

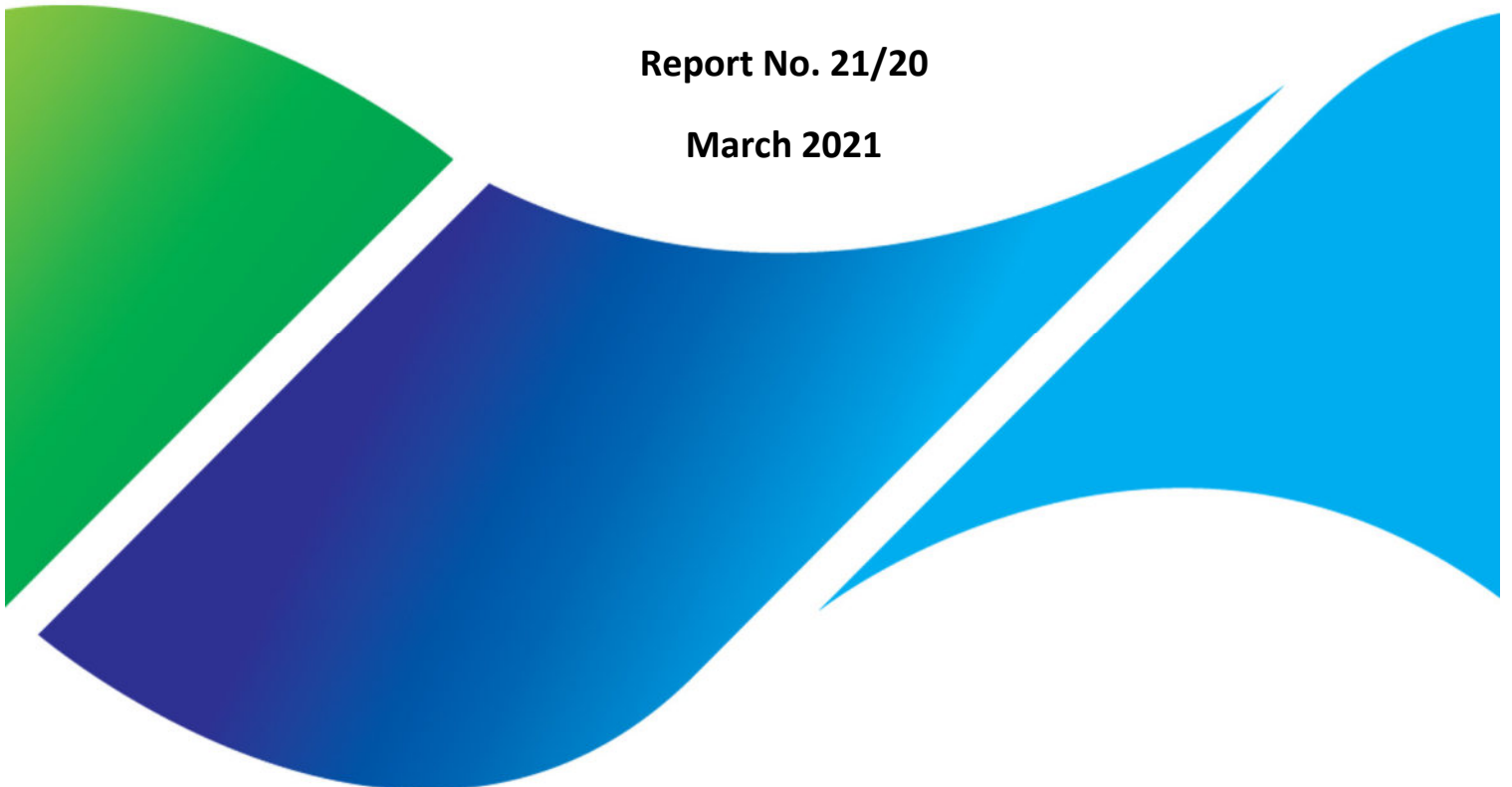


ANNUAL SEAGRASS MONITORING IN THE MACKAY-HAY POINT REGION – 2020

York PH and Rasheed MA

Report No. 21/20

March 2021



ANNUAL SEAGRASS MONITORING IN THE MACKAY-HAY POINT REGION – 2020

Report No. 21/20

March 2021

Prepared by Paul York and Michael Rasheed

Centre for Tropical Water & Aquatic Ecosystem Research
(TropWATER)

James Cook University

PO Box 6811

Cairns Qld 4870

Phone : (07) 4781 4262

Email: seagrass@jcu.edu.au

Web: <https://www.tropwater.com>



Information should be cited as:

York PH and Rasheed MA 2021, 'Annual Seagrass Monitoring in the Mackay-Hay Point Region – 2020', JCU Centre for Tropical Water & Aquatic Ecosystem Research Publication 21/20, Cairns. 42pp.

For further information contact:

Michael Rasheed
Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
michael.rasheed@jcu.edu.au
PO Box 6811
Cairns QLD 4870

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

© James Cook University, 2021.

Except as permitted by the *Copyright Act 1968*, no part of the work may in any form or by any electronic, mechanical, photocopying, recording, or any other means be reproduced, stored in a retrieval system or be broadcast or transmitted without the prior written permission of TropWATER. The information contained herein is subject to change without notice. The copyright owner shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.

Enquiries about reproduction, including downloading or printing the web version, should be directed to seagrass@jcu.edu.au

Acknowledgments:

This project was funded by North Queensland Bulk Ports. We wish to thank the many TropWATER staff that helped put this project and report together.

KEY FINDINGS

OVERALL CONDITION

Hay Point and Mackay



HABITAT TYPES

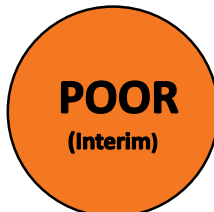
Coastal

Dudgeon Point



Deepwater

Hay Point-Mackay



Offshore Island

Keswick and St Bees



- This report compiles findings of the annual Hay Point-Mackay long-term seagrass monitoring conducted in October 2020
- The overall seagrass condition in 2020 in the Hay Point-Mackay region was classified as satisfactory negating improvement to good condition in 2019. Seagrass condition was variable among different seagrass habitats and locations.
 - Coastal meadows at Dudgeon Point shifted from good to satisfactory condition in 2020 due to a decline in meadow area.
 - The highly variable seagrass in the Hay Point offshore deep-water declined from very good to poor in 2020 due to substantial decline in meadow area and a moderate decline in biomass. This meadow has been in poor condition for 3 out of the last 4 years.
 - In contrast, the Mackay offshore monitoring area recorded its largest area of deep-water seagrass since sampling began in 2017.
 - Meadows at offshore Islands (Keswick and St Bees combined) maintained their overall good condition for 2020 with the highest biomass recorded since surveys began in 2014 despite loss of meadow area at St Bees Island.
- Although overall conditions were favourable for seagrass growth in the 12 months before to the survey, higher than average wave heights in September may have caused sediment resuspension that impacted the colonising, deep-water and coastal species prior to the monitoring.

Likely causes of seagrass condition:

- *Above average wave height in the month prior to the survey may have negatively impacted water quality and seagrass growth*
- *No significant large-scale adverse weather events over the last three years*

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 2020 the annual monitoring survey of seagrass included an extended, broad-scale survey for the first time since 2017. Overall seagrass condition throughout the region was satisfactory in 2020, a decline from good in 2019, however, condition also varied among locations and seagrass community types. The deep-water meadows offshore from Hay Point were in poor condition, the coastal meadow at Dudgeon Point and the meadow adjacent to St Bees Island were in satisfactory condition and the meadow adjacent to Keswick Island was in good condition (Figure 1).

The shift in condition of deep-water seagrass offshore from Hay Point from very good condition to poor was primarily due to a large reduction in the area of seagrass and a decline in biomass due to the absence in 2020 of the larger species *H. spinulosa*. Deep-water seagrasses in this monitoring area are dominated by the colonising species *Halophila decipiens* which is adapted to surviving in low light conditions. *Halophila* species have been shown to have much lower resistance to light deprivation with mortality occurring in days to weeks rather than months for other larger seagrass species. Since 2004 the spatial footprint of the Hay Point offshore meadow has shifted location and expanded or contracted on an annual basis. The month prior to the annual survey (September) experienced above-average maximum wave height which may have increased sediment resuspension in the area, diminishing water quality and leading to a decline in the area of seagrass. In contrast, the Mackay offshore annual monitoring meadow had the largest area of seagrass since monitoring began there in 2017. This highlights the very local environmental conditions influencing seagrass distribution in these types of meadows.

Seagrass meadows at Keswick Island and St Bees Island were in good and satisfactory condition in 2020 respectively. At both of these locations the biomass was the highest recorded at the site since monitoring began in 2014. The meadow area at St Bees Island, however, declined by 29 percent compared to the 2019 survey resulting in a shift in condition for this indicator from very good in 2019. The seagrass communities around Keswick and St Bees Island also include *Halophila* species, however, these meadows are dominated by structurally larger species (*H. tricostata* and *H. spinulosa*). These meadows are further offshore than the Hay Point meadows and are less susceptible to fluctuations in light and water quality, however they are still colonising species that can have considerable inter-annual variability.

The aggregated patches that comprise the coastal meadows in the Dudgeon Point monitoring area declined from a good condition in 2019 to satisfactory in 2020 mainly due to a substantial reduction in the area of the meadow. The above average maximum wave heights in September may also have had an impact on the seagrass here. The area where these seagrass meadows occur, interspersed among rocky reef habitat at Dudgeon Point, can be exposed to wave action and high tidal currents that can both scour and resuspend sediments. While the species dominating these coastal meadows are more resistant to disturbance than the offshore meadows, they are still quite dynamic and variable.

At the time of the 2020 survey, the region had experienced three-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 average rainfall, below-average river flows and sea surface temperatures that were above the long term average (Figure 2). However, maximum wave height was above the long-term average, (Figure 2) particularly in the month of September, immediately prior to the survey which may have driven prolonged periods of sediment resuspension leading to reduced water quality. Monitoring at other port locations in Queensland have shown a range of results during 2020. Coastal areas to the north and south of the Hay Point-Mackay region had seagrass in good condition (e.g. Gladstone,

Cairns Harbour and Townsville while the estuarine habitat in Trinity inlet and Mourilyan Harbour were in poor condition and the only other locations where seagrass condition declined in 2020.

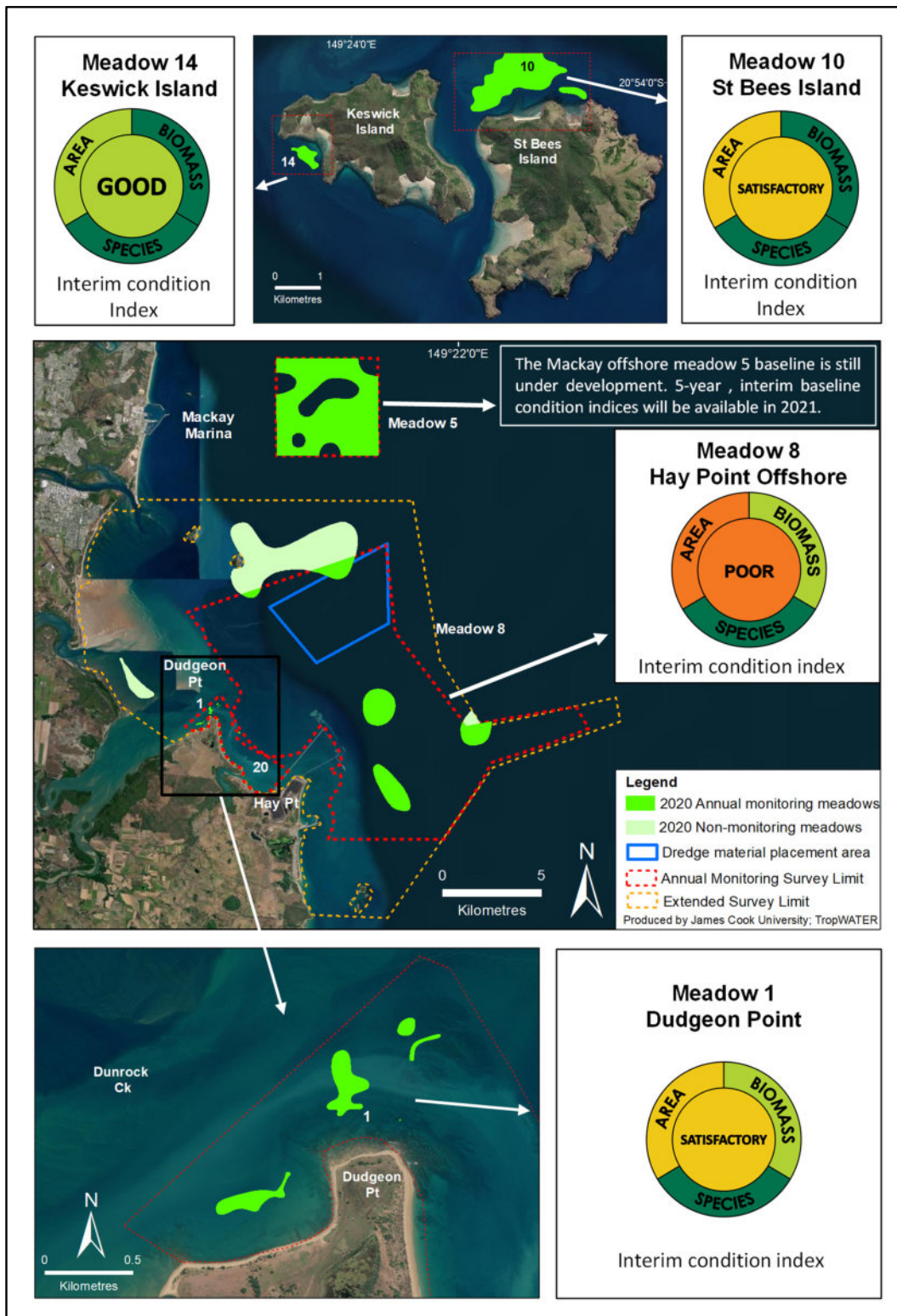


Figure 1. Seagrass meadow condition for the ports of Mackay, Hay Point, Keswick and St Bees Island 2020.

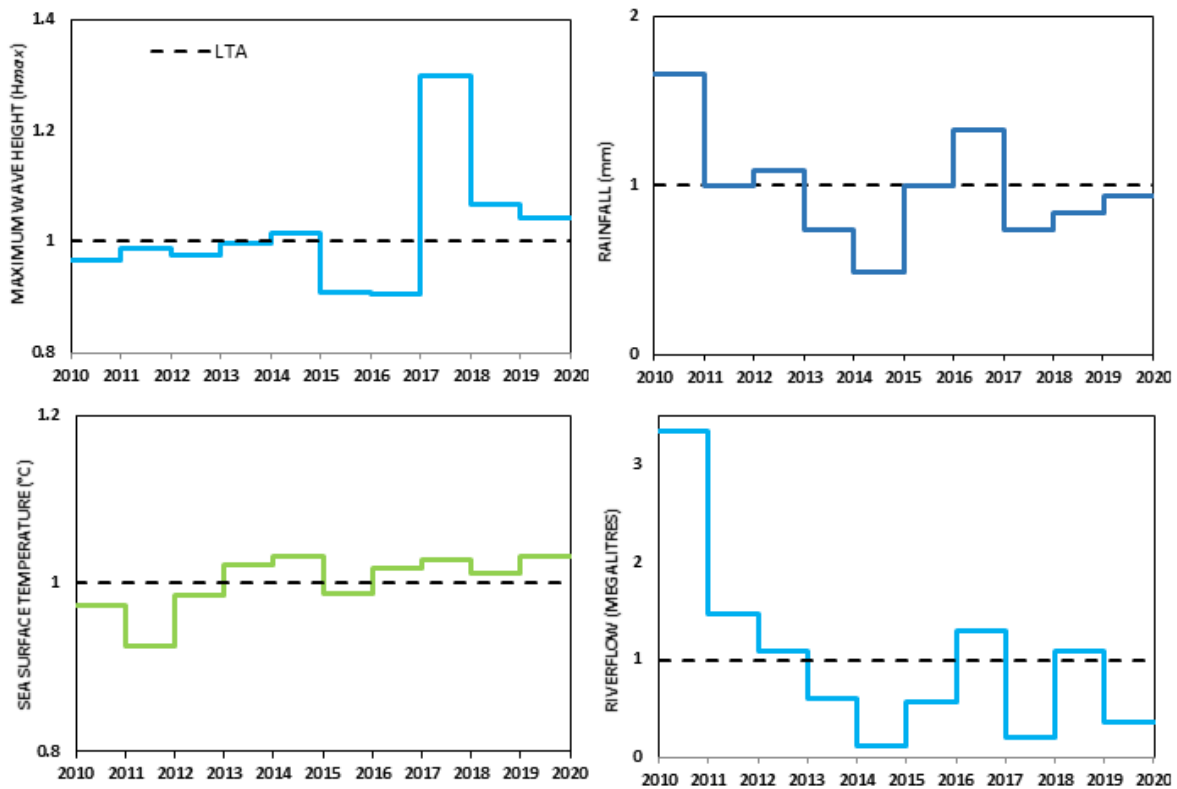


Figure 2. Recent climate trends in the Hay Point Area: change in climate variables as a proportion of the long-term average over the last 10 years (2010 – 2020). Black dotted line represents the long-term average. (See section 3.3 for detailed climate data).

TABLE OF CONTENTS

Key Findings	iv
In Brief	v
1 INTRODUCTION	1
1.1 Queensland ports seagrass monitoring program	1
1.2 Mackay and Hay Point seagrass monitoring program	2
2 METHODS	2
2.1 Annual monitoring within the intensive monitoring area	2
2.2 Seagrass monitoring, habitat mapping and Geographic Information System	2
2.3 Seagrass meadow condition index	5
2.4 Environmental data	6
3 RESULTS	7
3.1 Seagrass in the Hay Point, Mackay and Keswick Island areas	7
3.2 Seagrass condition	10
3.3 Environmental conditions	19
4 DISCUSSION	25
5 REFERENCES	28
6 Appendices	32
Appendix 1 Score Calculation Methods.	32
Appendix 2. Seagrass community types and species composition	38

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).

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

The program delivers key information for the management of port activities to minimise impacts on seagrass habitat and has resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses, and an understanding of the causes of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses.



For more information on the program and reports from the other monitoring locations see: <https://www.tropwater.com/project/management-of-ports-and-coastal-facilities/>

1.2 Mackay and Hay Point seagrass monitoring program

The Port of Hay Point (approximately 38 km south of Mackay) is one of the world's largest coal exporting ports and comprises two coal export terminals; Dalrymple Bay Coal Terminal and the Hay Point Coal Terminal.

The Port of Mackay is a multi-commodity port mainly exporting sugar and grain; located 5km from the city of Mackay. The Port comprises four wharves and a harbour formed by rock breakwaters. North Queensland Bulk Ports (NQBP) is the port authority for the Port of Hay Point and the Port of Mackay.

TropWATER's Seagrass Ecology Group first mapped significant areas of seagrass within the Port of Hay Point in a benthic survey conducted in July 2004 (Rasheed et al. 2004) and in Mackay in 2001 (Rasheed et al. 2001). The broad-scale habitat surveys that have since occurred at Hay Point (2005, 2010, 2011, 2014, 2016 and 2017), as well as the seagrass monitoring program that ran between 2005 and 2012, has established that the majority of seagrass in the area is of low density and cover ($< 1 \text{ gdw m}^{-2}$ 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 marine port environments. Information collected in these programs aims to assist in planning and managing future developments in coastal areas. The monitoring program also forms part of Queensland's network of long-term monitoring sites of important fish habitats in high risk areas. It provides a key input into the condition and trend of seagrasses in the Mackay-Whitsundays NRM region, an area which otherwise has a poor spatial coverage for seagrass assessment and condition.

From 2017 there has been a change in approach to annual monitoring and reporting of the highly variable offshore seagrasses at Hay Point, from focusing on the fixed blocks originally established to detect changes related to the 2006 capital dredging program, to a more expansive meadow scale assessment with an increased sampling effort. This change has been implemented due to the extreme spatial variability in the area these seagrasses limiting the effectiveness of the fixed design. The spatial variability is a natural consequence of the ephemeral nature of deep-water *Halophila* meadows. The new level of sampling is achieved by spreading sampling during annual monitoring to cover the same footprint as the original 2004 extended survey. Historically, this was already done in extended surveys at intervals covering several years beginning in 2004. This historical sampling covering the 2004 survey limit allows for the calculation of an interim seagrass condition score for reporting to continue with the additional advantage of incorporating change in seagrass area to the assessment. When a 10-year baseline has been established over the broader footprint of the 2004 survey limit this condition index will become permanent. Since 2018, the surveys of the annual monitoring areas along the coast between Dudgeon Point and Hay Point and at meadows adjacent to Keswick and St Bees Islands have been used to calculate seagrass condition scores. This is possible now due to the availability of 5-years of survey data at these sites allowing for the establishment of interim long-term averages. These averages will be adjusted with additional annual data until a permanent baseline can be established with 10 years of data. The recently established monitoring meadow offshore from Mackay still requires one more year of data before an interim baseline can be established. These changes bring the assessment of seagrass meadows in line with seagrass monitoring programs in other ports and significantly improves the monitoring program's power to understand seagrass changes.

In 2020, an extended broad-scale survey of the port area was conducted in conjunction with the annual monitoring program. The previous broad-scale survey was in 2017. This report presents the findings of the annual seagrass habitat monitoring survey and the extended broad-scale survey conducted in October 2020 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 included in the extended broad-scale survey limits 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.

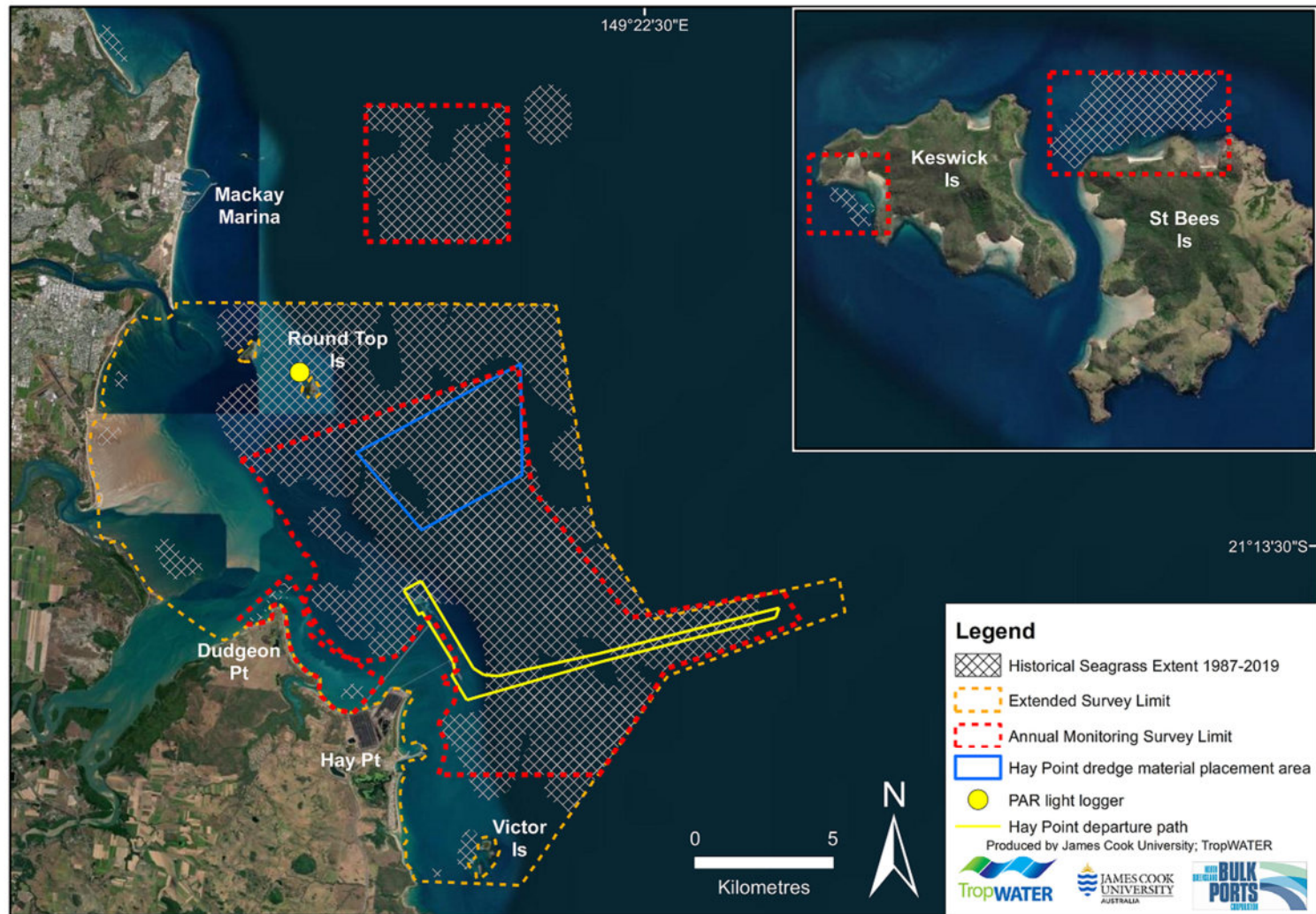


Figure 4. Location of survey limits of annual and extended seagrass monitoring areas around Mackay, Hay Point and the Keswick Island group in 2020.

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 October 2020 (Figure 4). The previous broad-scale mapping and monitoring of meadows across the greater region was last undertaken in 2017.

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 0.25m² 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 0.25m² quadrat, scaled to the video camera lens used in the field, was superimposed on the screen to standardise biomass estimates.

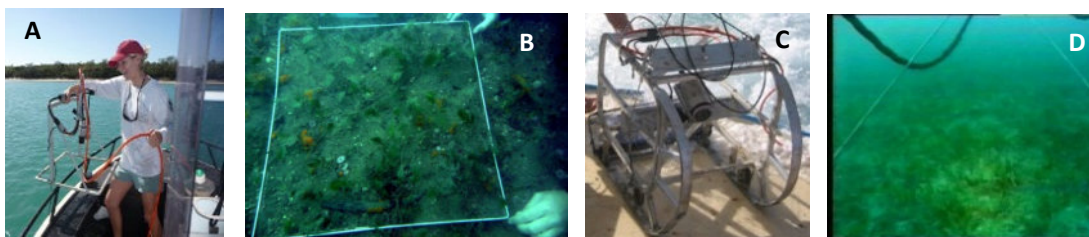


Figure 5. (A) Shallow subtidal mapping of seagrass meadows using digital camera mounted on a 0.25m² drop frame, (B) visual observation by free diver and (C-D) offshore underwater sled tows with digital camera.

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)				
	<i>H. uninervis</i> (narrow)	<i>H. ovalis</i> <i>H. decipiens</i>	<i>H. uninervis</i> (wide)	<i>H. spinulosa</i> <i>H. tricostrata</i>	<i>Z. muelleri</i>
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 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 ≤ 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 2020, the condition index was applied to the offshore monitoring sites at Hay Point, and coastal monitoring meadows at Dudgeon Point, Keswick Island and St Bees Island. The Hay Point offshore meadow condition is presently based on 9-years of data (2004, 2010, 2011, 2014, 2016, 2017, 2018, 2019 & 2020). Scores will vary until 10 years of data become available to establish a baseline. The survey conducted in 2005 in the monitoring area was excluded from the baseline calculation as it was conducted late in the year (December) a time period when the dominant species for the meadow (*Halophila decipiens*) was likely to have already died off for the season leaving only a small patch of much higher biomass *H. spinulosa* remaining. Including this small patch as representing the entire offshore seagrass meadow would result in significantly skewing the long-term average biomass data. Presently, interim scores for the Dudgeon Point, Keswick Island and St Bees Island monitoring meadows are assessed against 7 years of averaged data (2014-2020). These averages will vary annually

until 10 years of data become settled in 2023. The monitoring meadow at Dudgeon Point comprises an amalgamation of meadows previously reported as meadows 1, 2 and 3 in previous reports. The Mackay offshore monitoring meadow was established (2017) and there is insufficient data available to calculate meadow condition scores until 2021.

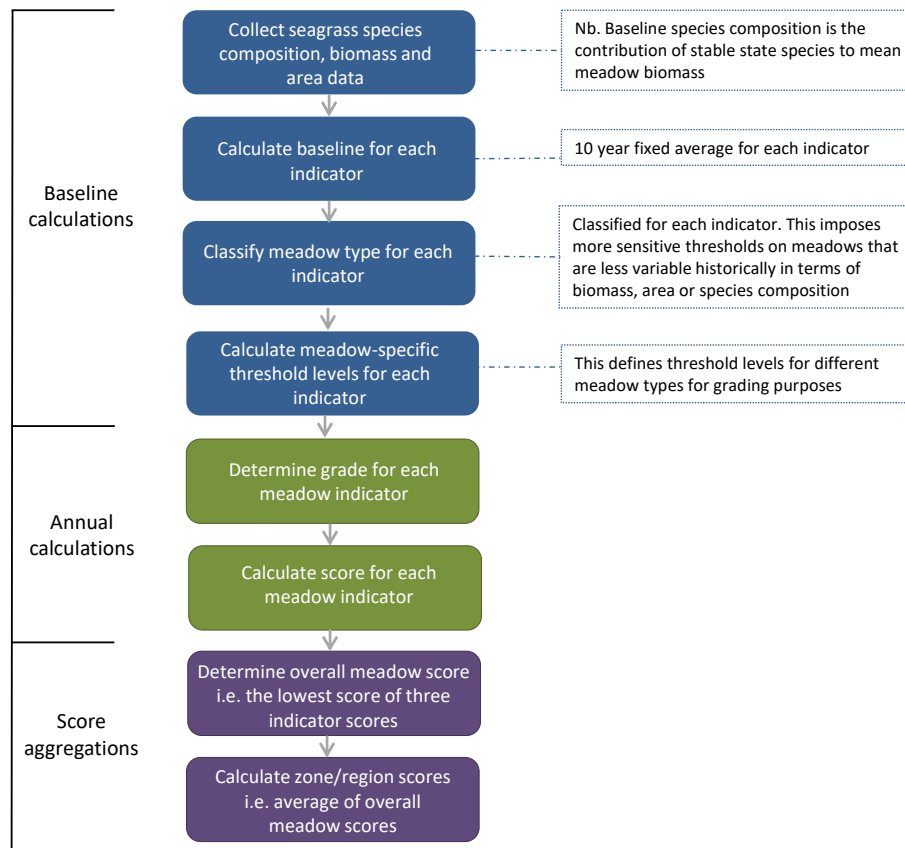


Figure 7. Flow chart to assess seagrass monitoring meadow condition.

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 - $\text{mol photons m}^{-2} \text{ day}^{-1}$) 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. 2020). 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 483 sites were surveyed as part of the annual and extended monitoring survey in the Hay Point, Mackay and Keswick Island area in October 2020 (Figure 9). Seagrass was present at 17.8 % of all coastal sites in the extended survey which includes 14.0 % of sites within the Dudgeon Point annual monitoring areas, as well as 44.7 % of sites at the Keswick and St Bees Islands annual monitoring areas (Figure 9). Seagrass was present at 27.4 % of all the offshore sites in the extended survey which included 73.1 % of sites in the Mackay offshore annual monitoring area (Meadow 5) and 10.3 % of sites in the Hay Point offshore annual monitoring area (Meadow 8) (Figure 9). Deep-water seagrass communities in the extended survey area offshore from Hay Point and Mackay covered an area of 3784.5 ± 684.3 ha. Coastal meadows covered 112.0 ± 14.6 ha around Dudgeon Point which included a non-monitoring meadow (Meadow 9) of 103.4 ± 11.4 ha. Seagrass adjacent to Keswick and St Bees Islands covered 154.5 ± 40.3 ha (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 10, Appendix 2). Five seagrass species were observed in 2020, down from six reported in 2019 (Figure 8). Deepwater assemblages offshore from Hay Point and Mackay were dominated by *Halophila decipiens* with *Halophila spinulosa* also occurring 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* and *H. ovalis* also occurring (Figure 10), Appendix 2). *Halodule uninervis* (both wide and narrow forms) dominated the inshore meadows at Dudgeon Point with *H. ovalis* also occurring (Figure 10, Appendix 2). Following two consecutive years (2018-2019) of the presence of *Zostera muelleri* in the Dudgeon Point coastal meadow it was not recorded in 2020.

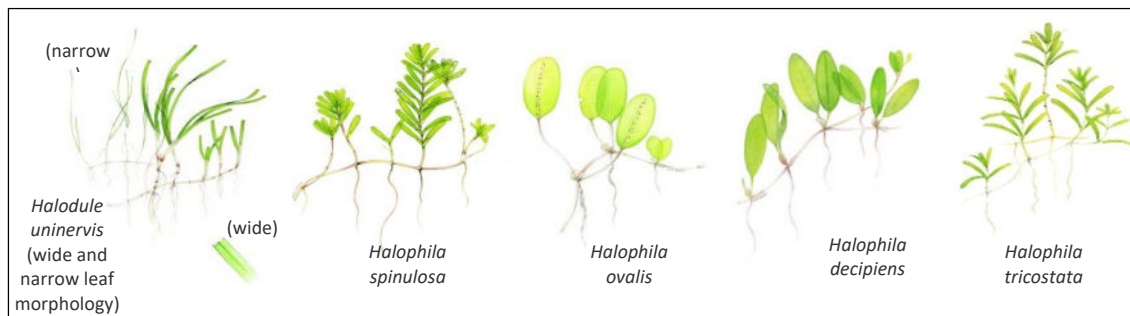


Figure 8. Seagrass species identified in the Hay Point-Mackay annual monitoring program in 2020. Leaf size varies widely within species and diagrams are not to scale.

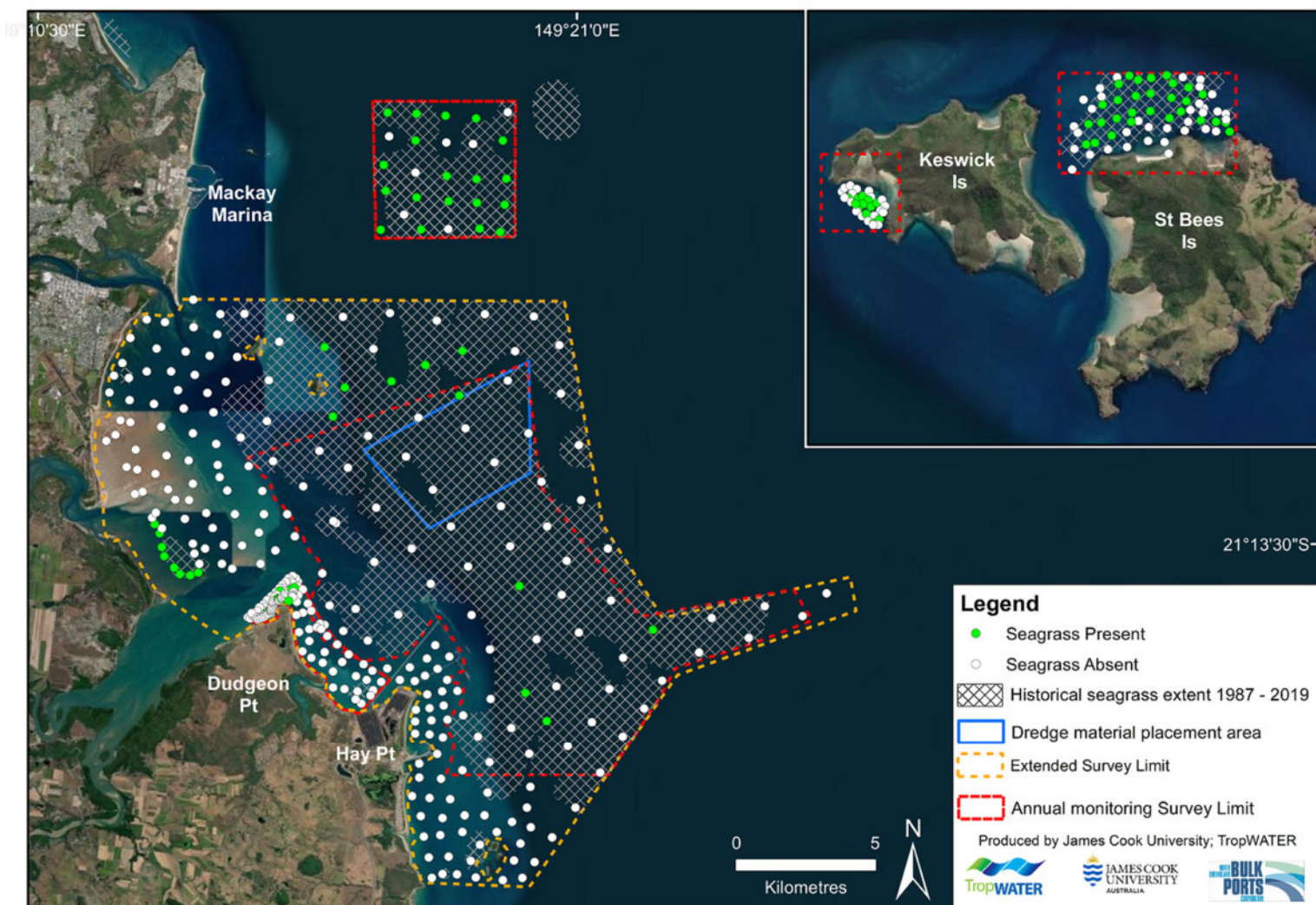


Figure 9. Location of 2020 annual and extended seagrass monitoring survey sites in the Hay Point-Mackay region.

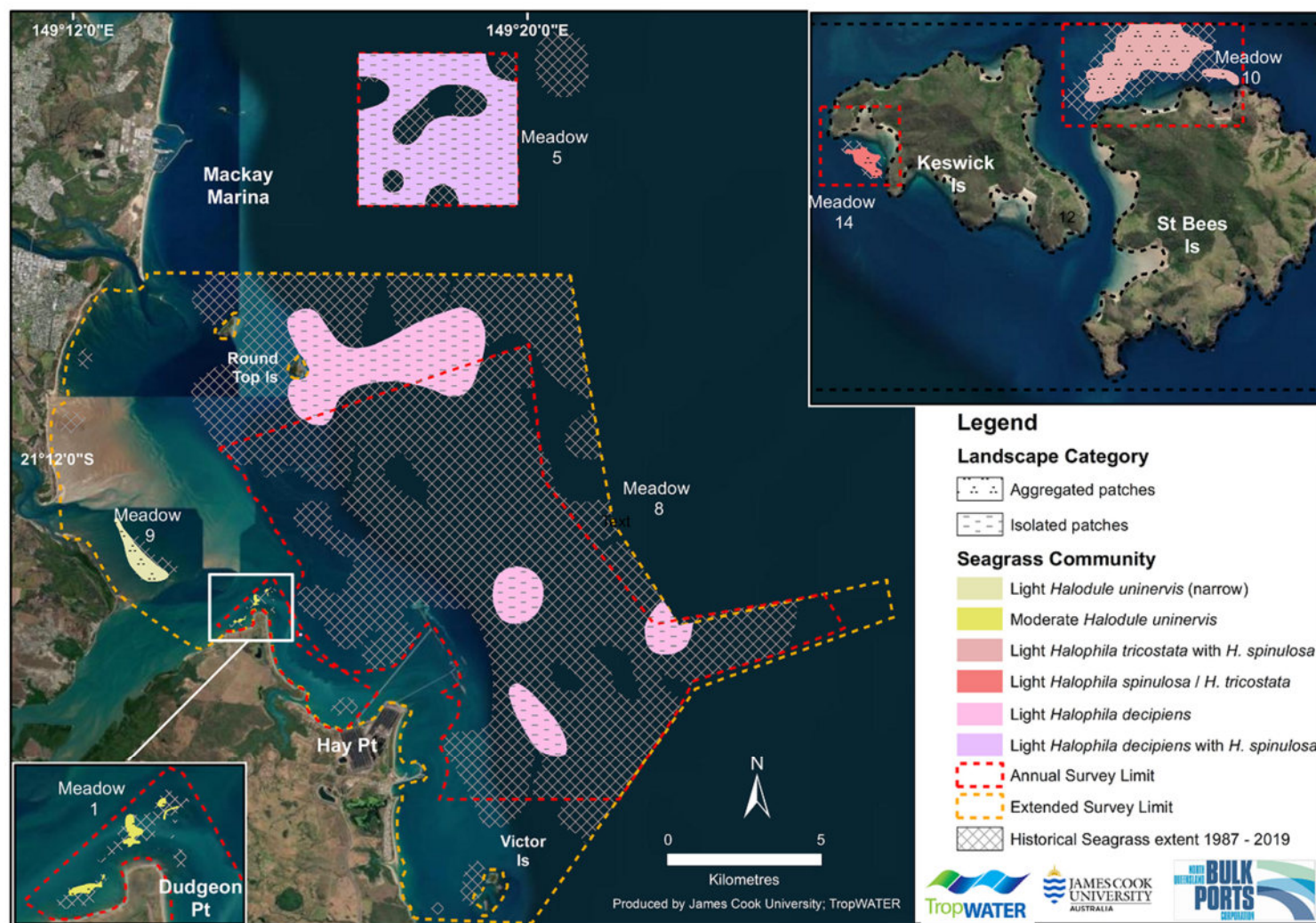


Figure 10. Location of 2020 seagrass meadows in the Hay Point region showing seagrass communities and landscape categories.

3.2 Seagrass condition in the Hay Point, Mackay and Keswick Island annual monitoring areas and extended broad-scale survey.

Offshore seagrass at Hay Point and Mackay

The overall condition of offshore seagrasses in the Hay Point monitoring area scored poor in 2020, a decline from a very good condition in 2019, which was the best condition this meadow had experienced since the condition index was introduced in 2015. The decline in condition was the result of a substantial decreases in seagrass meadow area and a smaller decrease in biomass. The area of the meadow reduced in size to 736.9 ± 258.2 ha in 2020, only 17.1 % of the spatial footprint covered by the meadow in 2019 (Figure 11 & 15, Appendix 2; Table A4). The extended broad-scale survey also found an area of deep-water seagrass outside of the annual monitoring area to the east of Round Top Island that increased the overall area of offshore seagrass to 1912.9 ± 377.7 ha (Figure 10) but is not included in the condition score. Biomass in 2020 (mean \pm 1SE = 0.041 ± 0.004 g DW m²) also declined from high levels recorded in 2019 (0.096 ± 0.023 g DW m²). Despite this decline the biomass was still in good condition compared to the long-term baseline average for this meadow (Figure 11, Appendix 2; Table A4). The only species present within the Hay Point offshore meadow in 2020 was the pioneering *H. decipiens*, which has been the dominant species for this area throughout the programs history. *H. spinulosa* was present in the area in 2019 but was not found in 2020 (Appendix 2; Figure A2).

The 2020 survey of the area offshore from Mackay Harbour found the largest seagrass area (1871.6 ± 306.6 ha) since this location was included in the monitoring program (Figure 10). This was a slight increase on the 2019 area and considerably larger than the area surveyed in 2017 and 2018 (Appendix 2; Table A4). The seagrass biomass recorded in the 2020 survey (mean \pm 1SE = 0.077 ± 0.013 g DW m²) was lower than in the previous surveys when the mean biomass was 0.135 ± 0.073 g DW m² in 2019 (Appendix 2; Table A4). This decline in biomass is likely driven by a shift in the species composition from *H. spinulosa* dominated meadow in 2019 (54.4 % by weight) to a *H. decipiens* dominated meadow in 2020 (76.5 % by weight) (Appendix 2; Figure A2). As this is the fourth year that the Mackay offshore meadow has been monitored, a condition score cannot be produced until 2021 when the 5 years of data required for an interim score will be reached.

Inshore seagrass at Dudgeon Point

The coastal intertidal monitoring meadow at Dudgeon Point changed in condition from good to satisfactory in 2020. The change in score was primarily the result of a large declines in the area of the aggregated patches over the previous two years from a high of 22.6 ± 4.2 ha in 2018 to 8.6 ± 3.3 ha in 2020 (Figure 12 & 16, Appendix 2; Table A5). Biomass at the site declined from 3.01 ± 0.72 g DW m² in 2019 to 1.76 ± 0.62 g DW m² in 2020, however still remained in good condition (Figure 12, Appendix 2; Table A5). Only two species, *H. uninervis* (both wide and narrow leaf forms) and *H. ovalis*, were found in the Dudgeon Point monitoring area in 2020 with *Z. muelleri* and *H. decipiens* not found despite these species being present in 2019 (Appendix 2; Figure A2). In the extended survey area a large intertidal meadow of *H. uninervis* to the north of Dudgeon Point (Meadow 9) was mapped with an area of 103.4 ± 11.4 ha and a mean biomass of 0.45 ± 0.19 g DW m² (Figure 10). The small patch of *H. uninervis* observed in Meadow 20, north of the Hay Point terminal in 2019 was not present in the 2020 survey (Appendix 2; Table A5, Meadow 20).

Keswick and St Bees Islands

The seagrass monitoring meadow adjacent to St Bees Islands was scored as in satisfactory condition in 2020, down from a good classification in 2019 and very good in 2018 (Table 4). The change in

classification was due to a decline in the area of the meadow from 197.3 ± 42.9 ha in 2019 to 140.4 ± 36.5 ha (Figure 13 & 17, Appendix 2; Table A6). Biomass increased to 2.90 ± 0.36 g DW m² in 2020, the highest level recorded at the site since monitoring began in 2014 (Figure 13, Appendix 2; Table A6). Three species were found in the meadow in 2020 dominated by *H. tricostata* (83 % by weight) with *H. spinulosa* (13 %) and *H. decipiens* (4 %), also occurring (Appendix 2; Figure A2). The Keswick Island monitoring meadow remained in a good condition in 2020 (Table 4). The area of the meadow (14.2 ± 3.8 ha) remained stable around the long-term average for the site while the biomass increased to the highest level recorded at the site 3.96 ± 1.23 g DW m² in 2020 (Figure 14, Appendix 2; Table A6). The increase in biomass is likely due to the dominance of *H. spinulosa* (49.4 % by weight) in the meadow in 2020. Three other species were also present; *H. tricostata* (42.8 %), *H. decipiens* (4.7 %) and *H. uninervis* (3.1%) (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 2020.

Meadow	Location	Biomass	Area	Species Composition	Overall Meadow Score
1	Dudgeon Point	0.68	0.58	0.91	0.58
8	Hay Point - Offshore	0.70	0.47	1.00	0.47
10	St Bees Island	0.93	0.64	0.95	0.64
14	Keswick Island	0.92	0.73	0.98	0.73
Overall Score for the Hay Point-Mackay region					0.61

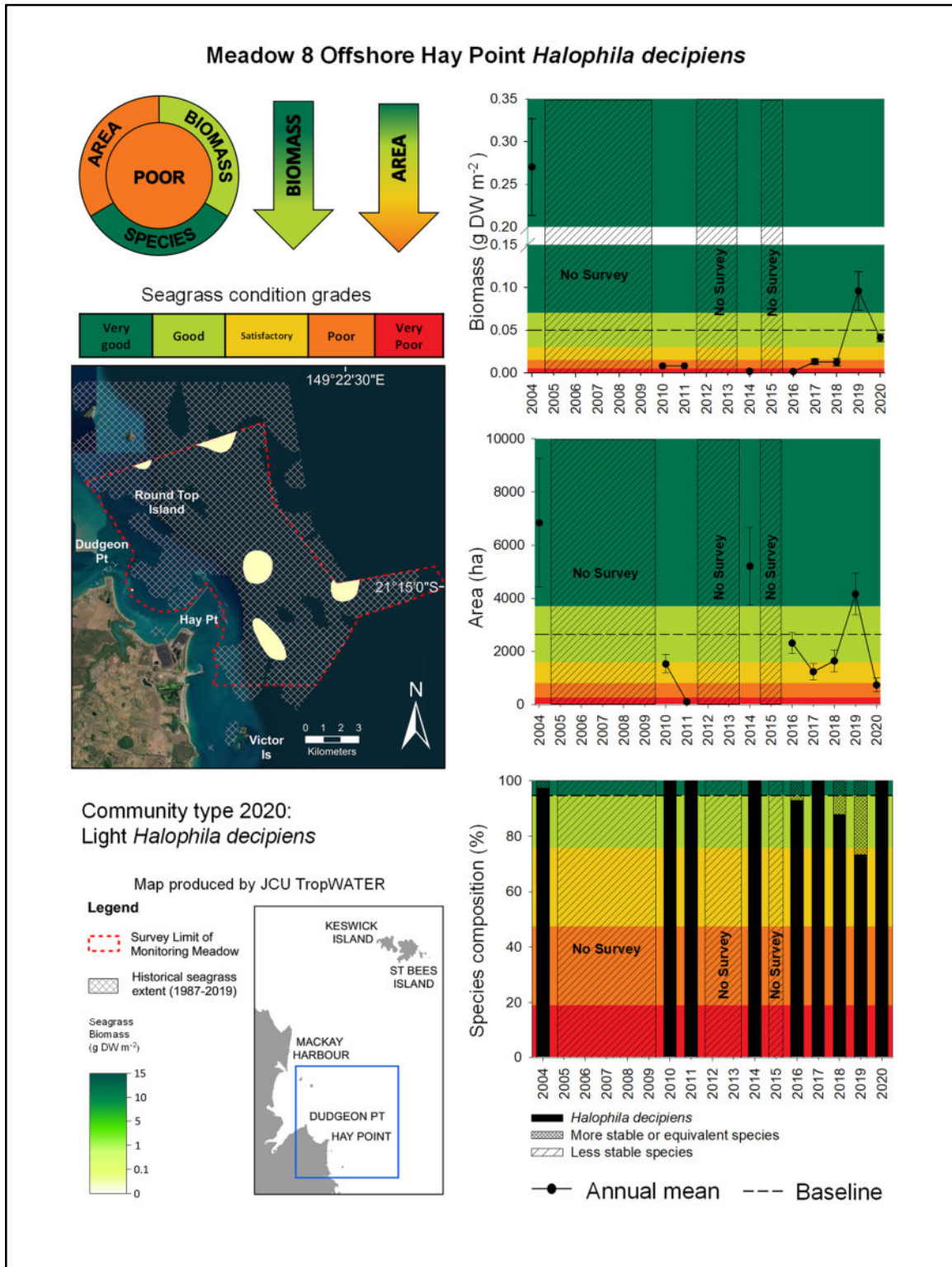


Figure 11. Changes in meadow biomass, area and species composition for seagrass in the Hay Point offshore area (Meadow 8), 2004 – 2020 (biomass error bars = SE).

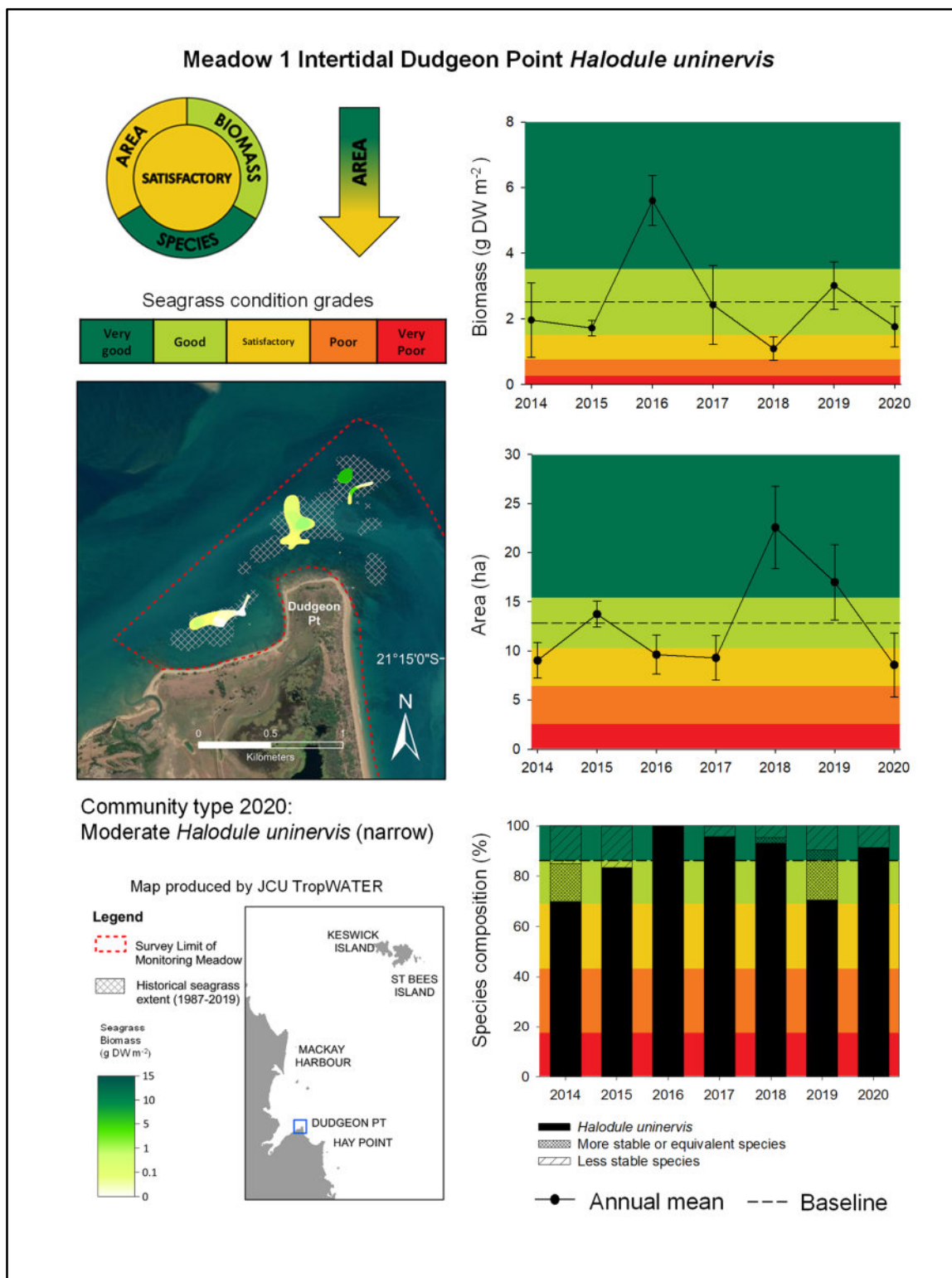


Figure 12. Changes in meadow biomass, area and species composition for seagrass in the Dudgeon Point coastal area (Meadow 1), 2014 – 2020 (biomass error bars = SE).

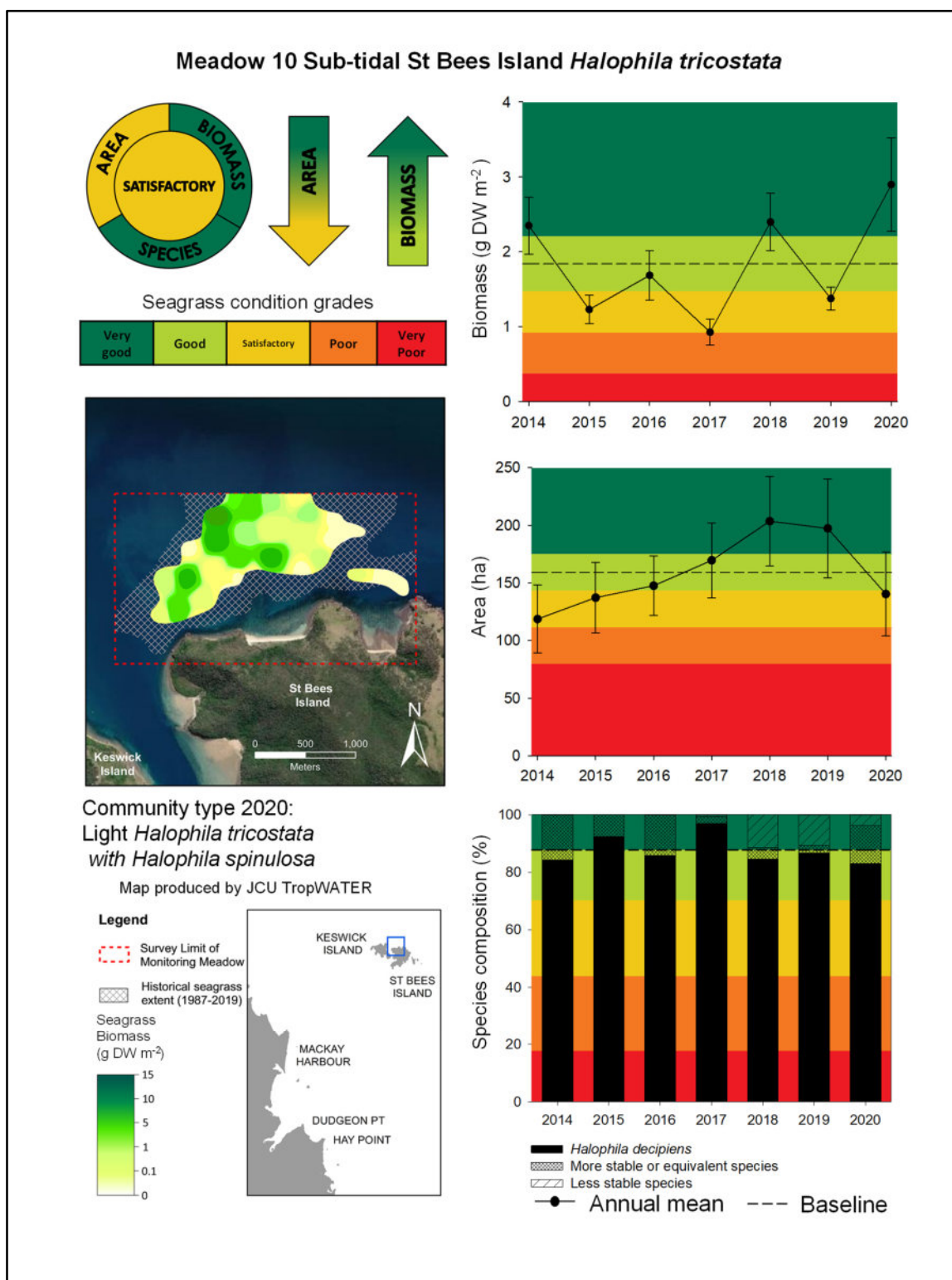


Figure 13. Changes in meadow biomass, area and species composition for seagrass in the St Bees Island coastal area (Meadow 10), 2014 – 2020 (biomass error bars = SE).

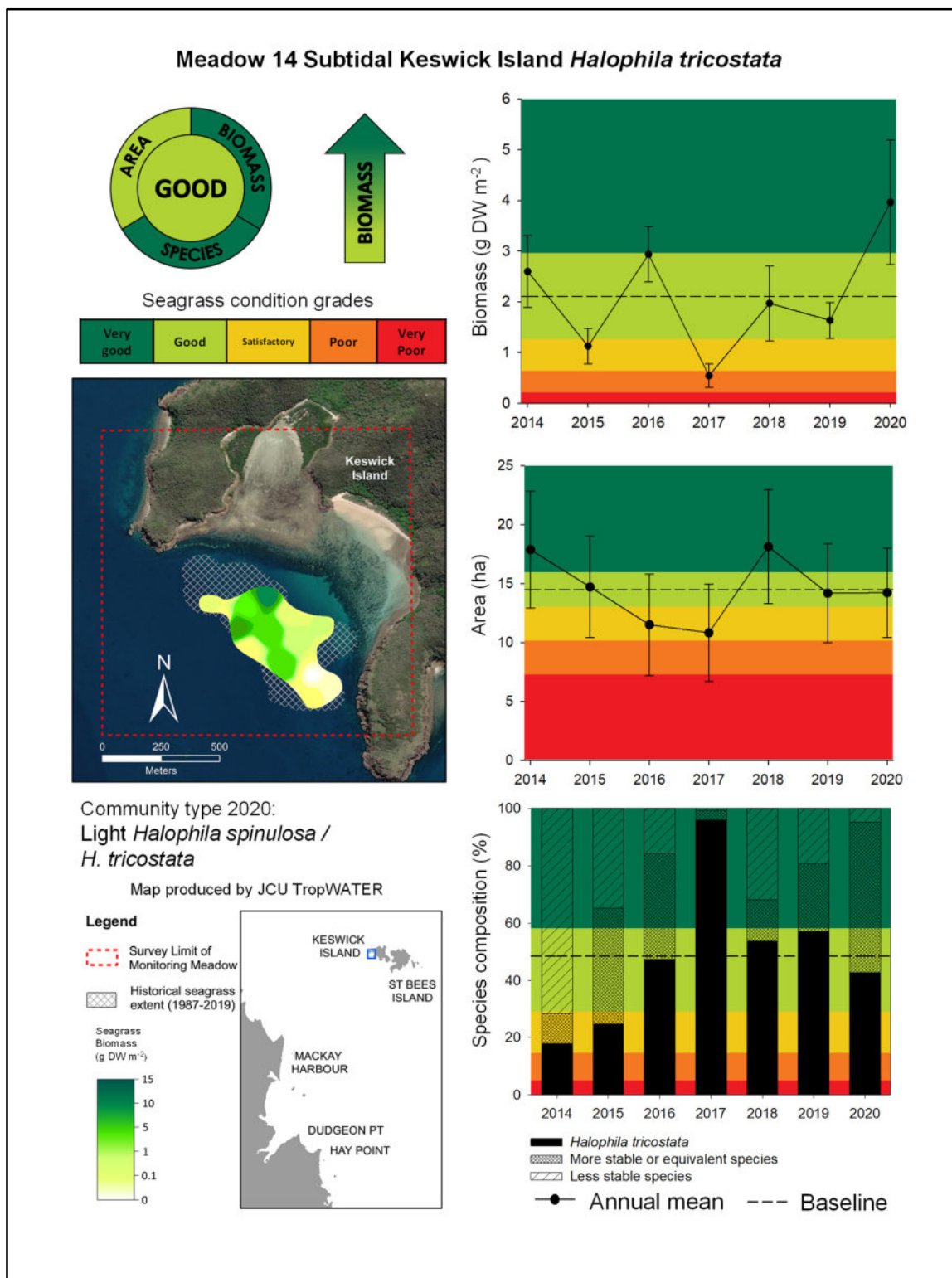


Figure 14. Changes in meadow biomass, area and species composition for seagrass in the Keswick Island coastal area (Meadow 14), 2014 – 2020 (biomass error bars = SE).

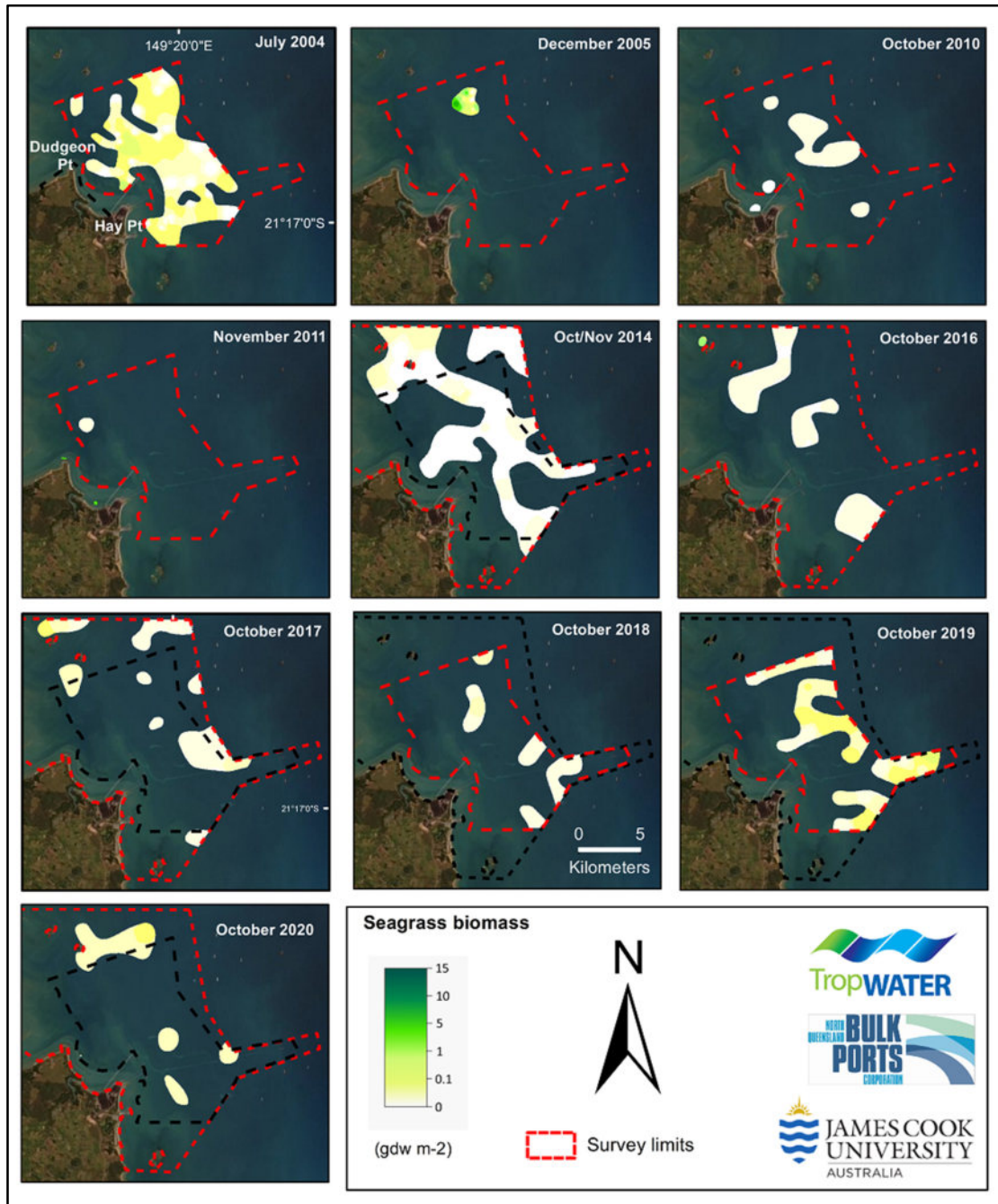


Figure 15. Seagrass biomass distribution in the Hay Point offshore monitoring area when surveys were conducted between 2004-2020.

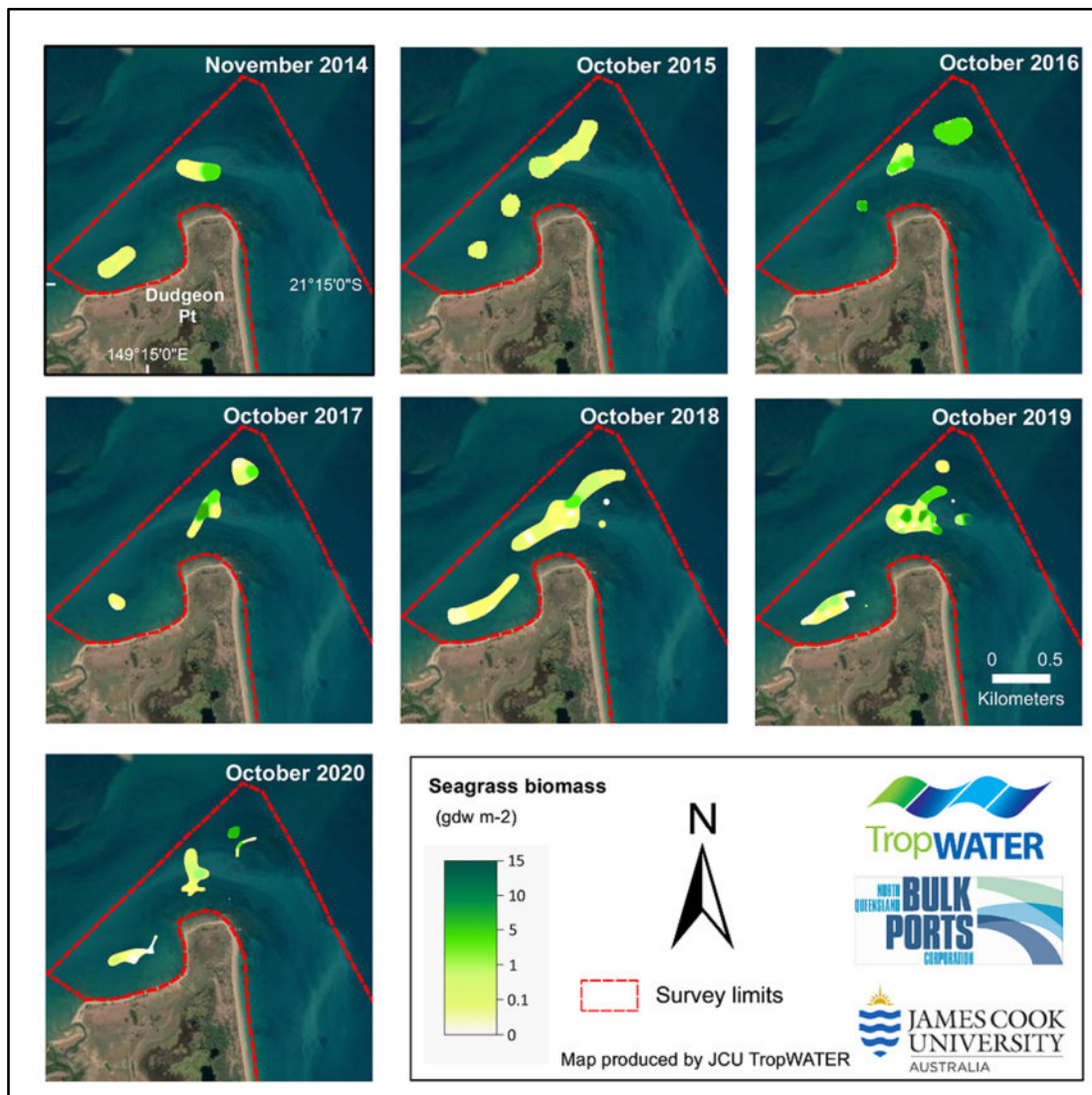


Figure 16. Seagrass biomass distribution in the Dudgeon Point to Hay Point annual monitoring area 2014 -2020.

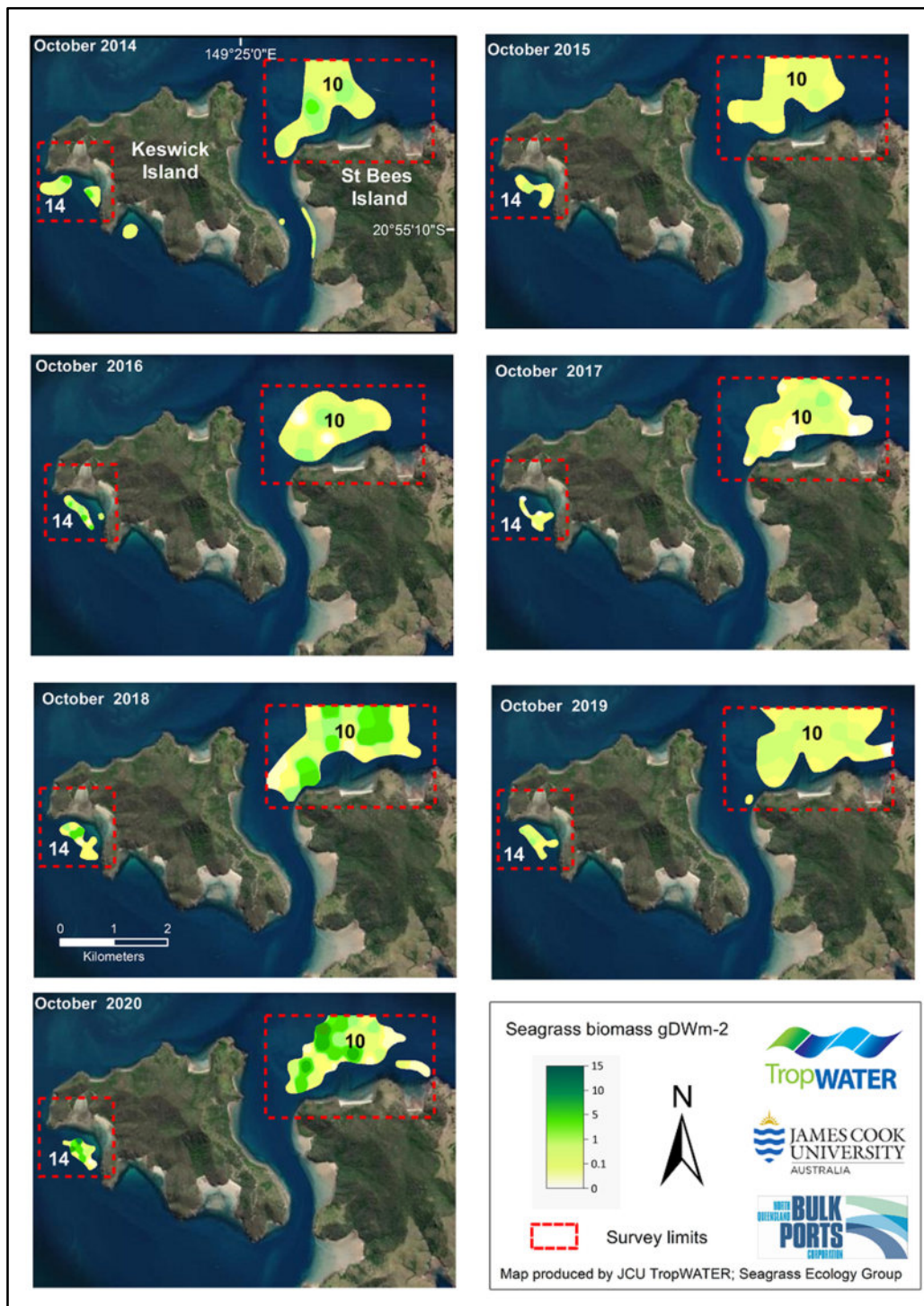


Figure 17. Seagrass biomass distribution in the annual monitoring meadows at Keswick and St Bees Islands 2014 – 2020.

3.3 Environmental conditions

Rainfall

Annual rainfall in the region was below the long term average in 2019/20 for the third consecutive year (Figure 18a). Throughout the year prior to the survey the majority of the rain fell from December 2019 to March 2020 with most of the monthly rainfall figures at or below the monthly long-term averages. Only December 2019 and March 2020 recorded rainfall that was above the long-term average for that month (Figure 18b).

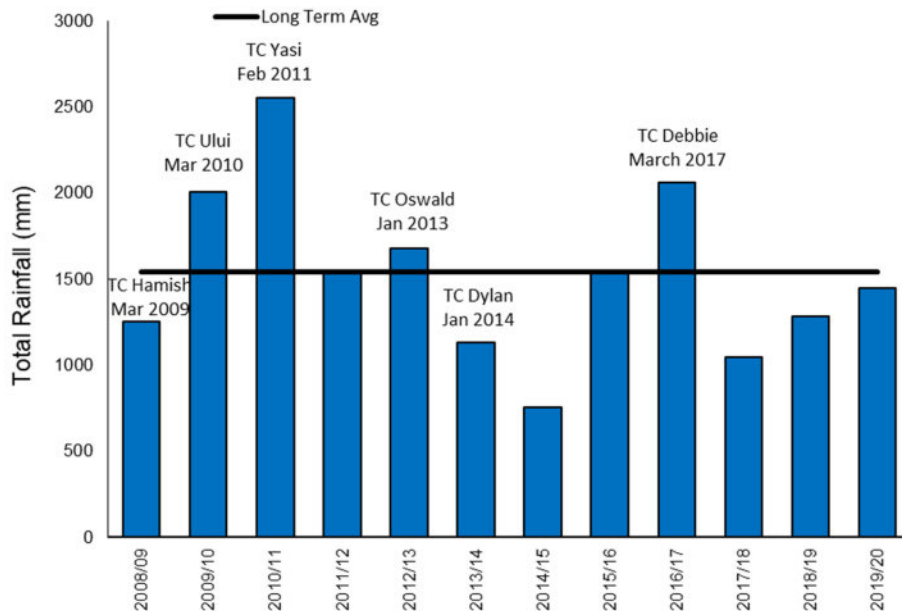


Figure 18a. Total annual rainfall (mm) recorded at Mackay Aero, 2008/09-2019/20. Twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033045.

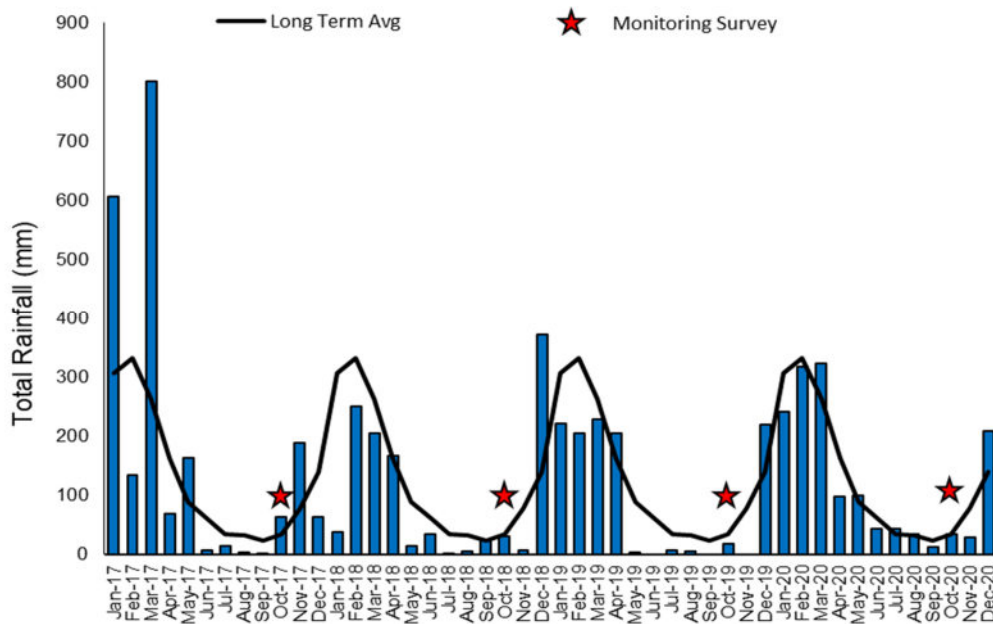


Figure 18b. Total monthly rainfall (mm) recorded at Mackay Aero, January 2017 - December 2020. Source: BOM, Station number 033045.

River flow

Annual river flow of the Pioneer River were only around 36 percent of the long-term average in the year leading up to the survey (Figure 19a). Monthly flow levels throughout the year were below the long-term average throughout the year (Figure 19b).

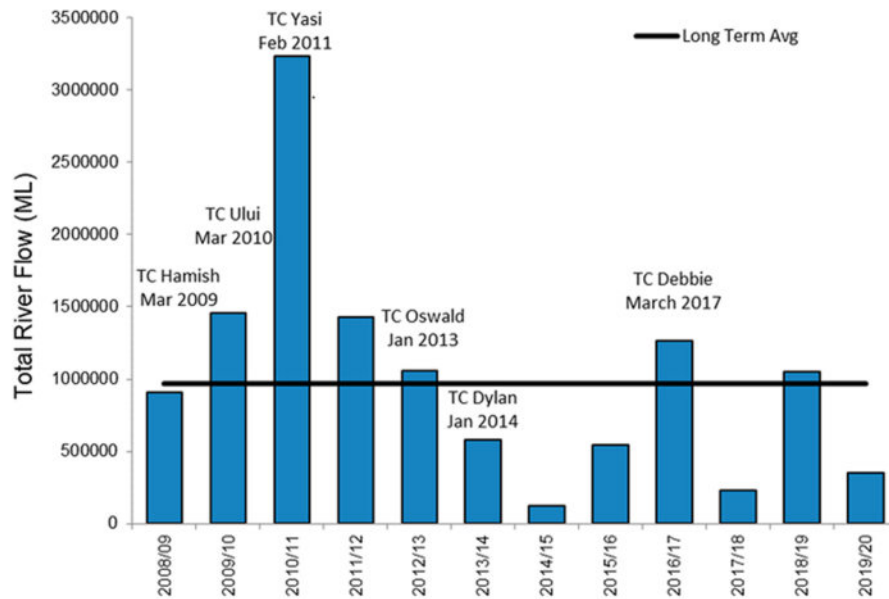


Figure 19a. Annual river flow (Mega litres) for the Pioneer River, 2008/09-2019/20. Source: Queensland Department of Natural Resources, Mines and Energy, Station number 125016A.

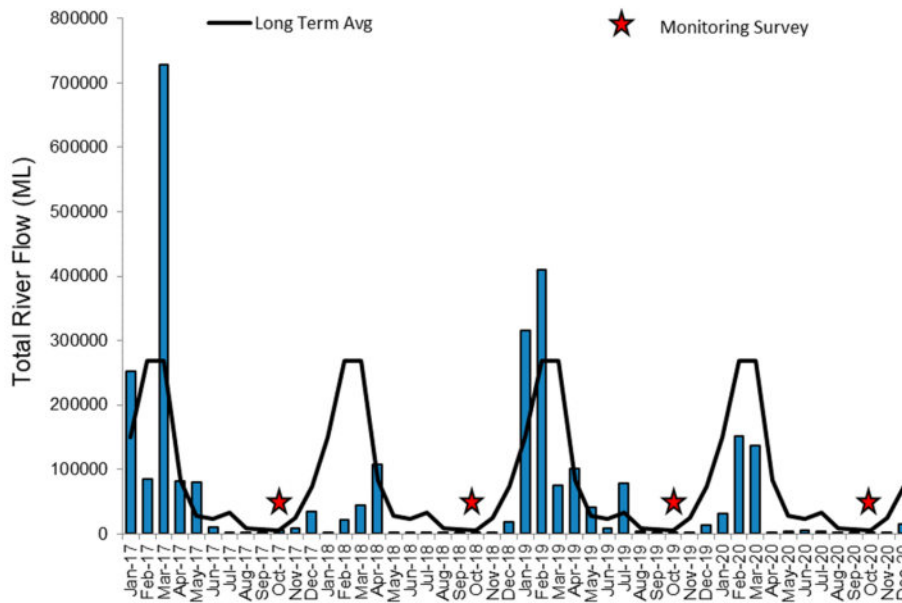


Figure 19b. Monthly river flow (Mega litres) for the Pioneer River January 2017-December 2020. Source: Queensland Department of Natural Resources, Mines and Energy, Station number 125016A.

Sea surface temperature

Sea surface temperature has been collected by the Queensland Government half hourly at Hay Point since 2008. The mean annual maximum daily sea surface temperature of 25.68° C in 2019-20 was 0.3681° C above the long-term average for this location (Figure 20a). Monthly data shows that sea surface temperature was well above the long-term monthly average in the first four months of 2020 (January 2020 to April) but was close to the monthly average in the five months preceding the annual survey (Figure 20b).

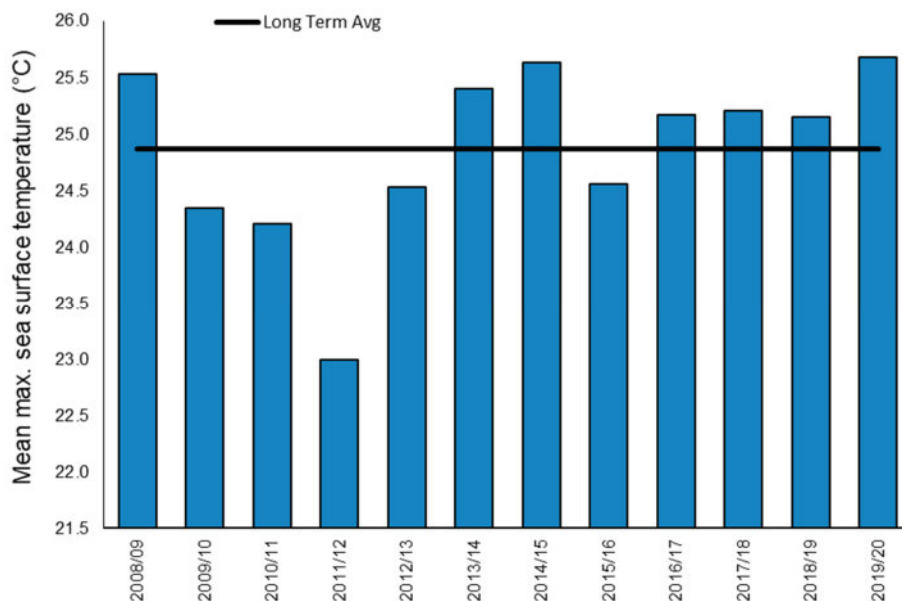


Figure 20a. Mean annual maximum sea surface temperature (°C) recorded at Hay Point 2008/09-2019/20. Source: QLD Department of Environment and Science

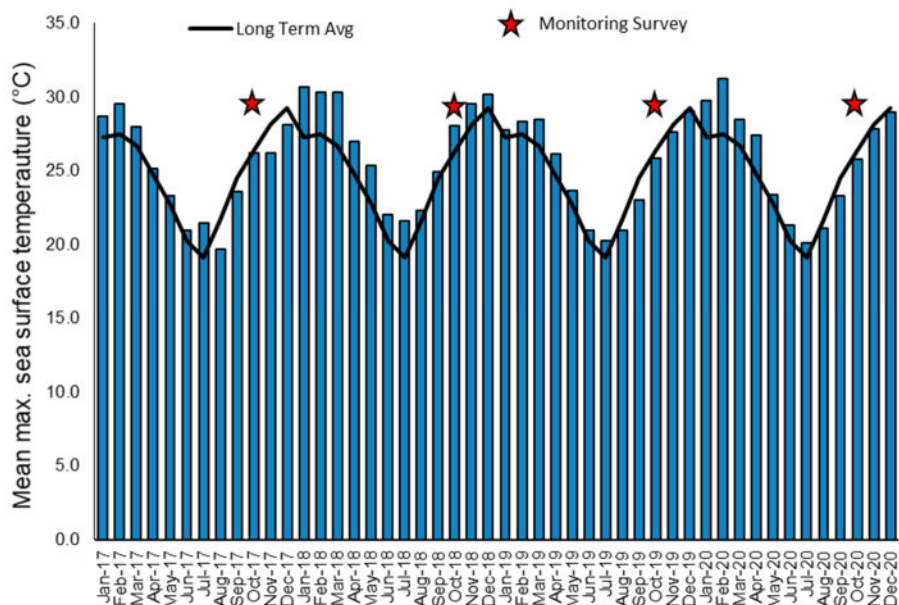


Figure 20b. Monthly maximum sea surface temperature (°C) recorded at Hay Point; January 2017 to December 2020. Source: QLD Department of Environment and Science

Daily solar radiation

Solar exposure in the Hay Point area in the twelve months to the 2019/20 survey was well above the regional long-term average (20.70 MJ m⁻²) (Figure 21a). This high annual mean was mainly due to above average monthly exposure from November 2019 through to February 2020. Monthly exposure was very close to the long-term average in the six months preceding the annual survey in October 2020 (Figure 21b).

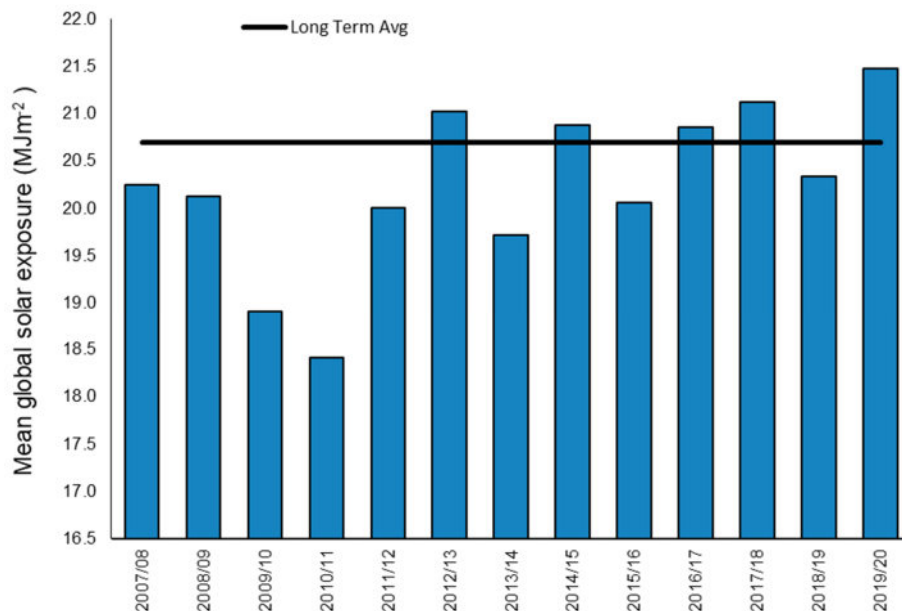


Figure 21a. Mean annual solar radiation (MJm⁻²) recorded Mackay Aero (Station 033045) 2008/09 -2019/20. Source: BOM

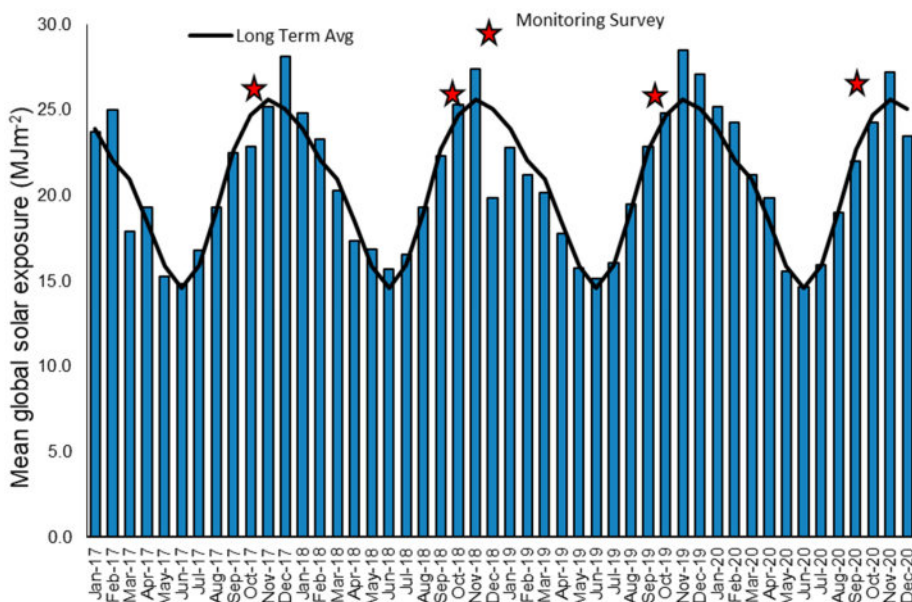


Figure 21b. Mean monthly daily global solar exposure (MJ m⁻²) recorded at Mackay Aero (Station 033045) January 2017-December 2020. Source: BOM.

Significant wave height

In the 12 months prior to the survey, the highest mean maximum monthly wave height of 1.44m was recorded in March 2020, with the lowest of 0.66 recorded in February 2020 (Figure 22). The general trend in the year prior to the annual survey was of monthly mean maximum wave heights close to the long-term monthly averages for the area. The exceptions were in January, February and April 2020 when mean maximum wave heights were considerably below the averages for those months and March and September 2020 when maximum wave heights were substantially above the long-term monthly average (Figure 22).

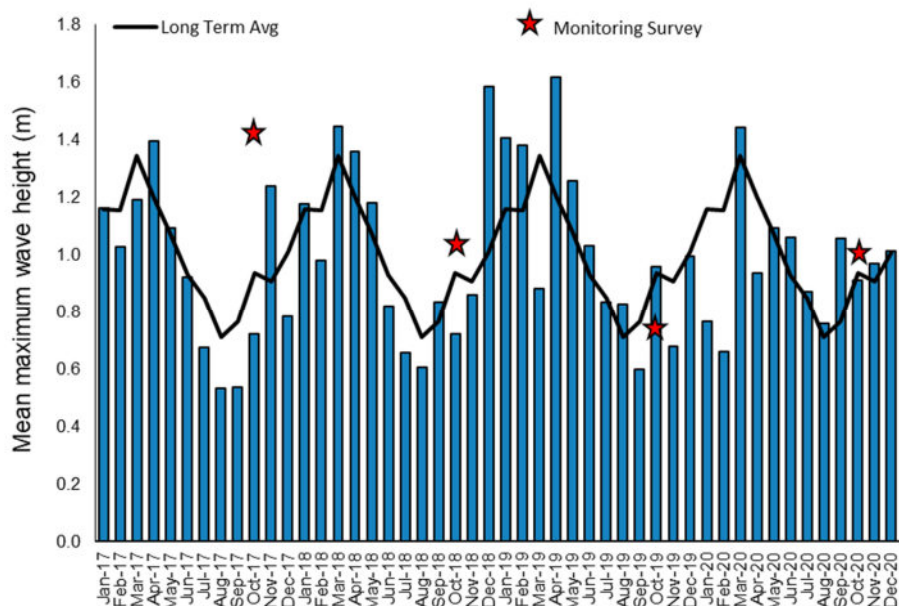


Figure 22. Mean monthly maximum wave height (m) recorded at Hay Point, January 2017-December 2020.

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 showed a general seasonal trend with higher benthic light availability from late July through to November 2020 (Figure 23). The PAR at both sites during this time of the year was generally above the light requirements for deep-water seagrass in the region (McKenna et al. 2015). These light levels are linked to environmental conditions and are higher when lighter winds and fewer rainfall events occurred. This period coincides with the presence and growing season of offshore seagrass in the Mackay area (York et al. 2015). Strong onshore winds and more regular rain events that characterize the period between January/February and June in combination with fine particulate sediment matter near the coast, drive resuspension of particles and lower benthic PAR levels (Waltham et al. 2020). This period coincides with the annual period of dormancy in the deep-water meadows off Hay Point and Mackay.

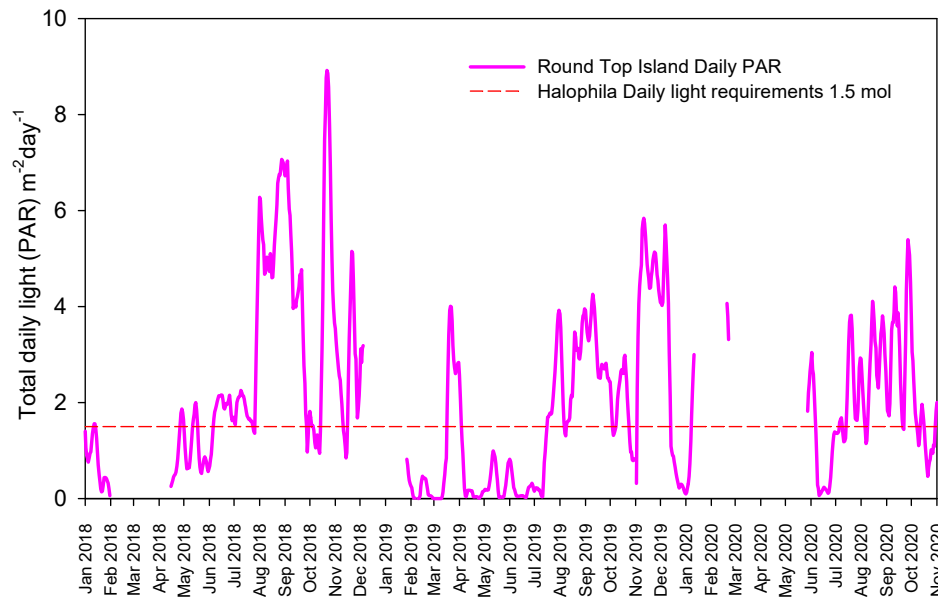


Figure 23. Daily photosynthetically active radiation (PAR; mol photons m⁻² day⁻¹) at Round Top Island. Data presented from January 2018 to November 2020. Source: Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program (Waltham et al. 2019).

4 DISCUSSION

The overall condition of seagrass meadows in the Hay Point-Mackay region in 2020 was classified as satisfactory which represents a shift from good in 2019. In 2020 conditions varied among habitat types and monitoring locations. The deep-water meadows offshore from Hay Point shifted from very good to poor condition, the coastal meadow at Dudgeon Point and the meadow adjacent to St Bees Island moved from good to satisfactory and the meadow adjacent to Keswick Island remaining in good condition. 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) with the condition of seagrasses influenced by climate and extreme weather events. At the time of the 2020 survey, the region had experienced three-and-a-half-years with no major flooding or cyclones, allowing seagrass meadows time to recover following several consecutive years of flood, storm and cyclone impacts. Although climate conditions for seagrass growth were favourable for much of the year prior to the seagrass survey in October 2020, the month of September saw above-average wave height which may have driven prolonged periods of sediment resuspension leading to reduced water quality. The region also experienced average rainfall, below-average river flows and solar exposure, and sea surface temperatures that were above the long term average.

The deep-water seagrass meadows offshore from Hay Point shifted from very good condition to poor in 2020 primarily due to a large reduction in the area of seagrass within the monitoring area. The mean biomass of this meadow also declined, which would have been influenced by the absence of the physically larger species *H. spinulosa* in 2020, however, this indicator was still in a good condition compared to the long-term average for this meadow. Deep-water seagrasses in this monitoring area consist of colonising *Halophila* species (mainly *H. decipiens*) that are adapted to surviving in low light conditions (Josselyn et al. 1986, McKenna et al. 2015, Chartrand et al. 2017). *Halophila* species have been shown to have much lower resistance to light deprivation than other seagrass species with mortality occurring in days to weeks rather than months 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). The occurrence and distribution of seagrass at this location coincides with higher light levels in the dry season, due to lighter winds and less rainfall (see Waltham et al. 2020). Since 2004 the spatial footprint of the Hay Point offshore meadow has shifted location and expanded or contracted on an annual basis. For these ephemeral deep-water meadows, these shifts may be influenced by relatively short-term, minor disturbances of several weeks. The month prior to the annual survey (September) had above-average maximum wave height which may have increased sediment resuspension in the area, diminishing water quality and leading to a decline in the area of seagrass. The PAR monitoring collected at nearby Round Top Island does not indicate a major decline in light levels in this period, however, this site is on the leeward side of the island and may have been buffered from the onshore wind and waves. The extended survey in 2020, however, did find deep-water seagrass immediately adjacent to the north of the annual monitoring area and the Mackay offshore annual monitoring meadow had the largest area of seagrass since monitoring began in 2017. This highlights the very local scale of environmental conditions influencing seagrass distribution in these types of meadows. Whilst expanding in size compared the 2019, the deep-water seagrass in the Mackay offshore monitoring area also declined in biomass. This area also had a larger proportion of the physically smaller *H. decipiens* than *H. spinulosa* compared to the previous year, which would account for much of the decline in mean biomass.

Seagrass meadows at Keswick Island and St Bees Island were in good and satisfactory condition in 2020 respectively. At both of these locations the biomass was the highest that had been recorded at the site since monitoring began in 2014. The meadow area at St Bees Island, however, declined by 29 percent compared to the 2019 survey resulting in a shift in condition for this indicator from very good to satisfactory. The seagrass communities around Keswick and St Bees Island meadows consist of species of larger biomass (*H. tricornata* and *H. spinulosa*) compared to the Hay Point deep-water meadows and therefore have greater stores of carbohydrates allowing greater resistance to short-term disturbances (Collier et al. 2016). The environment where these meadows are growing are also more stable as they are further offshore and occur in sheltered bays with sandy sediments. They are therefore less susceptible to fluctuations in water quality from rainfall

plumes or wind-driven resuspension of sediments. Despite this they are still comprised of colonising species and can have considerable inter-annual variability (Kilminster et al. 2015). The 2020 annual survey raises no reason for concern for the condition of these meadows.

The aggregated patches that comprise the coastal meadows in the Dudgeon Point monitoring area declined from a good condition in 2019 to satisfactory in 2020. This shift was primarily driven by a substantial reduction in the area of the meadow. Further, the opportunistic species *Zostera muelleri*, which has the highest light requirements of the species in the region, was not observed in the 2020 survey after being present in the meadow for the two previous years. These changes in meadow condition suggest a decline in the growing conditions at this location prior to the survey. A possible explanation for this may be the above average maximum wave heights recorded in the month before the survey. The area where these seagrass meadows occur, interspersed among rocky reef habitat at Dudgeon Point, can be exposed to wave action and high tidal currents that can both scour and resuspend sediments. This can lead to seagrass decline through the physical removal of the plants or through slower loss due to poor water quality. While the species dominating these coastal meadows are more resistant to disturbance than the offshore meadows (Collier et al. 2016), the Dudgeon Point meadows are still quite dynamic and variable and their current condition lies within the range expected for this type of coastal seagrass habitat.

The highly variable and low biomass nature of seagrass in the Mackay-Hay Point region suggests that seagrasses are living at the limits of light required to support their growth and reproduction and can be heavily impacted by disturbance events, both natural and anthropogenic. 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 Whitsundays NRM region, an area which otherwise has a poor coverage for seagrass assessment and condition. Monitoring at other sites in the network has shown a range of results during 2020. Coastal areas to the north and south of the Hay Point-Mackay region had seagrass in good condition (e.g. Gladstone – Smith et al. 2021a; Cairns Harbour - Reason et al. 2021; and Townsville – McKenna et al. 2021) while the estuarine habitat in Trinity inlet and Mourilyan were in poor condition and the only other locations where seagrass condition declined in 2020 (Reason et al. 2021a, Reason et al. 2021b). In the Gulf of Carpentaria seagrass, seagrass at Weipa was in good condition (Smith et al. 2021b) while seagrass condition at Karumba was satisfactory (Scott and Rasheed 2021).

Ongoing development of seagrass condition indices

This is the fourth 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 now has 9 years of data and will become a permanent baseline when 10 years of data is available in 2021. The Dudgeon Point and Keswick and St Bees Islands monitoring areas have now established an interim 7-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 mapped for only the fourth time in 2020. An interim score for this area will not be available until 2021 after 5-years of data is collected for all metrics.

Conclusion

Seagrasses in the Hay Point – Mackay – Keswick Island region are in satisfactory condition in 2020, however, there was considerable variability of condition among different seagrass habitat types and locations. This represents a shift in overall condition from good in 2019 which was primarily driven by a reduction in meadow size in many of the monitoring areas. Individual meadow conditions ranged from good for Keswick Island to satisfactory for St Bees Island and the Dudgeon Point coastal meadow to poor for the Hay Point offshore meadow. While climate conditions were generally favourable for seagrass growth and there were no major storms or floods, above-average wave height in the month before the survey may have led to resuspension of sediments and degraded water quality. This may have impacted the health of low-resilient colonising species, particularly in the nearshore, deep-water meadow at Hay Point prior to the survey. The good condition of seagrass in locations to the north (Townsville) and south (Gladstone) indicate that local to regional scale factors have influenced the condition of the Hay Point-Mackay region in 2020.

5 REFERENCES

Bryant CV, Jarvis JC, York PH and Rasheed MA (2014). Gladstone Healthy Harbour Partnership Pilot Report Card; ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication, James Cook University, Cairns, 74 pp.

Bureau of Meteorology 2021, Available from: <http://www.bom.gov.au>. March 2021.

Carter AB, Jarvis JC, Bryant CV and Rasheed MA (2015). Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass, Centre for Tropical Water & Aquatic Ecosystem Research Publication, James Cook University, Cairns, 71 pp.

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.

Collier CJ, Chartrand K, Honchin C, Fletcher A and Rasheed MA (2016). Light thresholds for seagrasses of the GBR: a synthesis and guiding document. Including knowledge gaps and future priorities. Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns 41pp.

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

Queensland Government (2021), www.qld.gov.au/waves

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.

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.

Jinks, KI, Brown CJ, Rasheed MA, Scott AL, Sheaves M, York PH and Connolly RM (2019). Habitat complexity influences the structure of food webs in Great Barrier Reef seagrass meadows. *Ecosphere* 10:e02928.

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 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.

McKenna S, Wilkinson J, Chartrand K, and van de Wetering C (2021). Port of Townsville Seagrass Monitoring Program: 2020, James Cook University Publication, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), Cairns.

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

Rasheed MA (2004). Recovery and succession in a multi-species tropical seagrass meadow following experimental disturbance: the role of sexual and asexual reproduction, *Journal of Experimental Marine Biology and Ecology*, 310:13-45.

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 (TropWATER), JCU Publication 19/49, Cairns.

Reason CL, Smith TM and Rasheed MA (2021a). Seagrass habitat of Cairns Harbour and Trinity Inlet: Cairns Shipping Development Program and Annual Monitoring Report 2020. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research Publication, Cairns.

Reason CL, York PH and Rasheed MA (2021b). Seagrass habitat of Mourilyan Harbour: Annual Monitoring Report - 2020. JCU Publication, 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 (2020). 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 AS & Rasheed MA (2021) Port of Karumba Long-term Annual Seagrass Monitoring 2020, Centre for Tropical Water & Aquatic Ecosystem Research Publication, James Cook University, Cairns.

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

Smith TM, Reason C and Rasheed MA (2021a). Seagrasses in Port Curtis and Rodds Bay 2020: Annual long-term monitoring and whole of port survey. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Cairns.

Smith TM, Reason, CL, McKenna, SA & Rasheed, MA (2021b). Port of Weipa long-term seagrass monitoring program, 2000 - 2020. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 20/58, JCU Cairns.

Waltham NJ, Iles J.A., Whinney J, Ramsby B, & Macdonald R (2020). Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual Report 2019-2020. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 20/47, James Cook University, Townsville, 112pp.

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.

Wu PP-Y, Mengersen K, McMahon K, Kendrick GA, Chartrand K, York PH, Rasheed MA and Caley MJ, (2017). Timing anthropogenic stressors to mitigate their impact on marine ecosystem resilience. *Nature Communications* 8:1263.

Wu, PP-Y, McMahon K, Rasheed MA, Kendrick GA, York PH, Chartrand K, Caley MJ and Mengersen K, (2018). Managing seagrass resilience under cumulative dredging affecting light: Predicting risk using dynamic Bayesian networks. *Journal of applied ecology*, 55: 1339-1350.

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 and Rasheed MA (2018). Blue Carbon stocks of Great Barrier Reef deep-water seagrasses. *Biology Letters* **14**:20180529.

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 9 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 7 years of data for biomass, area and species composition (2014–20). 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 $\geq 80\%$ 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	-	$CV < 40\%$	$CV \geq 40\%$	-
*Area	$< 10\%$	$CV \geq 10, < 40\%$	$CV \geq 40, < 80\%$	$CV \geq 80\%$
Species composition	-	$CV < 40\%$	$CV \geq 40\%$	-

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
		<div> <div>Increase above threshold from previous year</div> <div>  </div> <div>Decrease below threshold from previous year</div> <div>  </div> </div>				

Grade and score calculations

A score system (0–1) and score range was applied to each grade to allow numerical comparisons of seagrass condition among meadows for the Hay Point region (Table A3; see Carter et al. 2015 for a detailed description).

Score calculations for each meadow's condition required calculating the biomass, area and species composition for that year, allocating a grade for each indicator by comparing 2019 values against meadow-specific thresholds for each grade, then scaling biomass, area and species composition values against the prescribed score range for that grade.

Scaling was required because the score range in each grade was not equal (Table A3). Within each meadow, the upper limit for the very good grade (score = 1) for species composition was set as 100% (as a species could never account for >100% of species composition). For biomass and area the upper limit was set as the maximum mean plus standard error (SE; i.e. the top of the error bar) value for a given year, compared among years during the baseline period. For Hay Point this upper limit will be recalculated each year until the 10 year baseline period is complete

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

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

Table A3. Score range and grading colours used in the 2020 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).

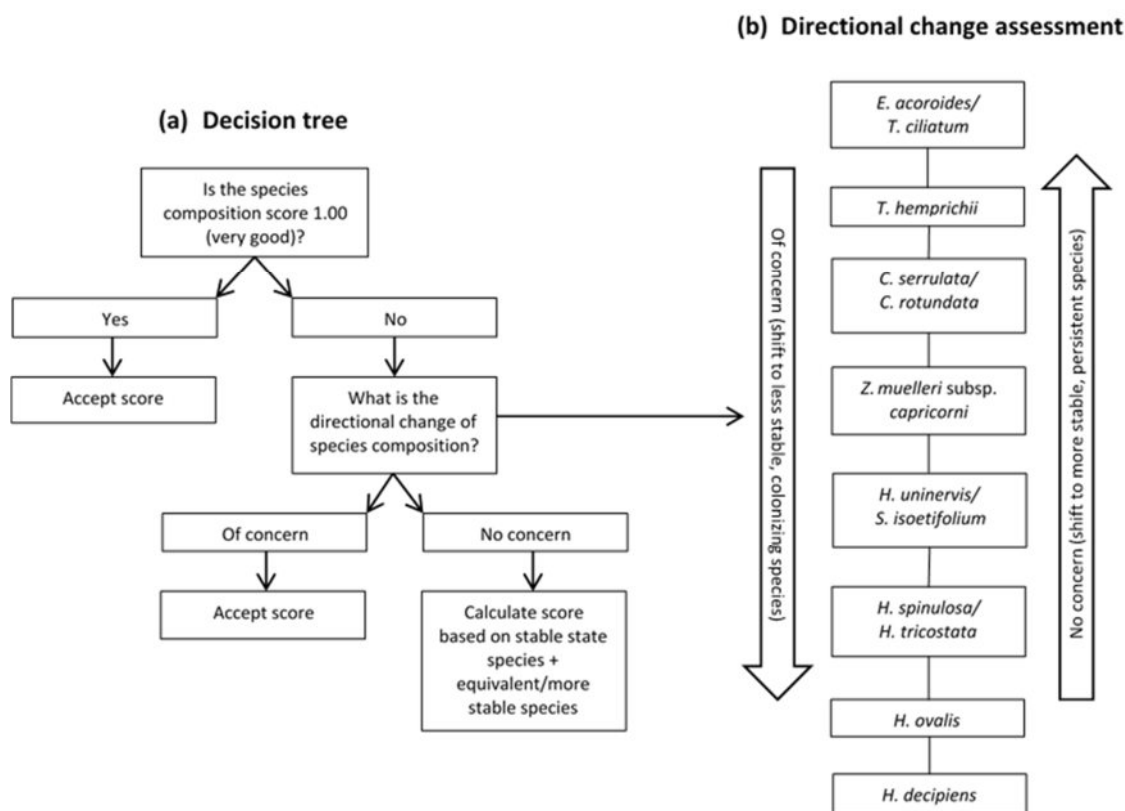


Figure A1. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Hay Point.

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 2020 (current) biomass value (i.e. satisfactory).
2. Calculate the difference in areas (A_{diff}) between the 2020 area value (A_{2015}) 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 2020 ($Score_{2019}$) by scaling A_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

$$Score_{2020} = LA_{satisfactory} + (A_{prop} \times SR_{satisfactory})$$

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

Appendix 2. Seagrass community types and species composition

Table A4. Seagrass community types, mean above-ground biomass and meadow area in the Hay Point (Meadow 8) and Mackay (Meadow 5) offshore area 2004, 2005, 2010, 2011, 2014, 2016, 2017, 2018, 2019 and 2020. (note: survey extent modified to 2004 survey limit see Figure 4).

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 <i>H. decipiens</i>	0.270 ± 0.057	6837.6 ± 2415.3
Total				6837.6 ± 2415.3
December 2005				
5	Offshore	Not surveyed	na	na
8	Offshore	Light <i>H. spinulosa</i>	2.186 ± 0.764	332.9 ± 152.9
Total				332.9 ± 152.9
October 2010				
5	Offshore	Not surveyed	na	na
8	Offshore	Light <i>H. decipiens</i>	0.008 ± 0.003	1528.6 ± 346.6
Total				1528.6 ± 346.6
November 2011				
5	Offshore	Not surveyed	na	na
8	Offshore	Light <i>H. decipiens</i>	0.008	105.1 ± 39.8
Total				105.1 ± 39.8
October/November 2014				
5	Offshore	Light <i>H. spinulosa</i> with <i>H. decipiens</i>	0.244 ± 0.108	Not mapped
8	Offshore	Light <i>H. decipiens</i>	0.002 ± 0.001	5204.7 ± 1448.1
Total				5204.7 ± 1448.1
October/November 2016				
5	Offshore	Light <i>H. spinulosa</i>	0.108 ± 0.078	Not mapped
8	Offshore	Light <i>H. decipiens</i>	0.002 ± 0.0001	2311.0 ± 387.0
Total				2311.0 ± 387.0
October 2017				
5	Offshore	Light <i>H. decipiens</i> with <i>H. spinulosa</i>	0.011 ± 0.003	652.8 ± 151.9
8	Offshore	Light <i>H. decipiens</i>	0.046 ± 0.032	1234.1 ± 309.9
Total				1886.9 ± 461.8
October 2018				
5	Offshore	Light <i>H. decipiens</i> with <i>H. spinulosa</i>	0.062 ± 0.015	381.6 ± 141.2
8	Offshore	Light <i>H. decipiens</i>	0.013 ± 0.004	1642.7 ± 406.2
Total				2024.3 ± 547.4
October 2019				
5	Offshore	Light <i>H. spinulosa</i> with <i>H. decipiens</i>	0.135 ± 0.073	1737.3 ± 277.4
8	Offshore	Light <i>H. decipiens</i> with <i>H. spinulosa</i>	0.096 ± 0.023	4160.8 ± 777.8
Total				5898.1 ± 1055.2
October 2020				
5	Offshore	Light <i>H. decipiens</i> with <i>H. spinulosa</i>	0.077 ± 0.0137	1871.6 ± 306.6
8	Offshore	Light <i>H. decipiens</i>	0.041 ± 0.004	736.9 ± 258.2
Total				2608.5 ± 564.8

Table A5. Seagrass community type, mean above-ground biomass and meadow area in the Dudgeon Point - Hay Point annual survey areas, 2010 – 2020.

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

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

Table A6. Seagrass community type, mean above-ground biomass and meadow area in the Keswick Island and St Bees Island annual survey areas, 2014 – 2020.

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 <i>Halophila tricostata</i> with <i>H. decipiens</i>	2.34 ± 0.38	118.6 ± 29.5
14	Inshore	Moderate <i>H. decipiens</i> with mixed species	2.6 ± 0.71	17.9 ± 5.0
Total				136.5 ± 34.5
October 2015				
10	Inshore	Light <i>Halophila tricostata</i>	1.23 ± 0.19	137.2 ± 30.5
14	Inshore	Light <i>H. spinulosa</i> with mixed species	1.13 ± 0.35	14.7 ± 4.3
Total				151.9 ± 34.8
October/November 2016				
10	Inshore	Light <i>Halophila tricostata</i>	1.69 ± 0.33	147.6 ± 25.9
14	Inshore	Light <i>H. spinulosa</i> with mixed species	2.94 ± 0.54	11.5 ± 4.3
Total				159.1 ± 30.2
October 2017				
10	Inshore	Light <i>Halophila tricostata</i>	1.09 ± 0.23	169.6 ± 32.5
14	Inshore	Light <i>Halophila tricostata</i>	0.54 ± 0.23	10.8 ± 4.1
Total				180.4 ± 36.6
October 2018				
10	Inshore	Light <i>Halophila tricostata</i> with <i>H. decipiens</i>	2.40 ± 0.38	203.6 ± 38.7
14	Inshore	Light <i>Halophila tricostata</i>	1.97 ± 0.74	18.1 ± 4.8
Total				221.7 ± 43.5
October 2019				
10	Inshore	Light <i>Halophila tricostata</i> with <i>H. decipiens</i>	1.37 ± 0.15	197.3 ± 42.9
14	Inshore	Light <i>Halophila tricostata</i> with <i>H. spinulosa</i> / <i>H. decipiens</i>	1.63 ± 0.35	14.2 ± 4.2
Total				211.5 ± 47.1
October 2020				
10	Inshore	Light <i>Halophila tricostata</i> with <i>H. spinulosa</i>	2.90 ± 0.63	140.4 ± 36.5
14	Inshore	Light <i>Halophila spinulosa</i> / <i>H. tricostata</i>	3.96 ± 1.23	14.2 ± 3.8
Total				154.6 ± 40.3

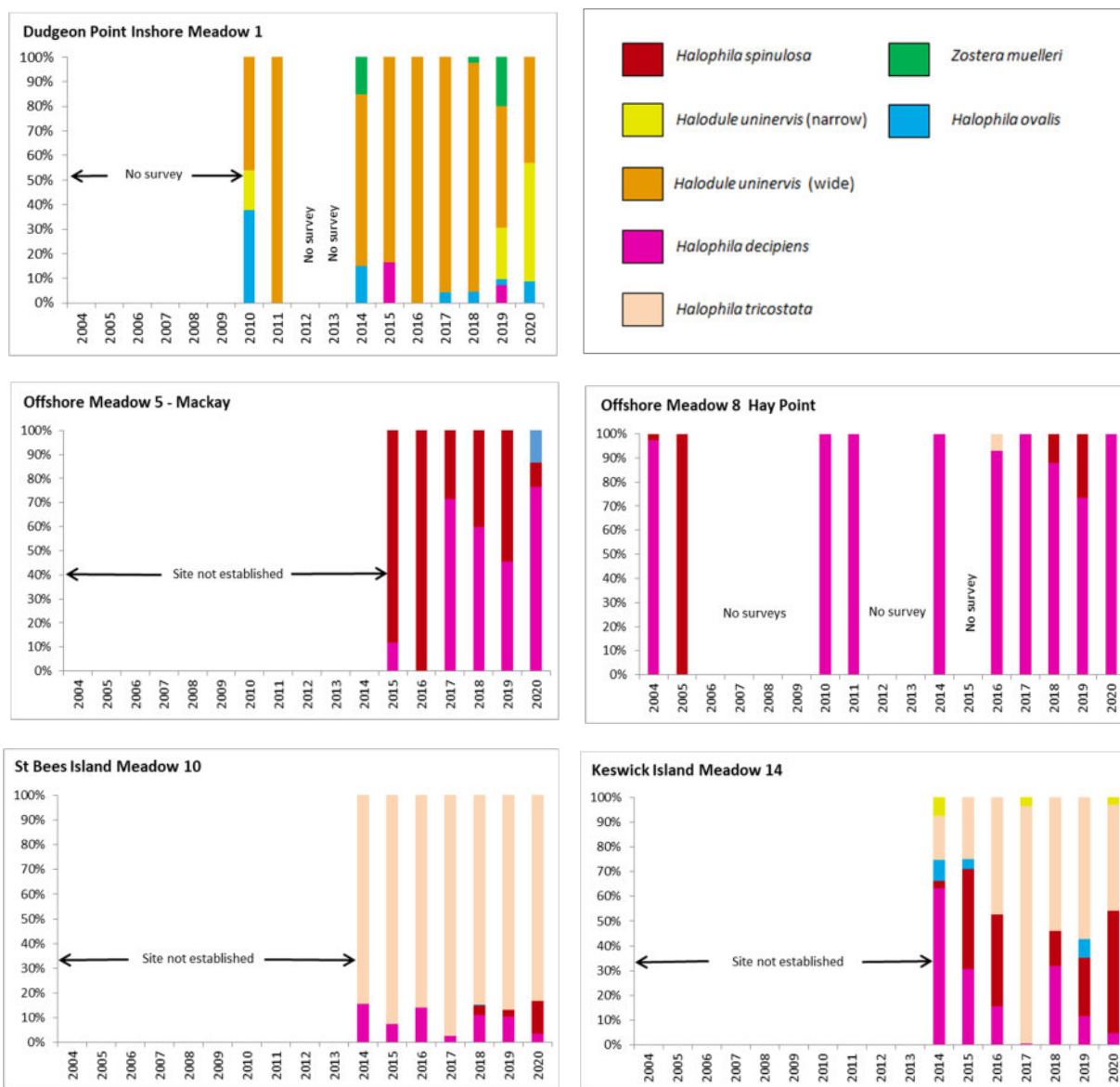


Figure A2: Species composition of monitoring meadows in the Hay Point-Mackay region, and the Keswick Island group.