. 2021); a small patch of *H. ovalis* and *H. decipiens* in different locations to the current meadow in September 2021 (York and McKenna 2021). These changes in species distribution and composition between years highlight the highly variable nature of *Halophila* seagrass habitats in these often turbid nearshore coastal environments (Josselyn et al. 1986; Kenworthy 2000; York et al. 2015).

Environmental conditions throughout the year, particularly in the months leading up to the survey can have an impact on seagrass distribution and abundance. This is particularly the case for fast the growing colonising species; *Halophila* spp., with low resistance to disturbance that occur throughout much of the Hay Point-Mackay region. In 2023 most environmental parameters were generally close to long-term averages, with benthic light levels sufficient to maintain deepwater seagrass growth requirements. While there was significant amounts of rainfall and river flow in January 2023, this was seven months before the annual monitoring survey and unlikely to have impacted the seed bank and the standing biomass of the fast-growing *Halophila* and *Halodule* species that are found in the Hay Point-Mackay region. Studies have found that during the wet season, or after a significant climate event (i.e. Cyclone) *Halophila* seed banks prevail, providing a source of propagules for re-colonisation following the unfavourable growing conditions (Chartrand et al. 2021; Hovey et al. 2015). Chartrand et al. (2021) found that at the Lizard Island deepwater seagrass study site, a *Halophila* seed bank prevailed after Tropical Cyclone ITA (April 2014) with *Halophila* germinating within three months post cyclone, once the sediments added from the storm had moved off the site and conditions for germination were present.

Wave shear stress at the sea floor (RMS) was generally higher more often and for longer periods of time in the Hay Point/Mackay region in 2023. This was also evident at Abbot Point and Townsville (McKenna et al. 2024a & b). Increased RMS for longer periods of time may have had a negative physical impact on Hay Point and

Keswick & St Bees deepwater seagrass through direct removal and burial. These meadows (the meadows that had declines) grow in and occupy areas where the sediment grain size typically has higher proportions of mud, silt and clay compared to the area offshore from Mackay (offshore meadow that didn't decline) that is dominated by more sandy/rubbly sediment. Fine sediments (including fine sands, silts, and clays) appear to have a greater negative effect on shoot density in *Halophila* species, compared to coarser sandy sediments (Benham et al. 2019). Increased deposition of sediment (via higher RMS wave shear stress) on small seagrass species like the *Halophila* genus can lead to abrasion of leaves, removal of plants and limited recruitment and growth because of the stability of surface sediments etc. (Benham et al. 2019). Benham et al. (2019) found that *H. ovalis* declined in shoot density at burial depths of 5-7.5mm and plants exhibit very little-to-no growth at burial depths ≥10mm. The higher RMS values seen throughout 2023 could have led to some loss of above-ground seagrass biomass in these offshore meadows that occupy more silty sediment.

The changes recorded in the offshore meadows, could also just be a reflection of their high variability from year to year. These deeper meadows and their species are ephemeral and are generally only present for part of the year (Chartrand et al. 2017; York et al 2015). The deepwater seagrass meadow in Cleveland Bay, Townsville, is also highly variable in its extent and footprint (Mckenna et al. 2024a).

The Hay Point-Mackay seagrass long-term monitoring program is incorporated into the broader Queensland Ports seagrass monitoring program using the consistent state-wide monitoring methodology. Seagrass monitoring in other locations of the Queensland coast was variable in 2023. Seagrasses to the north in the Abbot Point and Townsville regions declined from good to satisfactory conditions in 2023 (McKenna et al. 2024a, McKenna et al. 2024b) and to the south, shallow coastal seagrasses in the Clairview region and Gladstone were in a good condition in 2023 (Reason et al 2024a). In the Wet Tropics, Cairns Harbour meadows were in a good condition, but estuarine meadows were in a poor condition (Reason et al. 2024b). In the Gulf of Carpentaria, seagrass in Weipa declined in condition to satisfactory (Reason et al. 2024c) while the condition of seagrass meadows in Karumba was very good (Scott et al. 2024).

This is the seventh year of the monitoring program and reporting of seagrass condition established in 2017 for Hay Point, Mackay, and the Southern Whitsundays. As the program continues to develop and mature 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, Dudgeon Point, Keswick Island and St Bees Island the long-term averages for meadow indicator conditions have established a permanent baseline with 10 years of data. The Mackay offshore seagrasses were monitored for the seventh time in 2023 and an interim score for this area was assigned. The Half Tide Tug Harbour survey area will be incorporated into the Mackay/Hay Point condition reporting after five years of data where interim grades and scores to condition indicators can be assigned. For the HTTH and Mackay offshore areas interim baseline conditions will continue to change for these areas until a 10-year baseline is settled upon. This will ensure long-term data will be in place for benchmarking of seagrass meadow condition indicators into the future.

The condition of seagrasses in the Mackay - Hay Point region in 2023 meant they were likely to have a reasonable level of resilience in the coming year to future stressors and impacts. Overall, they were in a satisfactory condition with offshore and coastal areas to the north in particularly good condition and encouraging signs of expanding seagrass area around Dudgeon Point. In the larger Hay Point port limits, there were expansive areas of seagrass with the largest spatial footprint recorded for the last three port limits surveys. Declines in biomass in the highly variable offshore seagrasses to the south around Hay Point were within baseline expectations and seagrasses there remained in satisfactory condition. While not unusual for deepwater *Halophila,* the decline in biomass around St Bees and Keswick Island was of some concern. The

dominant species here *Halophila tricostata* is often annual in habit and has the ability to rapidly expand through seed germination and clonal growth when conditions are suitable. A close watch on seagrasses around the offshore islands in 2024 will reveal if this is a longer-term trend or a response to shorter stressors.

7 REFERENCES

Benham, Claudia F., Beavis, Sara G., and Jackson, Emma L. (2019). Tolerance of tropical seagrasses Zostera muelleri and Halophila ovalis to burial: Toward an understanding of threshold effects. Estuarine, Coastal and Shelf Science 218 131-138. https://doi.org/10.1016/j.ecss.2018.11.005

Bureau of Meteorology 2023, Available from: http://www.bom.gov.au.

Carter AB, Coles R, Jarvis JC, Bryant CV, Smith TM and Rasheed MA, 2023. A report card approach to describe temporal and spatial trends in parameters for coastal seagrass habitats. Scientific Reports **13:** 2295. https://doi.org/10.1038/s41598-023-29147-1

Cartwright, P., Iles JA., Waltham NJ, 2022. Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual Report 2021-2022, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 22/60, James Cook University, Townsville, 49 pp.

Chartrand, K.M., Bryant, C.V., Ralph P.J. and Rasheed M.A. PhDThesis Chapter 4 Seed bank density and stratification drives tropical deep-water seagrass meadow maintenance: a multi-year case study from the Great Barrier Reef.

Chartrand KM, Bryant CV, Sozou S, Ralph P.J and Rasheed MA 2017, Final Report: Deep-water seagrass dynamics - Light requirements, seasonal change and mechanisms of recruitment, Centre for Tropical Water & Aquatic Ecosystem Research Publication, James Cook University, Cairns.

Coles RG, Lee Long WJ, Watson RA and Derbyshire KJ, 1993. Distribution of seagrasses, and their fish and penaeid prawn communities, in Cairns Harbour, a tropical estuary, Northern Queensland, Australia. *Marine and Freshwater Research* 44:193-210.

Coles RG, Rasheed MA, McKenzie LJ, Grech A, York PH, Sheaves MJ, McKenna S and Bryant CV 2015. The Great Barrier Reef World Heritage Area seagrasses: managing this iconic Australian ecosystem resource for the future. *Estuarine, Coastal and Shelf Science*, 153: A1-A12.

Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S and Turner RK 2014. Changes in the global value of ecosystem services. *Global Environmental Change* 26:152-158

Fourqurean JW, Duarte CM, Kennedy H, Marba N, Holmer M, Mateo MA, Apostolaki ET, Kendrick GA, Krause-Jensen D, McGlathery KJ and Serrano O 2012. Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience* 5: 505-509

Grech A, Coles R and Marsh H 2011. A broad-scale assessment of the risk to coastal seagrasses from cumulative threats, *Marine Policy* 35: 560-567.

Hayes MA, McClure EC, York PH, Jinks KI, Rasheed MA, Sheaves M and Connolly RM 2020. The Differential Importance of Deep and Shallow Seagrass to Nekton Assemblages of the Great Barrier Reef. *Diversity, 12*(8), 292.

Heck KL, Hays G, Orth RJ 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series* 253: 123-136.

Heck KL, Carruthers TJB, Duarte CM, Hughes AR., Kendrick G, Orth, RJ, Williams SW 2008. Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers. *Ecosystems* 11:1198-1210.

Hovey, R.K., Statton, J., Fraser, M.W., Ruiz-Montoya, L., Zavala-Perez, A., Rees, M., Stoddart, J., Kendrick, G.A. 2015. Strategy for assessing impacts in ephemeral tropical seagrasses. Marine Pollution Bulletin, Volume 101, Issue 2, Pages 594-599, https://doi.org/10.1016/j.marpolbul.2015.10.054.

James RK, Silva R, van Tussenbroek BI, Escudero-Castillo M, Mariño-Tapia I, Dijkstra HA, van Westen RM, Pietrzak JD, Candy AS, Katsman CA, van der Boog CG, Riva REM, Slobbe C, Klees R, Stapel J, van der Heide T, van Katwijk MM, Herman PMJ and Bouma TJ 2019. Maintaining tropical beaches with seagrass and algae: a promising alternative to engineering solutions. *BioScience* 69:136-142.

Josselyn M, Fonseca M, Niesen T and Larson R 1986. Biomass, production and decomposition of a deep water seagrass, *Halophila decipiens* Ostenf, *Aquatic Botany* 25:47–61.

Kenworthy WJ 2000. The role of sexual reproduction in maintaining populations of *Halophila decipiens*: implications for the biodiversity and conservation of tropical seagrass ecosystems, *Pacific Conservation Biology*, 5:260–268.

Kilminster K, McMahon K, Waycott M, Kendrick GA, Scanes P, McKenzie L, O'Brien KR, Lyons M, Ferguson A, Maxwell P, Glasby T and Udy J 2015. Unravelling complexity in seagrass systems for management: Australia as a microcosm. *Science of The Total Environment*, 534: 97-109.

Kirkman, H 1978. Decline of seagrass in northern areas of Moreton Bay, Queensland. *Aquatic Botany* 5:63-76.

Lavery PS, Mateo M-Á, Serrano O and Rozaimi M 2013. Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. *PLoS ONE* 8:e73748.

McGlathery KJ, Sundback K and Anderson IC 2007. Eutrophication in shallow coastal bays and lagoons: the role of plants in the coastal filter. *Marine Ecology-Progress Series* 348:1-18.

McMahon K and Walker DI 1998. Fate of seasonal, terrestrial nutrient inputs to a shallow seagrass dominated embayment. *Estuarine, Coastal and Shelf Science* 46:15-25.

McKenna, S.A., Concannon, T., Reason, C.L., & Rasheed, M.A. 2024a. Port of Abbot Point Long-Term Seagrass Monitoring Program - 2023', Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

McKenna S., Murphy, T. & Hoffmann, L. 2024b Port of Townsville Seagrass Monitoring Program 2023. James Cook University Publication 23/30, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), Cairns.

McKenna S & Van De Wetering C, 2024a. Marine Benthic Habitat Assessment – Half Tide Tug Harbour, December 2023. James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), Cairns.

McKenna SA, Chartrand KM, Jarvis JC, Carter AB, Davies JN and Rasheed MA 2015. Port of Abbot Point: initial light thresholds for modelling impacts to seagrass from the Abbot Point Growth Gateway project. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research, pp. 18.

Mellors JE 1991. An evaluation of a rapid visual technique for estimating seagrass biomass. *Aquatic Botany* 42:67-73.

Rasheed MA, Roder CA and Thomas R 2001. Port of Mackay Seagrass, Macro-algae and Macro-invertebrate Communities. February 2001, CRC Reef Research Centre, Technical Report: 43 CRC Reef Research Centre, Townsville, 38 pp.

Rasheed MA, Thomas R and McKenna SA 2004. Port of Hay Point seagrass, algae and benthic macro-invertebrate community survey - July 2004. DPI&F Information Series QI04084 (DPI&F, Cairns), 27 pp.

Rasheed MA, Macreadie PI, York PH, Carter AB and Costa MDP 2019. Blue Carbon Opportunities for NQBP Ports: Pilot Assessment and Scoping. Centre for Tropical Water & Aquatic Ecosystem Research (Trop[WATER), JCU Publication 19/49, Cairns.

Reason C.L., Smith T.M., and Rasheed M.A. 2024a. Seagrasses in Port Curtis and Rodds Bay 2023 Annual long-term monitoring. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 24/07, James Cook University, Cairns, 48 pp.

Reason C, Hoffmann L, McKenna S & Rasheed M. 2024b. Seagrass habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring Report 2023, Centre for Tropical Water & Aquatic Ecosystem Research, Publication Number 24/20, James Cook University, Cairns, 44 pp.

Reason, C. L., McKenna, S.A., Smith T., & Rasheed, M.A., 2024c Port of Weipa Long-Term Seagrass Monitoring Program - 2023', Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

Scott AL, York PH, Duncan C, Macreadie PI, Connolly RM, Ellis MT, Jarvis JC, Jinks KI, Marsh H, Rasheed MA 2018. The role of herbivory in structuring tropical seagrass ecosystem service delivery. Frontiers in Plant Science 9:127.

Scott AL, York PH and Rasheed MA 2021. Green turtle (*Chelonia mydas*) grazing plot formation creates structural changes in a multi-species Great Barrier Reef seagrass meadow. *Marine Environmental Research* 162:105183.

Scott A & Rasheed M 2024 Port of Karumba Long-term Annual Seagrass Monitoring 2023, Centre for Tropical Water & Aquatic Ecosystem Research Publication Number 24/04, James Cook University, Cairns

Short FT and Wyllie-Echeverria S 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* 23**:**17–27.

Waycott M, Duarte CM, Carruthers TJB, Orth R Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck Jr KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT and Williams SL 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America* 106**:** 12377–12381.

York PH, Carter AB, Chartrand K, Sankey T, Wells L and Rasheed MA 2015. Dynamics of a deep-water seagrass population on the Great Barrier Reef: annual occurrence and response to a major dredging program, *Scientific Reports*. 5:13167

York PH, Macreadie PI & Rasheed MA 2018. Blue Carbon stocks of Great Barrier Reef deep-water seagrasses. Biology Letters **14**:20180529.

York PH, van de Wetering C & Rasheed MA 2021. Hay Point Coal Terminal - Marine macrophyte assessment for potential mooring sites – October 2020, JCU Publication 21/03, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

York PH & McKenna SA 2021. Half Tide Tug Harbour, Hay Point Marine Plant Assessment – September 2021, JCU Publication 21/54, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

8 APPENDICES

Table A1. Seagrass community types, mean above-ground biomass and meadow area in the Hay Point (Meadow 8) and Mackay (Meadow 5) offshore areas.

Hay Point and Mackay Offshore survey area				
Meadow ID	**Meadow location**	**Community type**	**Mean meadow biomass ($gDWm^{-2}$ ± SE)**	**Area ± R (ha)**
July 2004				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. decipiens*	0.270 ± 0.057	6837.6 ± 2415.3
Total				**6837.6 ± 2415.3**
December 2005				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. spinulosa*	2.186 ± 0.764	332.9 ± 152.9
Total				**332.9 ± 152.9**
October 2010				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. decipiens*	0.008 ± 0.003	1528.6 ± 346.6
Total				**1528.6 ± 346.6**
November 2011				
5	Offshore	Not surveyed	na	na
8	Offshore	Light *H. decipiens*	0.008	105.1 ± 39.8
Total				**105.1 ± 39.8**
October/November 2014				
5	Offshore	Light *H. spinulosa* with *H. decipiens*	0.244 ± 0.108	Not mapped
8	Offshore	Light *H. decipiens*	0.002 ± 0.001	5204.7 ± 1448.1
Total				**5204.7 ± 1448.1**
October/November 2016				
5	Offshore	Light *H. spinulosa*	0.108 ± 0.078	Not mapped
8	Offshore	Light *H. decipiens*	0.002 ± 0.0001	2311.0 ± 387.0
Total				**2311.0 ± 387.0**
October 2017				
5	Offshore	Light *H. decipiens* with *H. spinulosa*	0.011 ± 0.003	652.8 ± 151.9
8	Offshore	Light *H. decipiens*	0.046 ± 0.032	1234.1 ± 309.9
Total				**1886.9 ± 461.8**
October 2018				
5	Offshore	Light *H. decipiens* with *H. spinulosa*	0.062 ± 0.015	381.6 ± 141.2
8	Offshore	Light *H. decipiens*	0.013 ± 0.004	1642.7 ± 406.2
Total				**2024.3 ± 547.4**
October 2019				
5	Offshore	Light *H. spinulosa* with *H. decipiens*	0.135 ± 0.073	1737.3 ± 277.4
8	Offshore	Light *H. decipiens* with *H. spinulosa*	0.096 ± 0.023	4160.8 ± 777.8
Total				**5898.1 ± 1055.2**
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**
September 2022				
5	Offshore	Light *H. spinulosa* with *H. decipiens*	0.09 ± 0.02	2326.3 ± 196.0
8	Offshore	Light *H. decipiens*	0.15 ± 0.1	3853.2 ± 559.65
Total				**6163.2 ± 729.6**
September 2023				

5	Offshore	Light *H. spinulosa*	0.30 ± 0.11	2274.78 ± 205.77
8	Offshore	Light *H. decipiens*	0.15 ± 0.11	3527.08.2 ± 647.04
Total				**5801.86 ± 852.81**

Table A2. Seagrass community types, mean above-ground biomass and meadow area in the St Bees Island (Meadow 10) and Keswick Island (Meadow 14) areas.

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 *H. 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 *H. 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 *H. 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 *H. tricostata*	1.09 ± 0.23	169.6 ± 32.5
14	Inshore	Light *H. 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 *H. 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. spinulosa / H. decipiens*	1.63 ± 0.35	14.2 ± 4.2
Total				**211.5 ± 47.1**
October 2020				
10	Inshore	Light *H. tricostata* with *H. spinulosa*	2.90 ± 0.63	140.4 ± 36.5
14	Inshore	Light *H. 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 *H. spinulosa* / *H. tricostata*	1.33 ± 0.27	22.5 ± 5.4
Total				**206.0 ± 46.5**
September 2022				
10	Inshore	Light *H. tricostata* with *H. spinulosa*	1.87 ± 0.65	132.2 ± 23.8
14	Inshore	Light *H. tricostata* with *H. decipiens*	2.86 ± 1.10	10.3 ± 3.9
Total				**142.5 ± 27.7**
September 2023				
10	Inshore	Light *H. tricostata* with *H. decipiens / H. uninervis*	0.39 ± 0.06	130.5 ± 38.56
14	Inshore	Light *H. tricostata* with *H. decipiens*	1.09 ± 0.17	14.55 ± 6.56
Total				**145.05 ± 45.12**

Table A3. Seagrass community types, mean above-ground biomass and meadow area in the Dudgeon Point (Meadow 1, Meadow 20) area.

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/November 2014				
1	Inshore	Light *H. uninervis* with *Z. muelleri* & *H. ovalis*	1.96 ± 1.14	9.0 ± 1.8
20	Inshore	Not present	Not assessed	-
Total				**9.0 ± 1.8**
October 2015				
1	Inshore	Light *H. 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 *H. uninervis* (wide)	5.60 ± 0.76	9.6 ± 2.0
20	Inshore	Not present	-	-
Total				**9.6 ± 2.0**
October 2017				
1	Inshore	Moderate *H. 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 *H. uninervis*	0.72 ± 0.72	1.7 ± 1.1
Total				**18.7 ± 4.9**
October 2020				
1	Inshore	Light *H. uninervis* with *H. ovalis*	1.76 ± 0.62	8.6 ± 3.3
20	Inshore	Not present	-	-
Total				**8.6 ± 3.3**
September 2021				
1	Inshore	Light *H. uninervis*	3.66 ± 1.12	17.0 ± 3.8
20	Inshore	Not present	-	1.7 ± 1.1
Total				**15.7 ± 4.3**
September 2022				
1	Inshore	Light *H. uninervis*	3.66 ± 0.64	8.97 ± 3.4
20	Inshore	Not present	-	-
Total				**8.97 ± 3.4**
September 2023				
1	Inshore	Light *H. uninervis* (wide)	2.77 ± 0.68	10.28 ± 5.5
20	Inshore	Not present	-	-
Total				**10.28 ± 5.5**

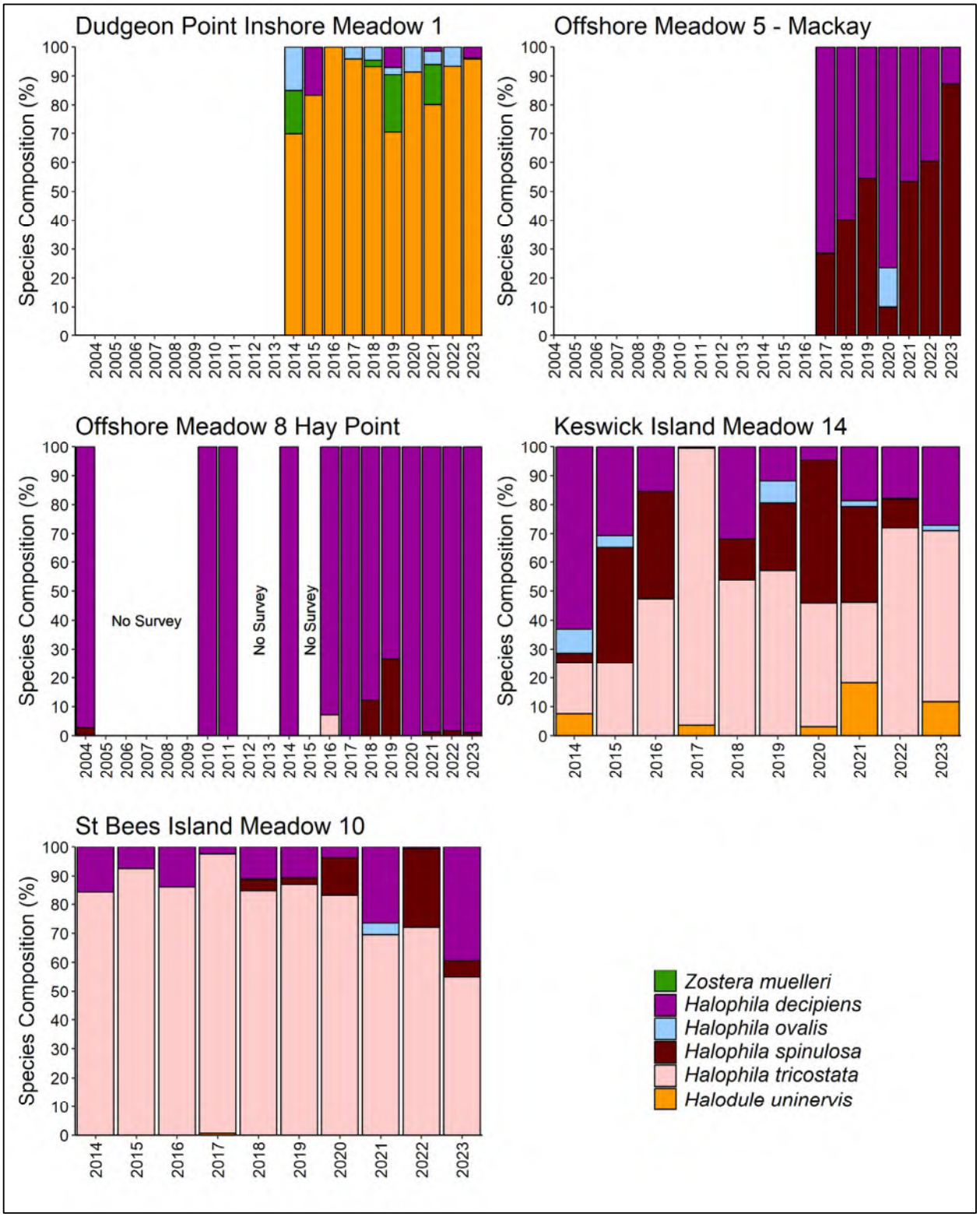

Figure A1. Species composition of monitoring meadows in the Hay Point-Mackay region, and the Keswick Island group.