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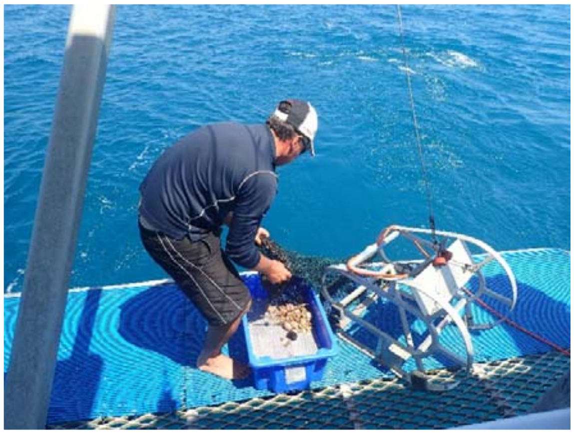

ANNUAL SEAGRASS MONITORING IN THE MACKAY-HAY POINT REGION – 2016

McKenna SA and Rasheed MA

Report No. 17/18

March 2017

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KEY FINDINGS

Offshore Seagrass Condition 2016

Likely causes of seagrass condition:

Linked to Climate

⬆ rainfall and river flow.

⬇ available light.

Inshore Seagrass Condition 2016

?

A condition score for inshore seagrasses is not able to be calculated until at least 5 years of baseline data have been collected

- A long term seagrass monitoring program was established for the Mackay-Hay Point region in 2014, and builds on the monitoring program for Hay Point offshore seagrasses first established in 2005, adding new coastal and offshore sites in the Port of Mackay, Hay Point and around Keswick Island.

- Annual monitoring found that offshore seagrass habitat in the Hay Point area was in a very poor condition in 2016.

- Declines were likely the result of unfavourable climate conditions (rainfall, river flow, light) in the months leading into the seagrass growing season in the critical period when deepwater seagrasses are likely undergoing annual recruitment from seed germination.

- 2016 was only the second year of monitoring for the new sites (outside of Hay Point offshore meadows). As such determining a condition score for them is not yet possible. Results of the second monitoring year for these meadows found:
    - Inshore meadows in the Dudgeon Point area remained in similar locations to the previous year but less than historical maximum extent.
    - Meadows adjacent to Keswick and St Bees Islands had increased slightly in area and biomass from previous two years, although there was some loss in area at the deeper margins of the meadows.

- A change in monitoring strategy for the highly variable offshore Hay Point meadow that better accounts for its variable spatial footprint is suggested. From next year the monitoring will expand so that the entire spatial footprint of the Hay Point deepwater meadow is included in the assessment, with a substantial increase in sampling effort. This will allow for a more robust assessment of biomass change as well as add change in area to the condition score calculation, in line with other seagrass assessments in the broader program

IN BRIEF

A long-term seagrass monitoring program and strategy was developed for the Mackay-Hay Point region following a broad-scale baseline survey in 2014. The program builds on seagrass monitoring that had been conducted at offshore areas around the Port of Hay Point since 2005, as well as numerous broad scale surveys that have been conducted since 2004. In addition to the annual monitoring areas, a broader-scale survey of all seagrasses in the region was also conducted in 2016.

The annual monitoring strategy assesses five offshore monitoring areas between Mackay and Hay Point, an inshore region between Dudgeon Point and Hay Point, and two inshore subtidal meadows at the Keswick Island group. Seagrass meadows in these areas represent the range of different seagrass community types found in the Mackay-Hay Point region. The offshore monitoring meadow in the Port of Hay Point has a long history of monitoring while monitoring in the other meadows only began in 2015 and natural ranges of change are still being established.

Offshore seagrasses in the monitoring areas near Hay Point were in a very poor condition in 2016, with biomass decreasing between 2015 and 2016 (Figure 1 & 3). The complementary broad scale survey also showed that the broader distribution of offshore seagrass decreased by 65% between 2014 and 2016 but remained larger than the three other previous broad scale surveys of the region. These results suggest that incorporating an element of spatial change in offshore seagrass condition assessment for Hay Point would provide a valuable addition to understanding seagrass health.

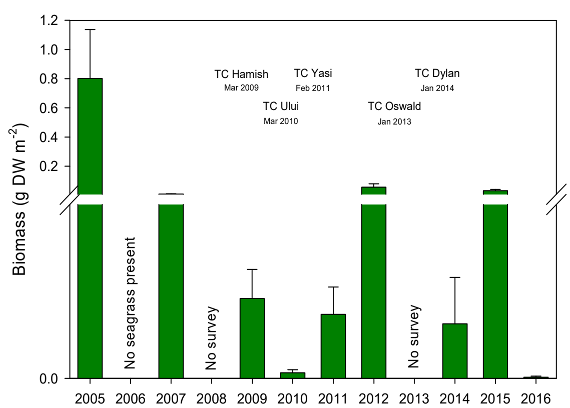

Figure 1. Mean seagrass biomass of Hay Point offshore monitoring sites; 2005 to 2016

The relatively smaller inshore seagrass meadows between Hay Point and Dudgeon Point also decreased in area between 2015 and 2016 (Figure 3). The total seagrass distribution in the two inshore Keswick/St Bees Is. monitoring meadows increased. Despite the overall increase there was a constriction in area of both of these meadows at the deeper edges which may be an indication of a less favourable light environment at the site during 2016. The biomass of the one remaining inshore monitoring meadow at Dudgeon Point was categorised as having a moderate density (an increase from previous years) and there were also small increases in biomass in the inshore meadows around Keswick Island.

Environmental conditions have been generally favourable for seagrass growth over the past three years (Figure 2) and were likely behind increases in biomass and area observed in 2015 (McKenna et al. 2016). However, conditions leading up to the 2016 sampling were less favourable, particularly during the critical growing season window of 2016, and were likely behind the observed declines in seagrass. Higher than average rainfall and river flow of the Pioneer River from June to September 2016 (1 – 4 months before the 2016 survey) (Figures 15b & 16b) resulted in benthic light falling below required light levels for *Halophila decipiens* for long periods of time during the key growing period. The reduction in light leading in to the growing season may have affected the annual recruitment, or resulted in the early loss of germinated shoots for this annual meadow. The offshore meadows around Mackay and Keswick/St Bees Islands were less impacted possibly due to the prevalence of the more robust species, *H. spinulosa* and *H. tricostata*, that have greater carbohydrate reserves to resist impacts associated with periods of low light.

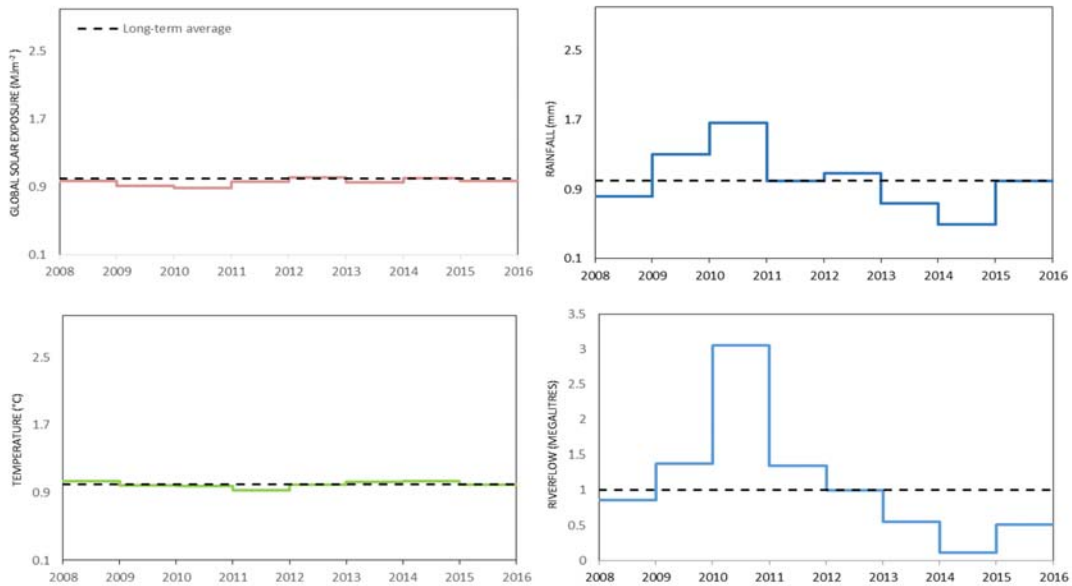

Figure 2. Recent climate trends in the Hay Point Area: change in climate variables as a proportion of the long-term average from 2008-2016. (See section 3.5 for detailed climate data).

The highly variable and low biomass nature of seagrass in the Mackay/Hay Point region indicates that seagrasses are living at the limits of light required to support their growth and reproduction. The management of seagrass therefore should remain focused on ensuring that the resilience of these habitats remains high enough to withstand expected natural and anthropogenic impacts and risks. While previous research has shown that these meadows are susceptible to impacts from large scale dredging (in 2006), they also had an ability to rapidly recover (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. While light and temperature may be the principal drivers of seagrass change for the majority of seagrasses, for some of the offshore species seasonal dynamics may be part of an annual programmed seasonal die off after investing in the production of fruits and seeds for the following season (Chartrand et al. 2017). It is critical then that sufficient light is maintained during the key growing periods (~July – December) for plant germination to replenish the seed bank for the subsequent year's germination and continuance of the meadow.

Given the highly variable nature of offshore seagrass meadows in the region we have suggested some modifications to the annual monitoring program that better account for the large changes in the spatial footprint of offshore seagrasses. These changes increase and spread the sampling effort over a greater area of the offshore region.

The Mackay-Hay Point seagrass monitoring program forms part of a broader Queensland program that examines condition of seagrasses in the majority of Queensland commercial ports and areas where seagrasses face the highest levels of cumulative risk. It also forms a component of James Cook University's (JCU) broader seagrass assessment and research program (see www.jcu.edu.au/portseagrassqld). The program also provides a key input into the condition and trend of seagrasses in the Mackay-Whitsundays NRM region, an area which otherwise has a poor spatial coverage for seagrass assessment and condition.

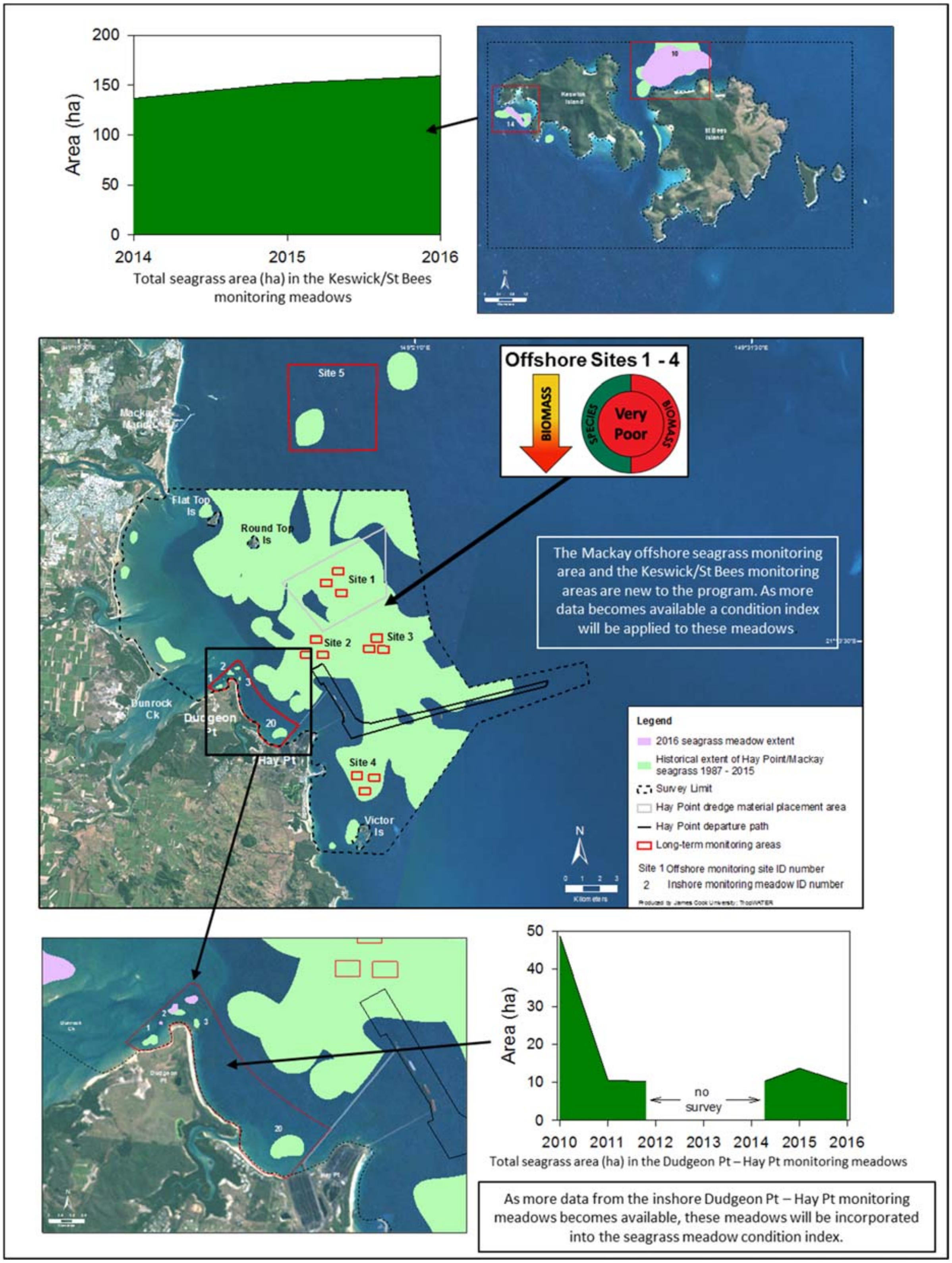

Figure 3. Seagrass meadow condition for the ports of Mackay and Hay Point, and Keswick/St Bees Island 2016

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1 INTRODUCTION

Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling and particle trapping (Costanza et al. 1997; Hemminga and Duarte 2000). With globally developing carbon markets, the role that seagrasses play in sequestering carbon is also becoming more widely recognised (McLeod et al. 2011; Fourqurean et al. 2012; Macreadie et al. 2013). Seagrass meadows show measurable responses to changes in water quality, making them ideal candidates for monitoring the long term health of marine environments (Dennison et al. 1993; Abal and Dennison 1996; Orth et al. 2006).

Globally, seagrasses have been declining at ever increasing rates due to both natural and anthropogenic causes (Waycott et al. 2009). Explanations for seagrass decline include natural disturbances such as storms, disease and overgrazing by herbivores, as well as anthropogenic stresses including direct disturbance from coastal development, dredging and trawling, coupled with indirect effects through changes in water quality due to sedimentation, pollution and eutrophication (Short and Wyllie-Echeverria 1996; York et al. 2015). Locally in the Great Barrier Reef (GBR) coastal region the hot spots with highest threat exposure for seagrasses all occur in the southern two thirds of the GBR, in areas where multiple threats accumulate including urban, port, industrial and agricultural runoff (Grech et al. 2011). These hot-spots arise as seagrasses preferentially occur in the same sheltered coastal locations that ports and urban centres are established (Coles et al. 2015). In Queensland this has been recognised and a strategic monitoring program of these high risk areas has been established to aid in their management and ensure impacts are minimised (Coles et al. 2015).

1.1 Queensland Ports Seagrass Monitoring Program

A long-term seagrass monitoring and assessment program has been established in the majority of Queensland commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) in partnership with the various Queensland port authorities. While each location is funded separately and they have a range of requirements for use of the information, a common methodology and rationale is utilised to provide a network of seagrass monitoring locations throughout the state (Figure 4).

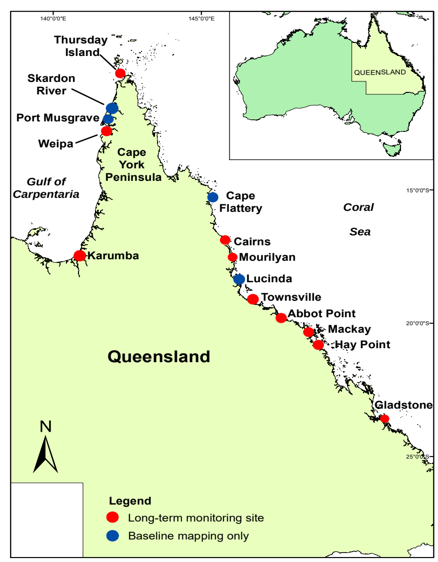


Figure 4. Location of Queensland Port Seagrass assessment sites

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

The program not only delivers key information for the management of port activities to minimise impacts on seagrass habitat but has also resulted in significant advances in the science and knowledge of tropical seagrass ecology. It has been instrumental in developing tools, indicators and thresholds for the protection and management of seagrasses, and an understanding of the drivers of tropical seagrass change. It provides local information for individual ports as well as feeding into regional assessments of the status of seagrasses.

For more information on the program and reports from the other monitoring locations see www.jcu.edu.au/portseagrassqld

1.2 Mackay and Hay Point Seagrass Monitoring Program

The Port of Hay Point (approximately 38 km south of Mackay) is one of the world's largest coal exporting ports and comprises two coal export terminals; Dalrymple Bay Coal Terminal (DBCT) leased from the State Government by DBCT Management Pty Ltd and the Hay Point Coal Terminal (HPCT) owned by BHP Billiton Mitsubishi Alliance (BMA). The Port of Mackay is a multi-commodity port mainly exporting sugar and grain, and located 5km from the city of Mackay. The Port comprises four wharves and a harbour formed by rock breakwaters. North Queensland Bulk Ports (NQBP) is the port authority for the Port of Hay Point and the Port of Mackay.

TropWATER's Seagrass Ecology Group first mapped significant areas of seagrass within the Port of Hay Point in a benthic survey conducted in July 2004 (Rasheed et al. 2004) and in Mackay in 2001 (Rasheed et al. 2001). The broad scale habitat surveys that have since occurred at Hay Point (2005, 2010, 2011, 2014, 2016), as well as the long-term segrass monitoring program that ran between 2005 and 2012 has established that the majority of seagrass in the area is of low density and cover (< 1 gdw m^{-2} and < 5% cover) and the spatial extent of deep water seagrasses around Hay Point is naturally extremely highly variable with an annual cycle of occurrence; deep water seagrass being present only from July to December each year (Chartrand et al. 2008; York et al. 2015). The broad scale surveys and current monitoring program similarly show that inshore seagrass meadows at Hay Point tend to be highly variable both in distribution and species composition. The small Dudgeon Point meadows while consistently present have experienced large changes in species composition from being dominated by the colonising *H. decipiens* species to the more persistent *Z. muelleri* and *H. uninervis*.

The long-term monitoring program between 2005 and 2012 found that Hay Point deep water seagrass meadows were susceptible to impacts associated with large-scale capital dredging operations, but recovered quickly once dredging was completed (Chartrand et al. 2008; York et al. 2015). York et al. (2015) found that deep water seagrasses at Hay Point, despite considerable inter annual variability, had a regular annual pattern of occurrence, low resistance to reduced water quality but a capacity for rapid colonisation on the cessation of impacts. Extensive and persistent turbid plumes from a large scale and extended dredging program (in 2006) over an eight month period resulted in a failure of the seagrasses to establish in 2006, however recruitment occurred the following year and the regular annual cycle was re-established (York et al. 2015).

NQBP recognise that seagrasses form a key ecological habitat in the Mackay-Hay Point region and commissioned TropWATER to re-establish and expand on the long-term seagrass monitoring program that was conducted between 2005 and 2012. The broad-scale survey conducted in 2014 was used as a platform to re-establish the program, and additional monitoring in the Keswick Island (southern Whitsunday Islands) and Mackay areas were also added (Figure 5). The long-term monitoring program coupled with regular broad scale surveys and other research programs being conducted in the Hay Point region by TropWATER enhance our understanding of water quality, seagrass and benthic habitat community dynamics, and enable more effective management of valuable marine habitats and marine port environments. Information collected in these programs aims to assist in planning and managing future developments in coastal areas. The monitoring program also forms part of Queensland's network of long-term monitoring sites of important fish habitats in high risk areas. It also provides a key input into the condition and trend of seagrasses in the Mackay-Whitsundays NRM region, an area which otherwise has a poor spatial coverage for seagrass assessment and condition.

This report presents the findings of the annual seagrass habitat monitoring survey conducted in October/November 2016. The objectives of these studies were to:

- Map seagrass distribution and determine seagrass density and community type at the identified monitoring areas;
- Compare results of monitoring surveys and assess any changes in seagrass distribution and abundance in relation to natural events or human induced port and catchment activities;
- Incorporate the results into the Geographic Information System (GIS) database for the Mackay-Hay Point region;
- Discuss the implications of monitoring results for overall health of the Mackay-Hay Point marine environment and provide advice to relevant management agencies.

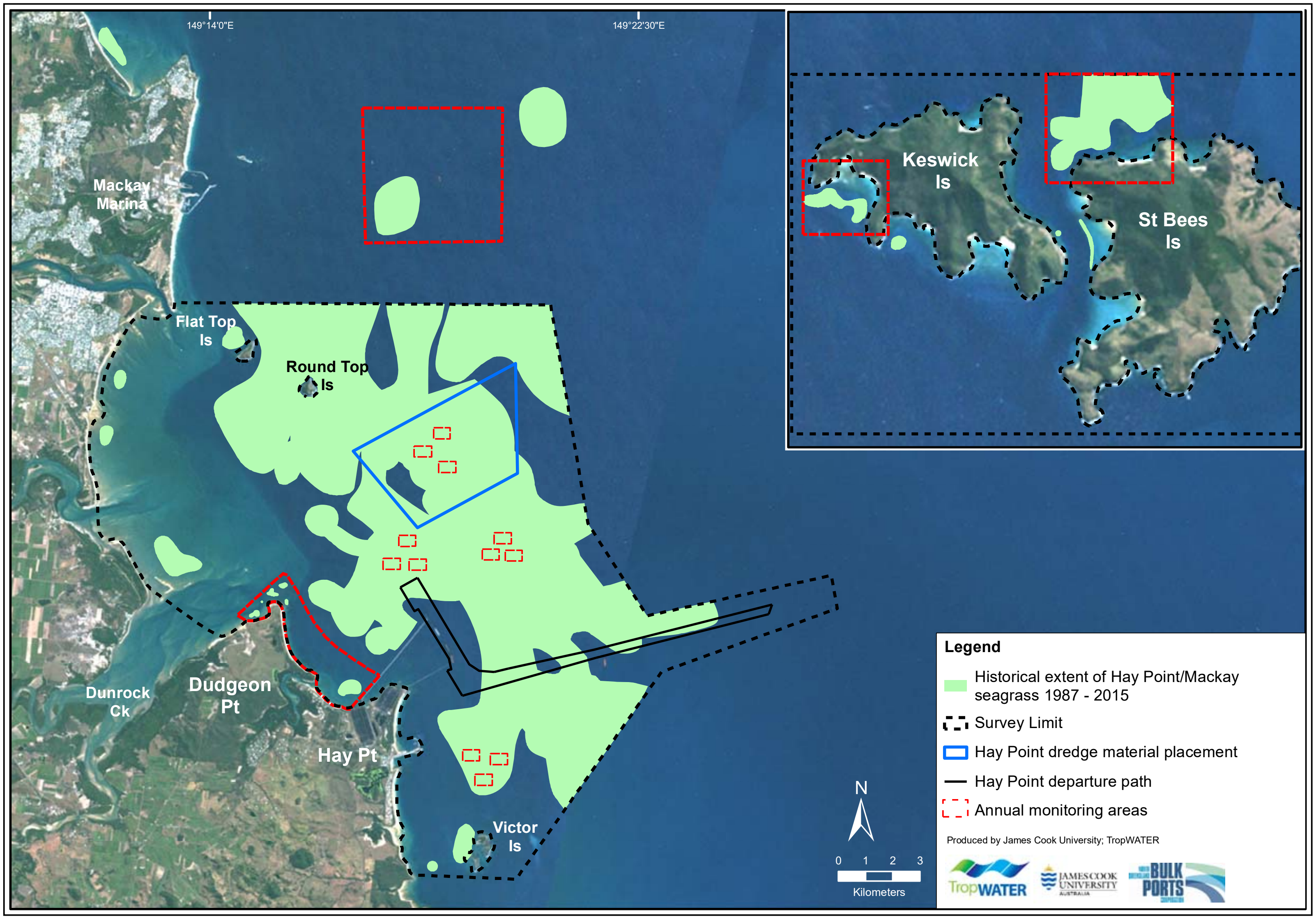


Figure 5. Location of annual seagrass monitoring areas around Mackay, Hay Point and the Keswick Island group.

2 METHODS

2.1 Survey Approach

The broad-scale survey conducted in 2014 was used as a platform to re-establish the long-term annual program that ran between 2005 and 2012. Additional monitoring sites in the Keswick Island (southern Whitsunday Islands) and Mackay areas have been added to the program (Figure 5). The long-term monitoring approach is based on periodic re-assessments of all seagrasses within the region (every three years) with a subset of representative areas monitored annually in the intervening years. This same approach is used as part of NQBP's other long-term seagrass programs in the Ports of Weipa and Abbot Point, and elsewhere in other Queensland ports.

The current three year cycle began with the broad-scale survey in 2014. From the results of the 2014 survey and further investigations in 2015, two inshore meadows at Keswick/St Bees Islands, one inshore region from Dudgeon Point to Hay Point, four offshore areas around Hay Point (the same areas monitored between 2005 and 2012), and one offshore area offshore from the Mackay Marina were identified as suitable for long term seagrass monitoring. Monitoring areas selected were representative of the range of seagrass communities in the Mackay-Hay Point region and were also located in areas considered ideal sensitive receptor sites for assessing seagrass condition in relation to port activity and development.

The inshore monitoring meadows located at Keswick and St Bees Islands have a depth gradient that ranges from approximately 2.5m to 30m below MSL and are dominated by *Halophila* species. Neither of these meadows expose to air on spring low tides. The inshore monitoring region between Dudgeon Point and Hay Point ranges in depth from 0m to 9m below MSL. On a spring low tide the shallower edge of Meadow 1 at Dudgeon Point exposes to air. No inshore seagrass areas suitable for monitoring were found near Mackay in 2014 or 2015.

Annual surveys are conducted between September and December to capture seagrasses at their likely seasonal peak in distribution and abundance, and to facilitate comparisons with the previous surveys conducted in the area.

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

In addition to the annual monitoring sites a broad scale survey of benthic habitats was also conducted in 2016 (McKenna and Rasheed 2017) as part of BHP Billiton Mitsubishi Alliance's (BMA) requirements for their Environmental Monitoring Program (EMP) for the HPCT expansion project (HPX3). The results from that broad scale survey are referred to throughout this report.

2.2 Survey Methods

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

1. Shallow subtidal areas <8m below MSL: Free diving;
2. Subtidal inshore areas >8m below MSL: Boat based underwater digital camera mounted on a drop frame;
3. Offshore subtidal areas >8m below MSL: Boat based digital camera sled tows with sled net attached.

At each survey site, seagrass habitat observations included seagrass species composition, above-ground biomass, percent algal cover, depth below mean sea level (MSL), sediment type, time and position (GPS). The percent cover of other major benthos at each site was also recorded.

At sites where seagrass presence was noted seagrass above-ground biomass was determined. Above-ground seagrass biomass was estimated using a "visual estimates of biomass" technique (Kirkman 1978; Mellors 1991). At free diving and camera drop sites this technique involved an observer ranking seagrass biomass within three randomly placed 0.25m^2 quadrats at each site (Figure 6A-C). 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 6D-F). The video was paused at each of the ten time frames then advanced to the nearest point on the tape where the bottom was visible and sled was stable on the bottom. From this frame an observer ranked seagrass biomass and species composition. A 0.25m^2 quadrat, scaled to the video camera lens used in the field, was superimposed on the screen to standardise biomass estimates.

Biomass ranks at all sites are made in reference to a series of quadrat photographs of similar seagrass habitats for which above-ground biomass has previously been measured. The relative proportion of the above-ground biomass (percentage) of each seagrass species within each survey quadrat was also recorded. Field biomass ranks were then converted into above-ground biomass estimates in grams dry weight per square metre (g dw m^2). At the completion of sampling, each observer ranked a series of calibration quadrats that represented the range of seagrass biomass in the survey. After ranking, seagrass in these quadrats were harvested and the actual biomass (separated by species) determined in the laboratory. A separate regression of ranks and biomass from these calibration quadrats was generated for each observer and applied to the field survey data to standardise the above-ground biomass estimates.

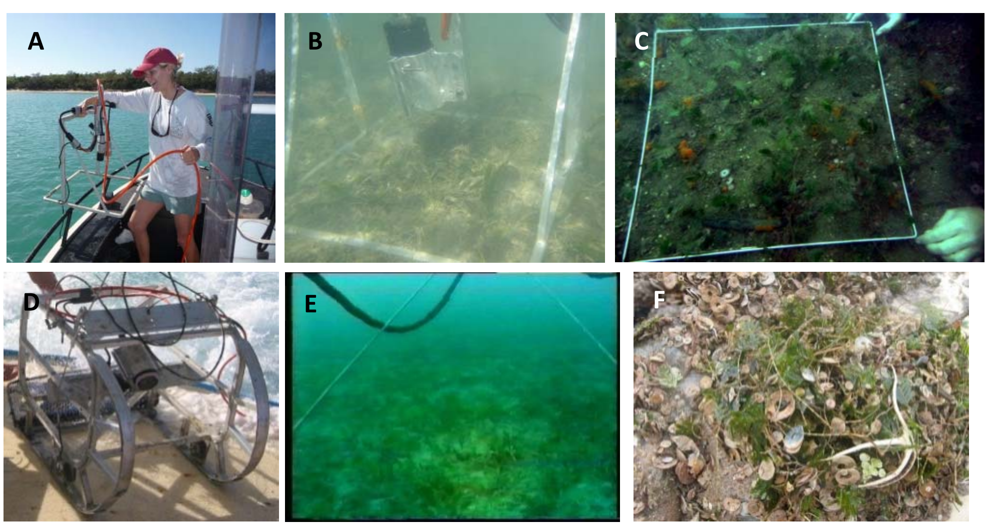


Figure 6. (A – B) Shallow subtidal mapping of seagrass meadows using digital camera mounted on a 0.25m^2 drop frame, (C) freediving and (D-F) offshore underwater sled tows with digital camera.

All survey data was entered into a Geographic Information System (GIS) database for presentation of seagrass species distribution and density. Three GIS layers were created in ArcGIS to describe the seagrass habitat in the survey areas:

- **Habitat characterisation survey sites** - site data containing above-ground biomass (total and for each species), depth below mean sea level (MSL), sediment type (based on visual estimates), latitude and longitude from GPS fixes, sampling method and comments.

- **Seagrass meadow biomass and community types** - Area data for seagrass meadows with summary information on meadow characteristics. Seagrass community types were determined according to overall species composition from nomenclature developed for seagrass meadows of Queensland (Table 1). This system was based on the percent composition of biomass contributed by each species within the meadow. This layer also included a measure of meadow density that was determined by the mean above-ground biomass of the dominant species within the community (Table 2).

- **Seagrass landscape category** - Area data for seagrass meadows showing the seagrass landscape category according to the below descriptions:

Isolated seagrass patches
The majority of area within the meadows consisted of un-vegetated sediment interspersed with isolated patches of seagrass.

Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of un-vegetated sediment within the meadow boundaries.

Continuous seagrass cover
The majority of area within the meadows comprised of continuous seagrass cover interspersed with a few gaps of un-vegetated sediment.

Table 1. Nomenclature for seagrass community types in Queensland.

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 Queensland.

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

The boundary of seagrass meadows was mapped by free diving, underwater camera techniques and the distance between sites, and then assigned a mapping precision estimate (±ha) (Table 3). The precision of the boundary was determined using an estimate of mapping reliability (R) based on the distance between sampling sites. This resulted in a range of meadow sizes which is expressed as an error (±ha) around the total meadow area (ha).

The boundary of the offshore annual monitoring meadow is not mapped in the intervening years, only in the three yearly broad-scale surveys (see Figure 5 for offshore monitoring areas).

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

Mapping precision	Mapping methodology
10-50m	Subtidal meadow boundaries determined from free diving surveys; Relatively high density of survey sites; Recent digital maps/landsat imagery aided in mapping.
50-100m	Subtidal meadow boundaries determined from free diving and underwater CCTV camera drops; Moderate to high density of survey sites; Recent digital maps/landsat imagery aided in mapping.

2.3 Seagrass meadow condition index

This is the second year of applying the seagrass condition index method that has been developed across the Queensland Ports Seagrass Monitoring Program, to Hay Point seagrass habitats. At this stage, a seagrass condition index is only be applied to the offshore monitoring sites at Hay Point, the dominant seagrass habitat in the area. Currently, there is insufficient data at the inshore sites and at the Mackay offshore monitoring site (only 2 years of data). As the monitoring program progresses and more data is collected, this will be reviewed for the inshore and Mackay monitoring sites.

A condition index was developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. Seagrass condition for each indicator at Hay Point was scored from 0 to 1 and assigned one of five grades: A (very good), B (good), C (satisfactory), D (poor) and E (very poor). The flow chart in Figure 7 summarises the methods used to calculate seagrass condition.

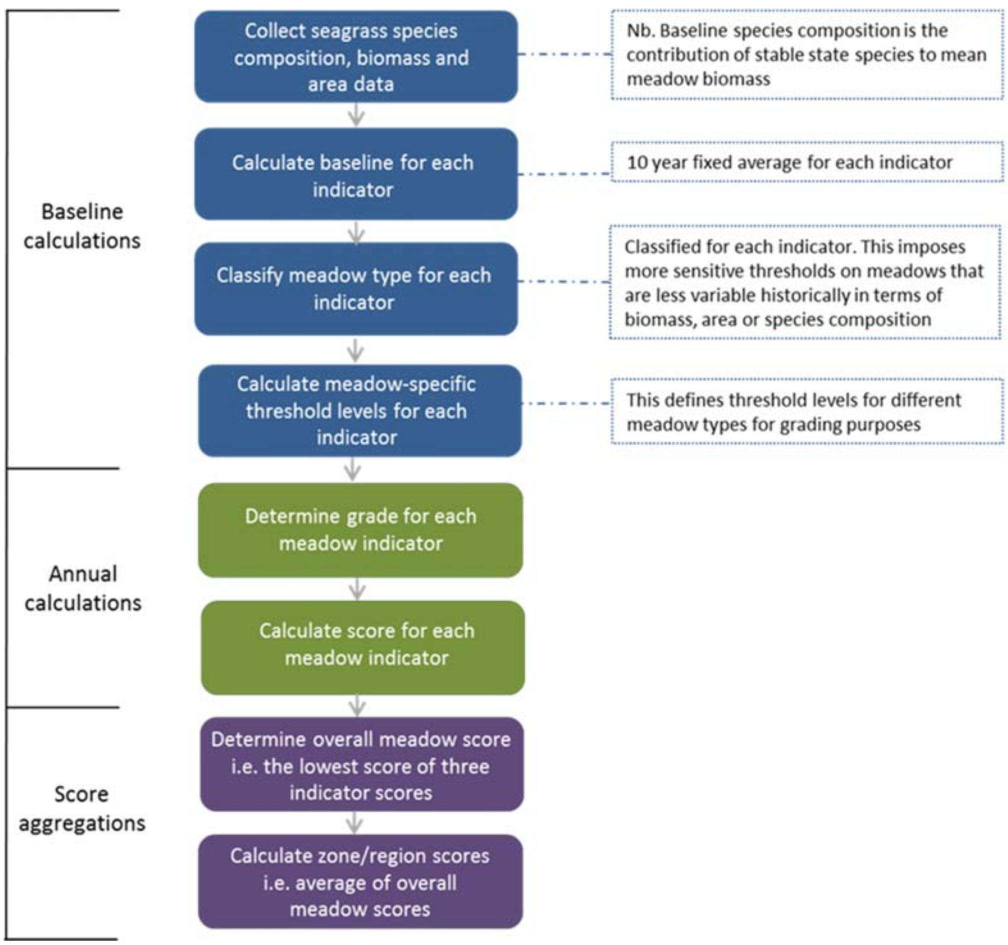


Figure 7. Flow chart to develop Hay Point grades and scores.

2.3.1 Baseline Calculations

Baseline conditions for seagrass biomass and species composition for the Hay Point offshore meadow were established from annual means calculated from 9 years of data for biomass and 8 years for species composition (2006 no seagrass present). This baseline was set based on results of the Gladstone Harbour 2014 pilot report card (Bryant et al. 2014). The 2005–2015 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 (McKenna et al. 2016). 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.

Meadow area was not calculated for offshore meadows as these are conducted using a transect method and transects are located within the meadow boundary; therefore a meadow area cannot be calculated every year.

Baseline conditions for species composition were determined based on the annual percent contribution of each species to mean meadow biomass of the baseline years. The meadow was classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). In 2016 an additional rule was applied: where a meadow baseline contained an approximately equal split in two dominant species (i.e. both species accounted for 40–60% of the baseline), the baseline was set according to the percent composition of the more persistent/stable species of the two (see Section 2.3.4 and Figure 8).

2.3.2 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 4). 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 4). The CV was calculated by dividing the standard deviation of the baseline years by the baseline for each condition indicator.

Table 4. Coefficient of variation (CV) thresholds used to classify historical stability or variability of meadow biomass and species composition.

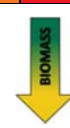
Indicator	Class			
	Highly stable	**Stable**	**Variable**	**Highly variable**
Biomass	-	CV < 40%	CV ≥ 40%	-
*Area	< 10%	CV ≥ 10, < 40%	CV ≥ 40, <80%	CV ≥ 80%
Species composition	-	CV < 40%	CV ≥ 40%	-

*Meadow area is not assessed for the Hay Point offshore monitoring sites

2.3.3 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 5).

Table 5. Threshold levels for grading seagrass indicators for various meadow classes relative to the baseline. Upwards/ downwards arrows are included where a change in condition has occurred in any of the three condition indicators (biomass, area, species composition) from the previous year.

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

*Meadow area is not assessed for the Hay Point offshore monitoring sites

2.3.4 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 6; 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 (described in Section 2.1), allocating a grade for each indicator by comparing 2016 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 6). 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 biomass in satisfactory condition is provided in Appendix 1.

Table 6. Score range and grading colours used in the 2016 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 8). 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 8). 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 8).

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).

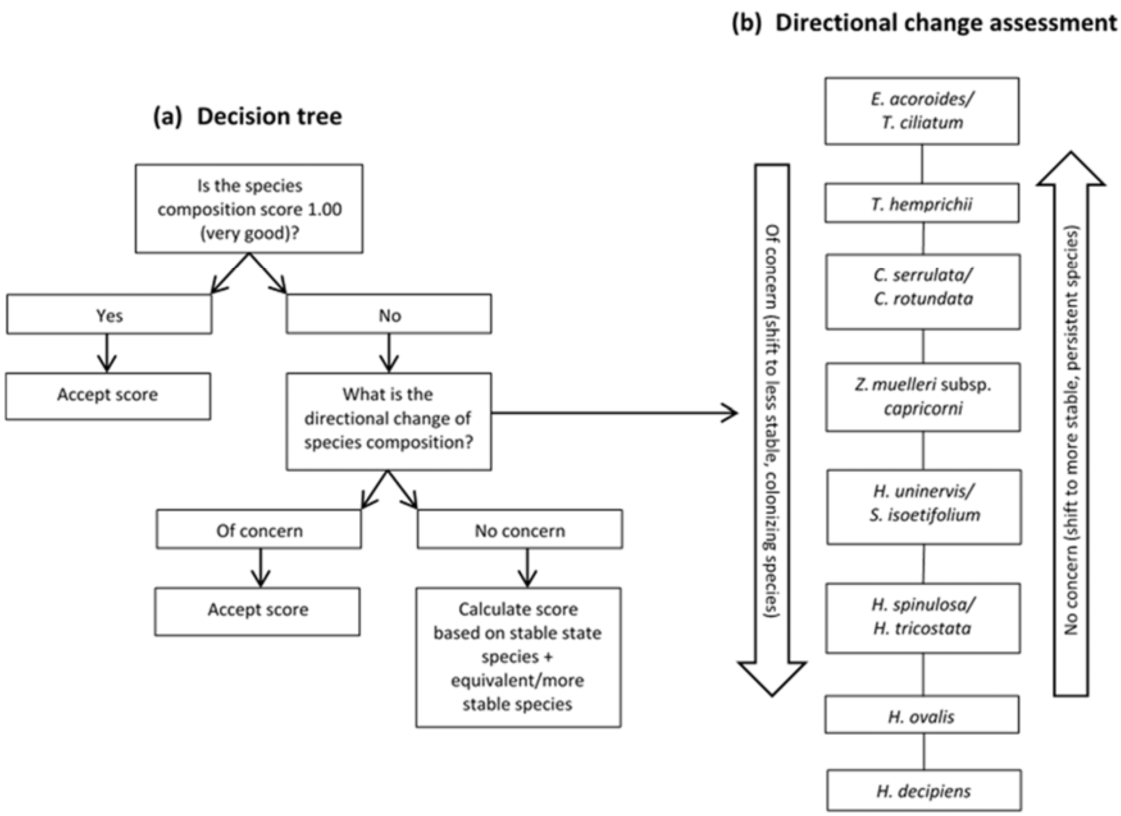


Figure 8. (a) Decision tree and (b) directional change assessment for grading and scoring species composition at Abbot Point.

2.3.5 Score Aggregation

Each overall meadow grade/score was defined as the lowest grade/score of the two condition indicators within that meadow. The lowest score, rather than the mean of the two indicator scores, was applied in recognition that a poor grade for any one of the three described a seagrass meadow in poor condition. Maintenance of each of these fundamental characteristics of a seagrass meadow is required to describe a healthy meadow. This method allowed the most conservative estimate of meadow condition to be made (Bryant et al. 2014).

Hay Point grades/scores were determined by averaging the overall meadow scores for each monitoring meadow within the port, and assigning the corresponding grade to that score (Figure 7; Table 6). 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 (outlined in Section 2.3.2) 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.

3 RESULTS

3.1 Seagrass in the Hay Point and Keswick Island areas

A total of 145 sites were surveyed as part of the annual monitoring program in the Hay Point/Mackay and Keswick Island area in October/November 2016 (Figure 10). An additional 174 sites were surveyed as part of the BMA/NQBP broad scale Hay Point benthic habitat survey (McKenna & Rasheed 2017). Seagrass was present at 28% of the inshore sites (Dudgeon Point – Hay Point & Keswick/St Bees islands) and at 15.5% of the offshore sites within the annual offshore monitoring areas (Hay Point & Mackay; Figure 5).

Five seagrass species were observed in 2016 (including the broad scale survey sites) (Figure 9). *Halophila tricostata* was found in the broad scale survey sites, outside of the Hay Point/Mackay offshore monitoring areas. This was the first record of *H. tricostata* occurring in the deep water meadows off Hay Point. The species regularly occurs at nearby Keswick and St Bees Islands. *Halophila ovalis* only occurred in one coastal meadow (non-monitoring meadow) in 2016. *H. ovalis* has occasionally been found in offshore meadows at Hay point but it is relatively uncommon having only been recorded on 2 previous occasions, in 2014 and in 2004 (McKenna and Rasheed 2015). Z*ostera muelleri* has only been found once during monitoring surveys at one of the small coastal monitoring meadows at Dudgeon Point in 2014.

The seagrass species found in the survey area were typical of those found for coastal and offshore seagrasses both in Hay Point and more broadly in central Queensland.

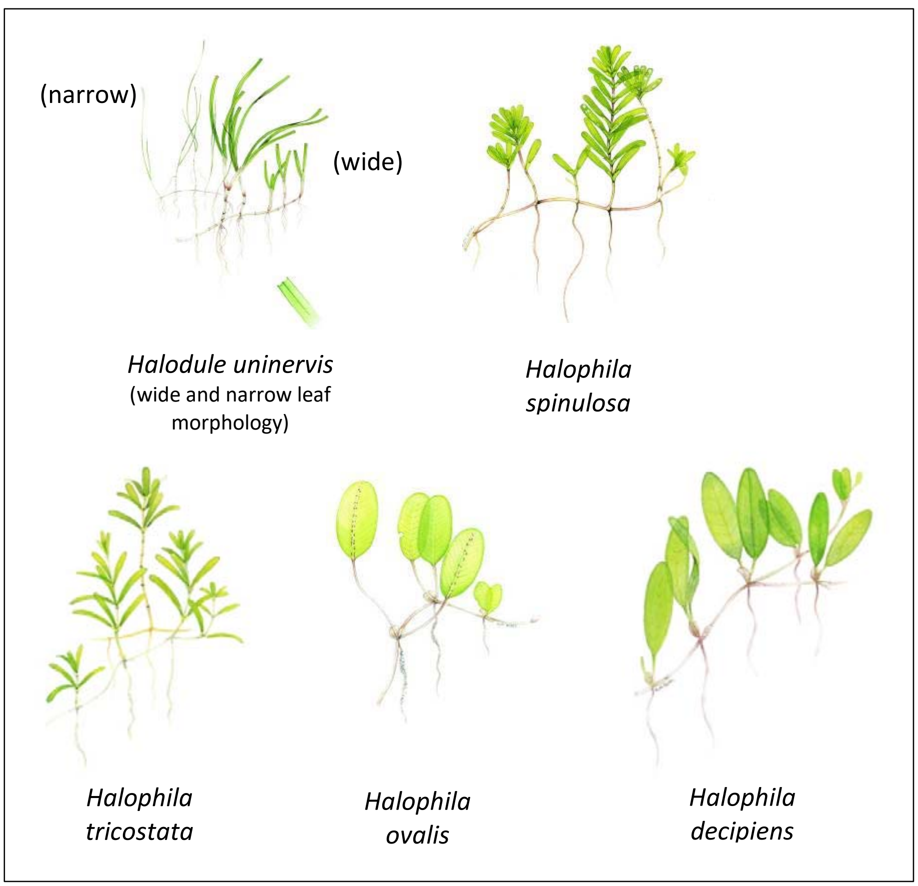


Figure 9. Seagrass species identified in the Hay point annual monitoring program in 2016.

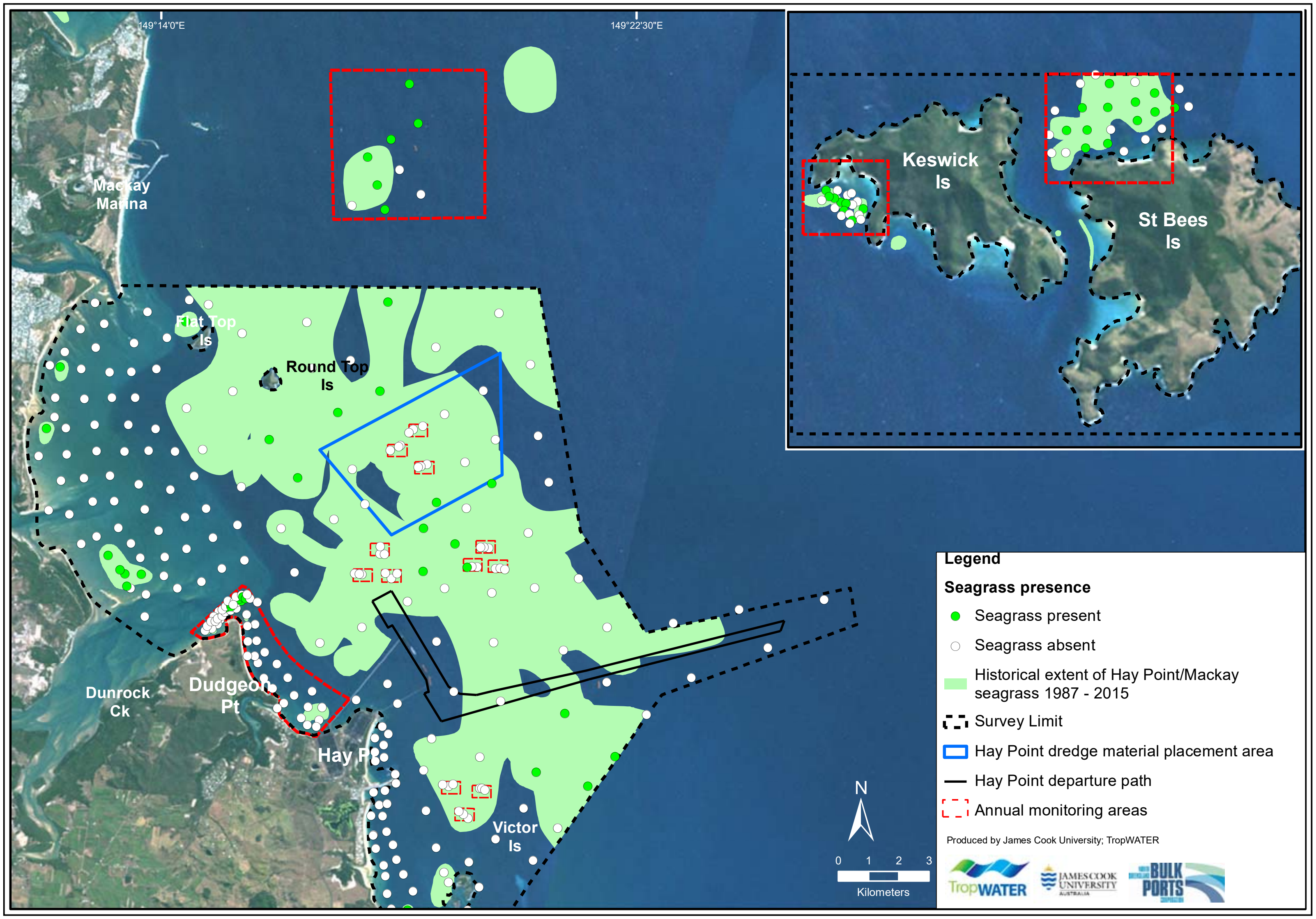


Figure 10. Location of 2016 annual monitoring survey sites in the Hay Point region

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

Offshore seagrass at Hay Point and Mackay

The overall condition of offshore seagrasses in the Hay Point monitoring sites was classed as very poor in 2016, a decrease in grade from satisfactory in 2015 (Table 7; Figure 12). This change was a reversal of the recovery that had occurred between 2014 and 2015 when condition improved from very poor to satisfactory, and emphasises the highly variable nature of seagrass within the offshore monitoring blocks. The species composition indicator was classed as very good while the biomass indicator was classed as very poor. It was the lower biomass indicator score that drove the overall offshore meadow score of very poor.

Seagrass was found in only one of the twelve Hay Point offshore monitoring blocks in 2016 (Figure 12) giving the offshore monitoring area a combined overall biomass of 0.00004 g dw m^2 for 2016. Between 2005 and 2016 seagrass biomass in the offshore Hay Point monitoring area (4 offshore sites combined (Figure 5)) has ranged from a high of 0.80 ± 0.33 g dw m^2 in 2005 to a low of 0.00004 ± 0 gdw m^2 in 2016. The survey of the broader region mapped this deep water meadow over an extended footprint with the overall biomass being 0.20 ± 0.19 g dw m^2. This higher biomass was mostly driven by one high biomass *H. spinulosa* site near Flat Top Island (see McKenna and Rasheed 2017). These results highlight the large spatial variability in offshore seagrass presence at Hay Point and indicate that incorporating a larger area of seagrass into the offshore monitoring approach is likely to yield better long term monitoring results in the future (see discussion pg 31 for further details).

Halophila decipiens was the only species recorded in the monitoring blocks. In the broad scale 2016 survey *H. decipiens* also dominated the wider offshore region of Hay Point. *Halophila tricostata* was present at one survey site on the south eastern boundary of the dredge material placement area (DMPA). *H. spinulosa* was found in the Mackay offshore monitoring area and at one site near Flat Top Island (Figure 10).

The 2016 broad scale survey found that offshore seagrass distribution had decreased by 65% between the 2014 and 2016 surveys, but was significantly larger than three of the previous surveys (2005, 2010 and 2011) (McKenna and Rasheed 2017).

The maximum depth that seagrass was recorded in the Hay Point broad scale survey was 20.9m below mean sea level (MSL).

Table 7. Grades and scores for seagrass indicators (biomass and species composition) for the Port of Hay Point.

Meadow	Biomass	Species Composition	Overall meadow score
Offshore monitoring areas	0.00096	1.0	0.00096
Overall score for the Port of Hay Point			**0.00096**

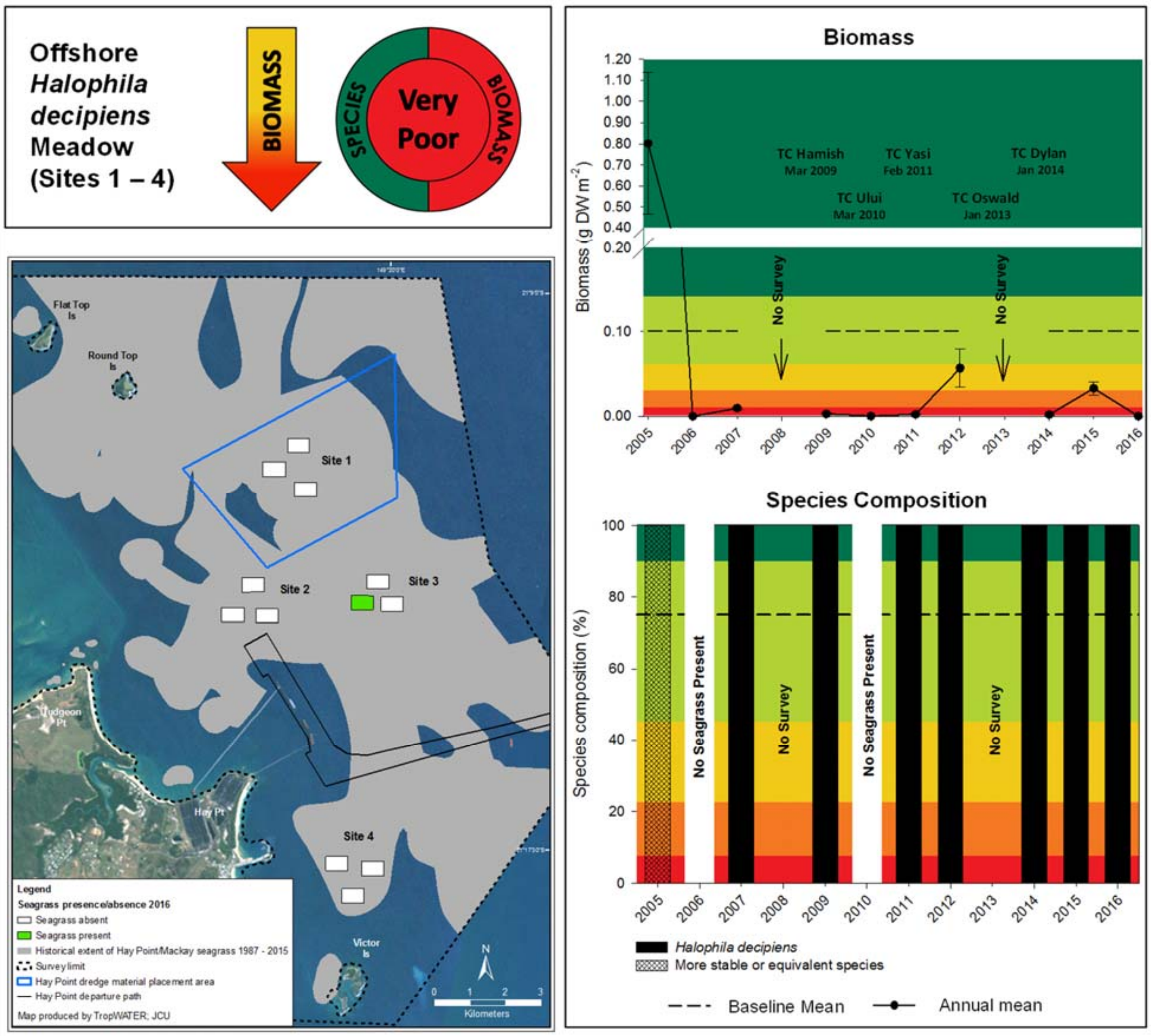
*****Meadow area is not assessed for the Hay Point offshore monitoring meadow

As part of the 2014 broad-scale survey we investigated inshore and offshore areas around the Port of Mackay that could become part of the long-term monitoring program. A deep water *H. spinulosa/H.*

decipiens meadow off the Mackay Marina was incorporated into the annual long-term monitoring program in 2015 (Figure 10). As 2016 is the second data point for this meadow, and it is a separate meadow from the Hay Point deep water seagrass meadow, the Mackay offshore meadow did not contribute to determining the above meadow condition indicator and score. This monitoring site will be treated as an independent site from the Hay Point offshore sites and will be integrated into the seagrass condition index once at least five years of data has been collected.

Seagrass in the Mackay monitoring area had a mean biomass of 0.12 ± 0.08 g dw m^2 and was comprised of 99.7% *H. spinulosa* with the remaining species composition made up of *H. decipiens*. The density of the meadow followed the same trend with the offshore Hay Point meadow and was lower in 2016 than 2015; 0.24 ± 0.12 g dw m^2 with a species composition of 88% *H. spinulosa* and 12% *H. decipiens*.

Seagrass in the Mackay monitoring area was found to a maximum depth of 21m below MSL.



Condition index

	A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass (variable)	More than 40% above the baseline	Within 40% of the baseline (above or below)	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline
Species (variable mixed sp.)	More than 20% above the baseline	20% above and 40% below the baseline	Between 40% and 70% below the baseline	Between 70% and 90% below the baseline	More than 90% below the baseline

Decrease below threshold from the previous year — BIOMASS

Increase above threshold from the previous year — BIOMASS

Figure 12. Changes in meadow biomass and species composition for seagrass in the offshore area around Hay Point, 2005 – 2016 (biomass error bars = SE).

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

The broad scale surveys and current monitoring program similarly show that inshore seagrass meadows at Hay Point tend to be highly variable both in distribution and species composition. The small Dudgeon Point meadows while consistently present have experienced large changes in species composition from being dominated by the colonising *H. decipiens* species to the more persistent *Z. muelleri* and *H. uninervis*. This is the third year that seagrass habitat at Keswick and St Bees Islands have been monitored. The two monitoring meadows in this region tend to be more stable in density, distribution and species composition than the Hay Point meadows.

Fifty five sites were surveyed in the annual coastal monitoring area between Dudgeon Point and Hay Point in 2016, 15% of which had seagrass present. Seagrass distribution in the Dudgeon Point to Hay Point monitoring area decreased between 2015 and 2016, and was similar to 2014 (Table 8). Seagrass at Dudgeon Point formed one *H. uninervis* (wide) meadow that was fragmented into three smaller meadows made up of aggregated and isolated patches of seagrass (Figure 13). This inshore meadow had a total area of 9.62 ± 4.16 ha and an overall biomass of 5.6 ± 0.76 g dw m^2 (moderate density) (Table 8; Figure 13).

These meadows were located in similar areas to previous surveys.

Forty five sites were surveyed for seagrass habitat in the two annual monitoring meadows at Keswick and St Bees Islands, 44% of which had seagrass present (Figure 10). Three seagrass species were observed in the two monitoring meadows in 2016: *H. decipiens, H. spinulosa* and *H. tricostata* (Table 9; Appendix 2). Seagrass within the two meadows formed two different meadows according to their community type (Meadow 10 and 14; Table 9) with a total combined area of 159.09 ± 60.08 ha. Total seagrass distribution has slowly been increasing in this monitoring area, however, the meadows tended to have a reduced distribution at their deeper margins in 2016. Biomass increased slightly in the St Bees Island monitoring meadow with the Keswick Island meadow showing a larger increase in biomass (Table 8). The larger increase in biomass in the Keswick Island meadow is likely due to *H. decipiens*, a smaller lighter species, contributing much less to the overall species composition of the meadow in 2016 compared to other years.

Similar to the Hay Point/Mackay area *H. ovalis* was absent from these meadows in 2016; the species was present in the 2014 and 2015 surveys.

Seagrass in the meadows ranged from shallow to deep subtidal sites and was found between 6.3m and 21.3m below MSL, a narrower depth range compared to 2015 (2.6m - 28.69 m below MSL).

Table 8. Inshore seagrass community type, mean above-ground biomass and meadow area in the Dudgeon Point - Hay Point annual survey areas, 2010 - 2016

Hay Point – Dudgeon Point inshore survey area				
Meadow ID	**Meadow location**	**Seagrass meadow community type**	**Mean meadow biomass (g dw m^2 ± SE)**	**Area ± R (ha)**
October 2010				
1	Inshore	Light *Halophila ovalis*	na	4.5 ± 1.6
2	Inshore	Light *Halophila ovalis/Halodule uninervis* (wide & narrow)	na	5.1 ± 2.0
3	Inshore	Light *Halodule uninervis* (wide)	na	2.6 ± 1.3
20	Inshore	Light *Halodule uninervis* (narrow)	na	36.5 ± 12.2
			Total	**48.7 ± 17.1**
November 2011				
1	Inshore	Not present	np	np
2	Inshore	Light *Halodule uninervis* (wide)	na	4.3 ± 1.9
3	Inshore	Not present	np	np
20	Inshore	Light *Halodule uninervis* (narrow)	na	6.3 ± 1.9
			Total	**10.6 ± 3.8**
October/November 2014				
1	Inshore	Light *Zostera muelleri/Halophila ovalis*	1.18 ± 0	4.3 ± 1.8
2	Inshore	Light *Halodule uninervis* (wide)	2.74 ± 0	4.7 ± 1.8
3	Inshore	Not present	np	np
20	Inshore	Not present	np	np
			Total	**9.0 ± 3.6**
October 2015				
1	Inshore	Moderate *Halophila decipiens*	1.42 ± 0	1.8 ± 0.3
2	Inshore	Light *Halodule uninervis* (wide)	1.79 ± 0.23	11.9 ± 1.1
3	Inshore	Not present	np	np
20	Inshore	Not present	np	np
			Total	**13.7 ± 1.4**
October/November 2016				
1	Inshore	Not present	np	np
2	Inshore	Light *Halodule uninervis* (wide)	5.6 ± 0.76	9.62 ± 4.16
3	Inshore	Not present	np	np
20	Inshore	Not present	np	np
			Total	**9.62 ± 4.16**

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

Table 9. Inshore seagrass community type, mean above-ground biomass and meadow area in the Keswick Island annual survey areas, 2014 – 2016.

Keswick/St Bees Islands inshore survey areas				
Meadow ID	**Meadow location**	**Seagrass meadow community type**	**Mean meadow biomass (g dw m^{-2} ± SE)**	**Area ± R (ha)**
October/November 2014				
10	Inshore	Light *Halophila tricostata* with *Halophila decipiens*	2.34 ± 0.38	118.6 ± 60.0
14	Inshore	Moderate *Halophila decipiens* with mixed species	2.6 ± 0.71	17.9 ± 13.3
			Total	**136.5 ± 73.3**
October 2015				
10	Inshore	Light *Halophila tricostata*	1.23 ± 0.19	137.2 ± 30.5
14	Inshore	Light *Halophila spinulosa* with mixed species	1.13 ± 0.35	14.7 ± 11.3
			Total	**151.9 ± 41.8**
October/November 2016				
10	Inshore	Light *Halophila tricostata*	1.69 ± 0.33	147.59 ± 53.42
14	Inshore	Light *Halophila spinulosa* with mixed species	2.94 ± 0.54	11.5 ± 6.66
			Total	**159.09 ± 60.08**

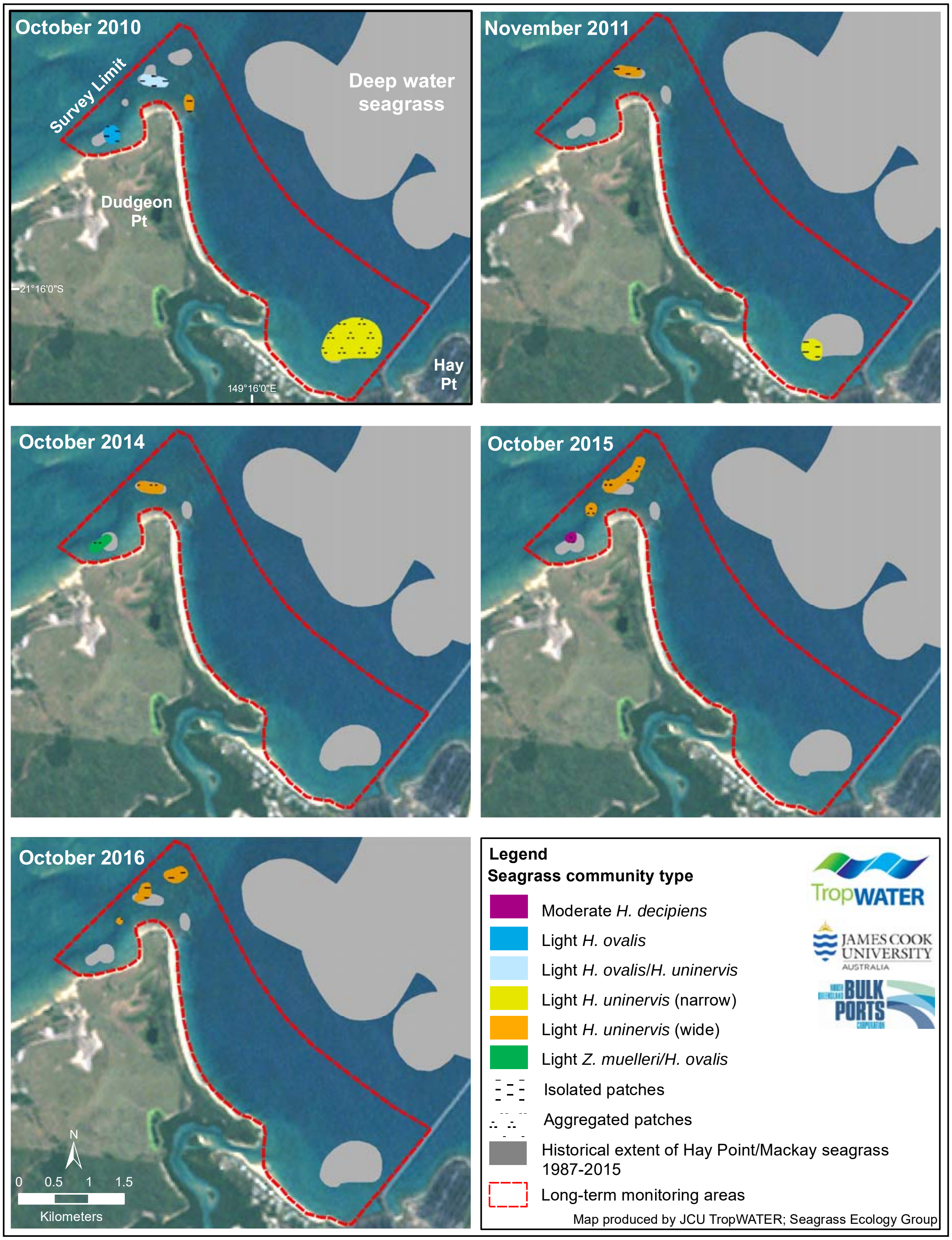


Figure 13. Seagrass community type in the Dudgeon Point to Hay Point annual monitoring area; 2010, 2011, 2014, 2015 and 2016.

Figure 14. Seagrass community type in the annual monitoring meadows at Keswick and St Bees Islands 2014 – 2016.

3.3 Hay Point Environmental Parameters

Rainfall

Annual rainfall has been similar to or below the long term average for the past three years (Figure 15a). Although total annual rainfall was similar to the long term average for the 2015/16 survey year, there was at least four months in the year that was above the monthly averages including months where deepwater seagrasses were likely to be establishing as part of their annual recruitment (Figure 15b). March, June, July and September 2016 all exceeded the monthly averages by nearly/at least double (Figure 15b).

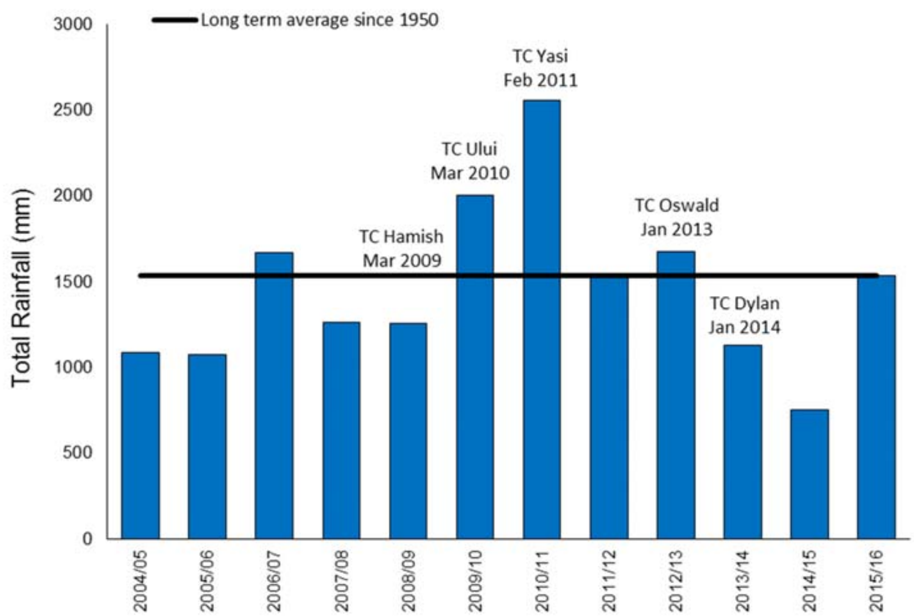


Figure 15a. Total annual rainfall (mm) recorded at Mackay Aero, 2004/05-2015/16. Twelve month year is twelve months prior to the survey. Source: Bureau of Meteorology (BOM), Station number 033045.

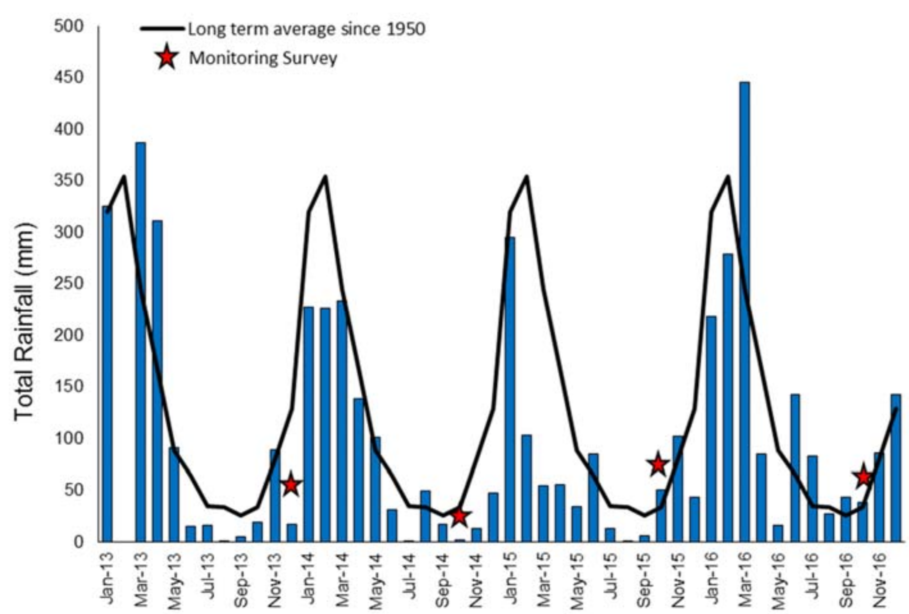


Figure 15b. Total monthly rainfall (mm) recorded at Mackay Aero, January 2013- December 2016. Source: BOM, Station number 033045.

River flow

Annual river flow of the Pioneer River has also been below the long term average for the past four years, with 2015/16 recording one of the lowest river flows for the past ten years (Figure 16a). Although total annual river flow was below the long term average in 2015/16, July – September 2016 recorded above average flows, coinciding with rainfall and catchment events and the normal peak growing time for deepwater seagrasses in the region.

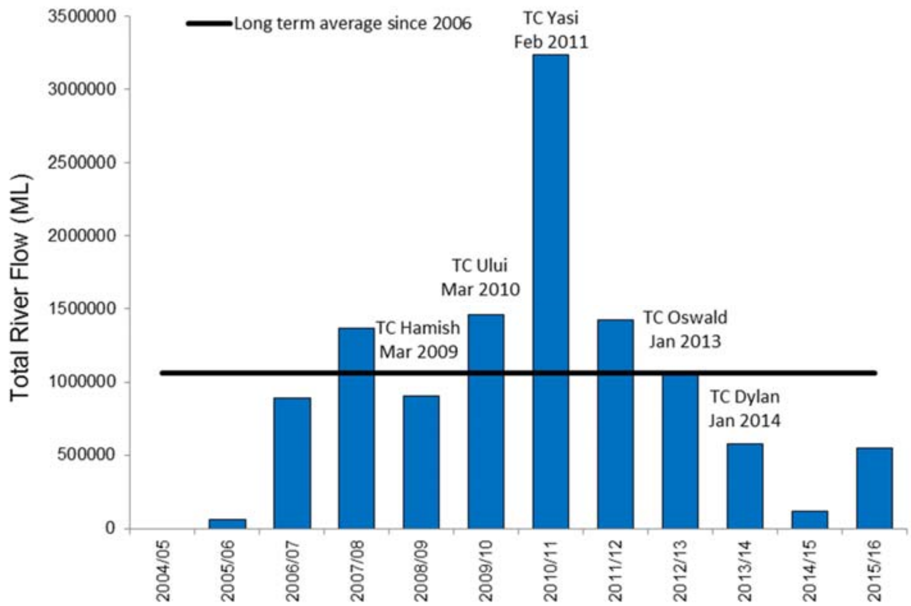


Figure 16a. Annual river flow (Mega litres) for the Pioneer River, 2004/05-2015/16. Twelve month year is twelve months prior to the survey. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

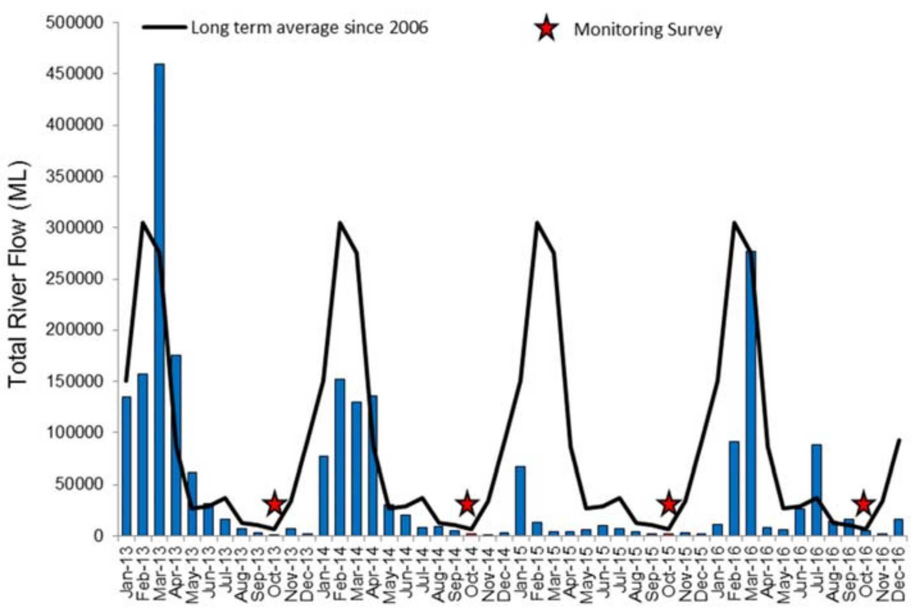


Figure 16b. Monthly river flow (Mega litres) for the Pioneer River January 2013-December 2016. Source: Queensland Department of Environment and Resource Management, Station number 125016A.

Sea Surface Temperature

Sea surface temperature has been collected half hourly at Hay Point since 2008 (QLD Department of Science, Information Technology and Innovation 2016). Mean annual maximum daily sea surface temperature was below the long-term average (8 years) in 2015-16, but was above the the long term average in the previous two years (Figure 17a). Monthly data shows that sea surface temperature was above the long-term monthly average in the first half of 2016, while for the second half year and leading up to the 2016 annual survey, temperatures were below average.

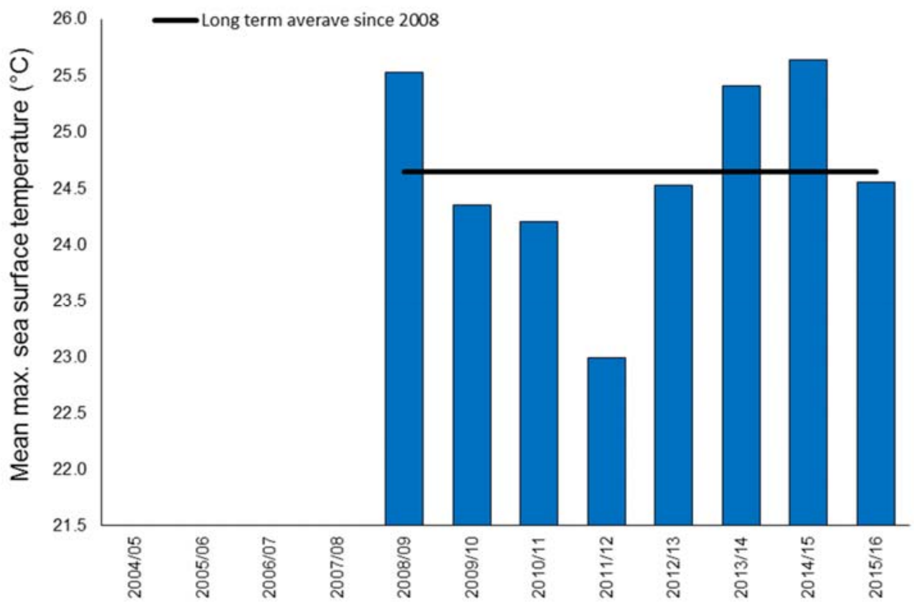


Figure 17a. Mean annual maximum sea surface temperature (°C) recorded at Hay Point 2008/09-2015/16. Twelve month year is twelve month prior to the survey. Source: QLD Department of Science, Information technology and Innovation

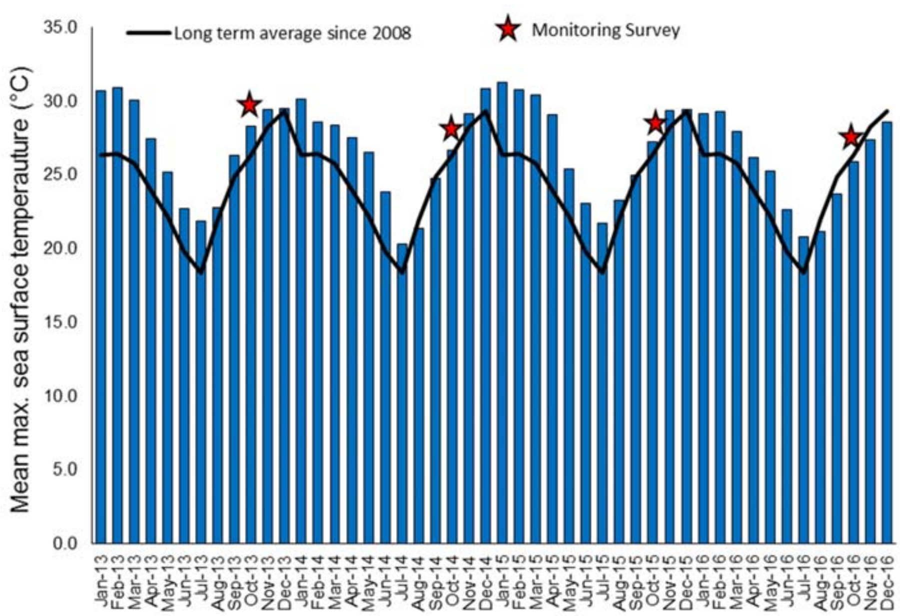


Figure 17b. Monthly maximum sea surface temperature (°C) recorded at Hay Point; January 2013 to December 2016. Source: QLD Department of Science, Information technology and Innovation

Daily Global Solar Radiation

Daily global exposure is a measure of the amount of the total solar energy falling on a horizontal surface in one day. Values are generally highest in clear sun conditions during spring/summer and lowest during winter. Solar exposure in the Hay Point area was below the long term average in 2015/16 with a measure of 20.06 MJ m^{-2} (Figure 18a). Exposure was generally below average each month in 2016 (Figure 18b).

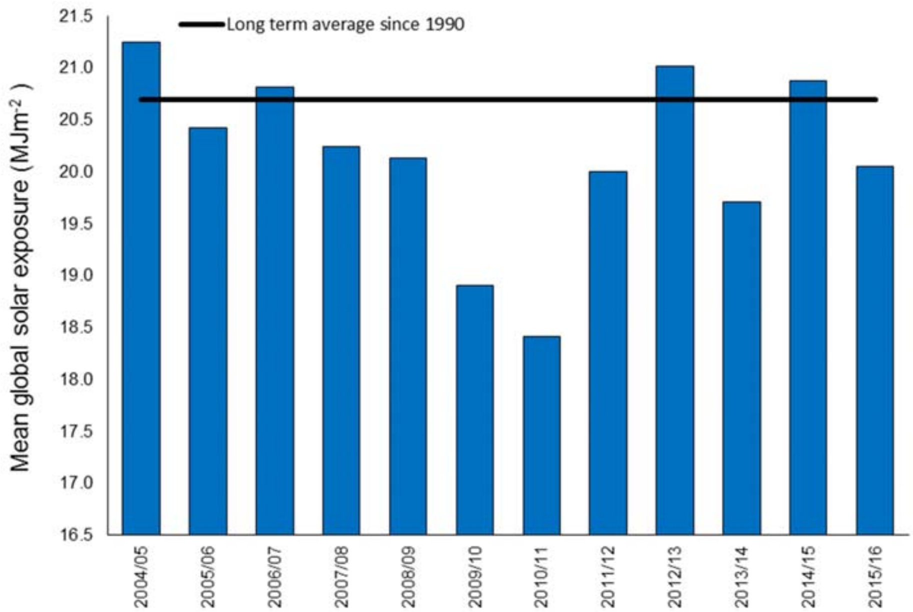


Figure 18a. Mean annual solar radiation (MJm^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) 2004/05 -2015/16. Twelve month year is twelve months prior to the survey. Source: BOM.

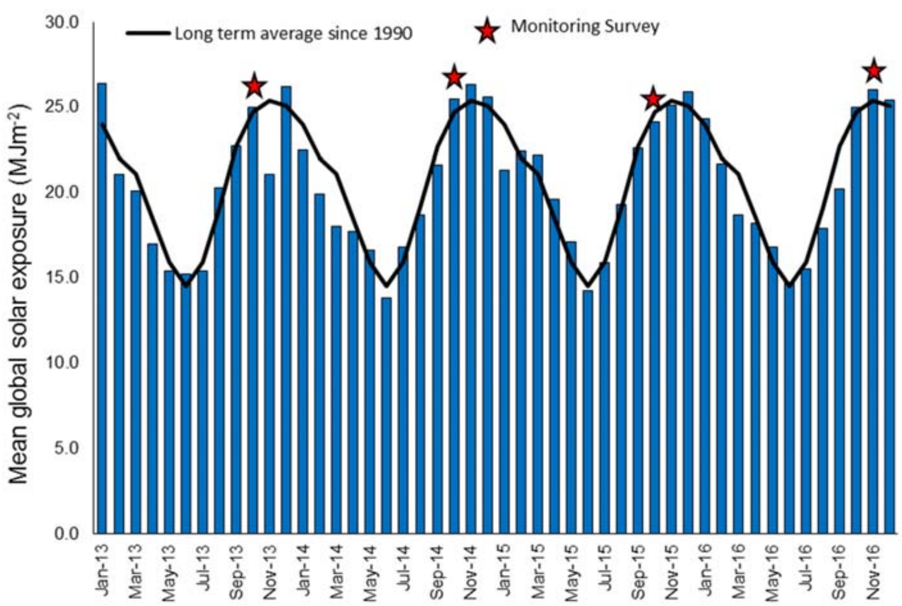


Figure 18b. Mean monthly daily global solar exposure (MJ m^{-2}) recorded at Hay Point (Station 033317) and Mackay Aero (Station 033045) January 2013-December 2016. Source: BOM.

4 DISCUSSION

There was an overall decline in seagrass condition in the Hay Point – Mackay area between 2015 and 2016. For deeper offshore areas this was the case for both the annual long term monitoring sites, as well as more broadly in the larger survey region, where biomass and area were much reduced (McKenna and Rasheed 2017). Despite this, total area of offshore meadows in Hay Point remained the third largest of the six broadscale surveys that have been conducted between 2004 and 2016 (Figure 19). Inshore coastal meadows also decreased substantially in area between 2015 and 2016, although biomass of the remaining seagrass increased. The monitoring meadows surrounding Keswick and St Bees Islands were less affected with area increasing and biomass similar to previous years. For the only region where sufficient length of data is available to develop a condition score; the offshore Hay point meadow, these declines resulted in a condition score of "very poor" in 2016. It is likely that these changes were related to climate conditions of high rainfall, increased river flow and low benthic light in the critical months at the start of the seagrass growing season.

The broad scale habitat surveys at Hay Point, as well as the long-term segrass monitoring program that ran between 2005 and 2012 established that the spatial extent of deep water seagrasses around Hay Point is naturally extremely highly variable with an annual cycle of occurrence; deep water seagrass being present only from July to December each year (Chartrand et al. 2008; York et al. 2015). The small Dudgeon Point meadows while consistently present, have experienced large changes in species composition from being dominated by the colonising *H. decipiens* species to the more persistent *Z. muelleri* and *H. uninervis*. This may be a sign of improved growing conditions for coastal seagrasses, although the small number of monitoring events makes it difficult, at this stage, to place the changes in context.

The diversity of seagrass species found in the offshore survey areas (*Halophila decipiens, Halophila ovalis, Halophila spinulosa* and *Halophila tricostata*) were typical of deep water seagrasses occurring in waters between the mainland and the Great Barrier Reef (Coles et al. 2009; Chartrand et al. 2017). The structurally small nature of *Halophila* species and their low biomass relative to other seagrass species means they have lower respiratory demands on photosynthetic carbon and therefore have lower light requirements for growth and survival allowing them to inhabit greater depths compared to other species (Josselyn et al. 1986; Erftemeijer & Stapel 1999; Kenworthy 2000; Lee et al. 2007; Chartrand et al. 2017). The ecological trade-off for low biomass *Halophila* meadows is that they have limited carbohydrate stores to support them once light levels drop below their requirements (Longstaff et al. 1999).

The availability and quality of light, as well as other environmental parameters such as temperature is a major driver of the seasonal cycle of senescence and recruitment of seagrasses including *Halophila* species in the tropics (Kuo and Kirkman 1995). However, a recently completed research program by TropWATER investigating the strategies that drive the spatial and seasonal dynamics of tropical deep water seagrass communities has found that seasonal changes to *Halophila* species are not always linked to light and temperature but may be due to a programmed seasonal die off after investing in the production of fruits and seeds for the following season (Chartrand et al. 2017). This seems to be especially the case for *H. decipiens*; the dominant species in the offshore Hay Point meadow (Chartrand et al. 2017). Such a pre-programmed senescence is not an unusual strategy for plants, and is seen in many monocarpic land plants, especially those that must survive in seasonally unfavourable conditions (Chartrand et al. 2017).

While light may not be the principal driver for some *Halophila* species in their seasonal senescence, there must still be enough light to maintain seagrass condition during the key growing periods (~July – December) for plant reproduction to replenish the seed bank for the subsequent year's germination and continuance of the meadow. Most *Halophila* species have a high reliance on a seed bank for annual recruitment prior to seasonal die off (Rasheed et al. 2014; Chartrand et al. 2017). Laboratory studies were able to confirm that a decline in light below 1.5-2 mol photons m^{-2} d^{-1} for greater than seven days for *H. decipiens* would likely impact the ability for a seed bank to be replenished (Chartrand et al. 2017). *Halophila tricostata* and *H. spinulosa* were likely to have a similar requirement, however carbohydrate reserves of these larger bodied species delays shoot loss to after fourteen days of low light as opposed to seven days (Chartrand et al. 2017).

At Hay Point environmental conditions for the last two years for offshore seagrass growth have generally been favourable with below average rainfall and river flow, and the prevailing El Nińo climate pattern resulting in drier weather patterns with fewer episodic rainfall events (McKenna and Rasheed 2017). Favourable climate conditions are likely to have facilitated the increases in biomass and area seen for the sub-set of annual monitoring meadows assessed in 2015 (McKenna et al. 2016). The subsequent decrease in deep water seagrass distribution around Hay Point in 2016 is likely the result of higher than average rainfall and river flow of the Pioneer River from June to September 2016 (1 – 4 months before the 2016 survey). These climatic events resulted in benthic light (PAR – photosynthetic active radiation) falling below required light levels for *Halophila* species for long periods of time during the peak growing period (Waltham et al. 2016; benthic PAR is collected as part of the ambient marine water quality monitoring program conducted by TropWATER). PAR at the spoil ground site for example, did not exceed 1.5 mol m^{-2} d^{-1} for the entire month of July, just as germination of *Halophila* seeds would be expected to occur at Hay Point. Similarly PAR at Keswick Island was below the biological threshold for *H. tricostata*; 2.2 mol m^{-2} d^{-1} (Collier et al. 2016) for up to 23 days between July and September 2016 (unpublished data from Mackay/Hay point ambient water quality monitoring program). The reduction in light leading in to the growing season may have impacted either the germination of seeds, or resulted in inadequate light during the critical early growth period of germinated shoots. At the Mackay and Keswick/St Bees Island offshore meadows, the impact of this may have been mitigated to some extent due to the presence of the more robust species *H. spinulosa* and *H. tricostata* that have larger carbohydrate reserves to draw down on during periods of light stress. Supporting this was the much reduced presence of the smaller less resilient *H. decipiens* in these meadows in 2016. Although the distribution and biomass of seagrass in the Keswick Island region did not change to the same extent as Hay Point, the reduction in the maximum depth at which seagrass was found (28.7m to 21m) is also an indication that there was not enough available light to support seagrass growth at depth.

The inshore seagrass at Hay Point considerably increased in distribution between the two broad scale surveys (2014 and 2016) (McKenna and Rasheed 2017). Much of this increase was due to the presence of three new inshore meadows and the significant increase in size of a *H. uninervis* meadow on the northern side of Dunrock Creek (McKenna and Rasheed 2017). While there was an overall increase in the two years between broad scale surveys (2014 to 2016), results from the annual monitoring program that examines a sub-set of these coastal meadows each year (Meadows 1, 2, 3 and 20) suggest that coastal seagrasses actually peaked in 2015 and then declined between 2015 and 2016 (McKenna and Rasheed 2017). So while shallow seagrasses were more extensive in 2016 than 2014, this was likely a reduction from a 2015 peak. Therefore coastal seagrasses were likely to have been impacted in a similar way as the offshore meadows by the environmental conditions (described above) that affected the period leading up to the survey. A combination of high rainfall, high river flow and increased wave/wind activity can negatively impact seagrass either physically (burial, scouring, direct removal of plants and seed-banks) (Preen et al. 1995; Bach et al. 1998; Campbell & McKenzie 2004) or physiologically (light limitation, excess nutrients and herbicides, and changes in salinity) (Björk et al. 1999; Ralph et al. 2007; Chartrand et al. 2017). The potential direct and indirect disturbances to these inshore meadows leading up to the survey may have resulted in the reduction in distribution of these meadows between 2015 and 2016.

The highly variable and low biomass nature of seagrass in the Mackay/Hay Point region indicates that seagrasses are living at the limits of light required to support their growth and reproduction. The management of seagrass therefore should remain focused on ensuring the resilience of these habitats remains high enough to withstand expected natural and anthropogenic impacts and risks. While previous research has shown that these meadows are susceptible to impacts from large scale dredging (in 2006), they also had an ability to rapidly recover (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. Given the critical nature of seed banks for this offshore annual seagrass, the addition of some regular assessment of seed banks as part of monitoring may be warranted. Seed banks have only been been examined for one location at Hay Point previously (Chartrand et al. 2017), and although no seeds were found there it seems likely that seeds do exist elswhere in the region and explain the annual recruitment and recovery of seagrasses recorded (York et al. 2015).

The Mackay-Hay Point long-term monitoring program has been incorporated into the broader Queensland Ports seagrass monitoring program using the consistent state-wide monitoring methodology. This enables direct comparisons with regional and state-wide trends to put local changes into a regional context. It also provides a key input into the condition and trend of seagrasses in the Mackay-Whitsundays NRM region, an area which otherwise has a poor spatial coverage for seagrass assessment and condition. Monitoring at other sites in the network has shown a range of results during 2016. For many locations coastal seagrasses have improved (Cairns, Townsville, Abbot Point – Wells et al. 2017; McKenna et al. 2017; York et al. in prep) yet at others they have declined (Gladstone – Wells et al. 2017). For offshore *Halophila* meadows, declines similar to Hay Point were recorded for the Bowen/Abbot Point region in 2016 (McKenna et al. 2017). Similar to Hay Point, the Abbot Point area also had higher than average rainfall and local river flows in the dry season which could explain the seagrass declines (McKenna et al. 2017). In 2016 it seems that local scale climate rather than larger scale regional drivers have been the major influence on seagrass changes.

Potential changes for ongoing monitoring

The broad scale surveys that complement the long-term annual monitoring program have given us an understanding of the extreme natural spatial variability of the offshore meadow at Hay Point (Figure 19; McKenna and Rasheed 2017). The fixed offshore annual monitoring blocks were originally established to detect changes from the 2006 capital dredging program and to this point have done a reasonable job of capturing seagrass change. However, in 2016 the blocks only just captured the presence of the meadow (in one block only) despite there being a relatively large spatial extent revealed in the concurrent broadscale survey. We recommend that due to this extreme spatial variability, sampling effort needs to be increased and spread throughout the whole meadow to adequately describe seagrass change. Based on the results from previous broader scale assessments of the meadow, this could be accomplished by spreading sampling during annual monitoring to cover the same spatial footprint as the original 2004 baseline survey (which would equate to an extra field sampling effort of around 2 days). There are now six previous surveys that cover this entire area (Figure 19) so the change in approach would still allow the calculation of an interim meadow condition score. An additional advantage to this approach is that area, the third metric of change, can be added to the condition assessment, bringing it in line with assessments of the coastal meadows. This change, with the addition of some assessments of the seed bank status for the meadow, would significantly improve the monitoring program's power to understand seagrass changes in the region.

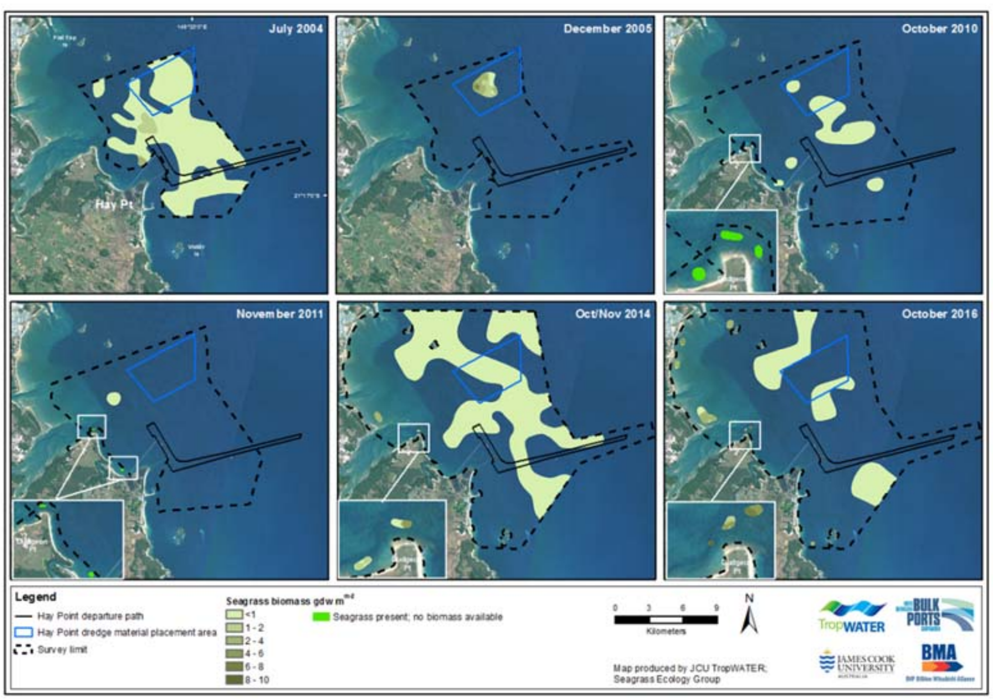


Figure 19. Seagrass distribution and density at the Port of Hay Point in 2004-2016 (McKenna & Rasheed 2017)

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6 APPENDICES

Appendix 1.

An example of calculating a meadow score for biomass in satisfactory condition.

1. Determine the grade for the 2015 (current) biomass value (i.e. satisfactory).

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

$$B_{diff} = B_{2015} - B_{satisfactory}$$

Where $B_{satisfactory}$ 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 (B_{range}) in that grade:

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

Where $B_{satisfactory}$ 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 (B_{prop}) that B_{2015} takes up:

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

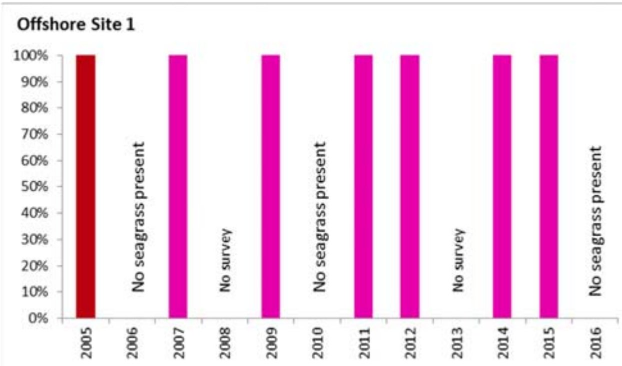
5. Determine the biomass score for 2015 ($Score_{2015}$) by scaling B_{prop} against the score range (SR) for the satisfactory grade ($SR_{satisfactory}$), i.e. 0.15 units:

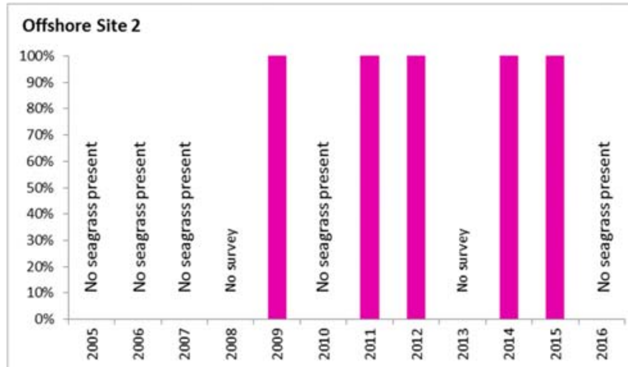
$$Score_{2015} = LB_{satisfactory} + (B_{prop} \times SR_{satisfactory})$$

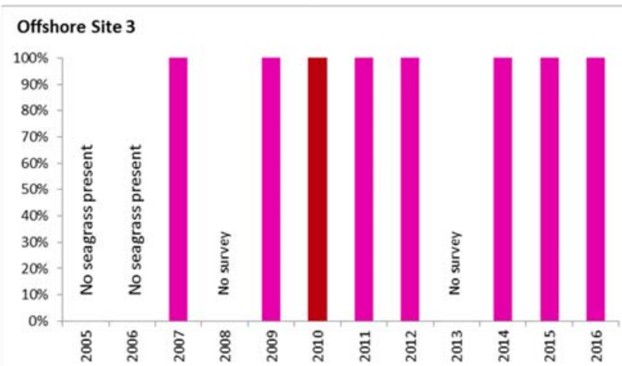
Where $LB_{satisfactory}$ is the defined lower bound (LB) score threshold for the satisfactory grade, i.e. 0.50 units.

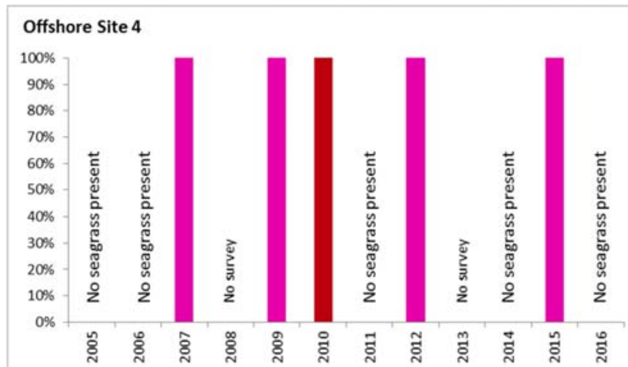
Appendix 2.

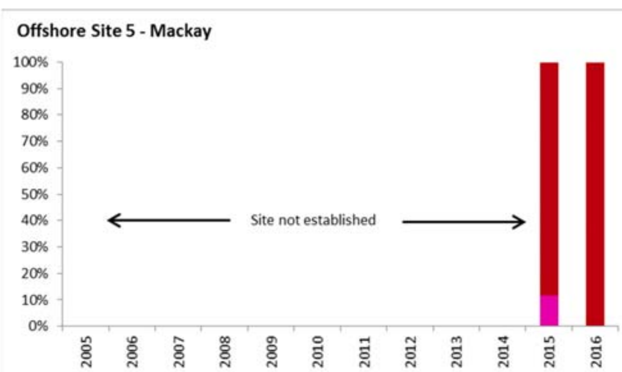
Species composition of monitoring meadows in the Hay Point/Mackay region, and the Keswick Island group.

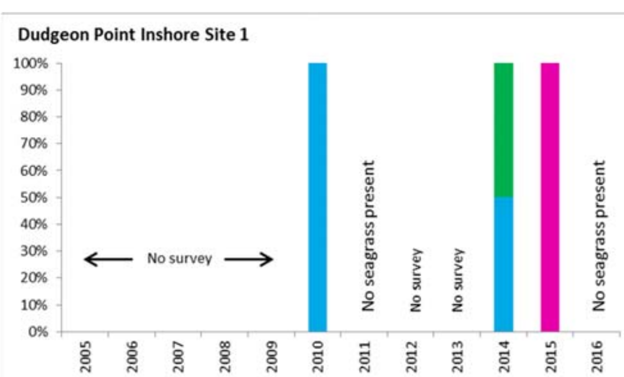


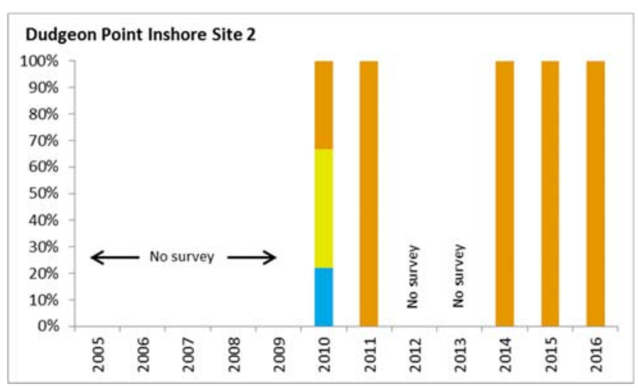


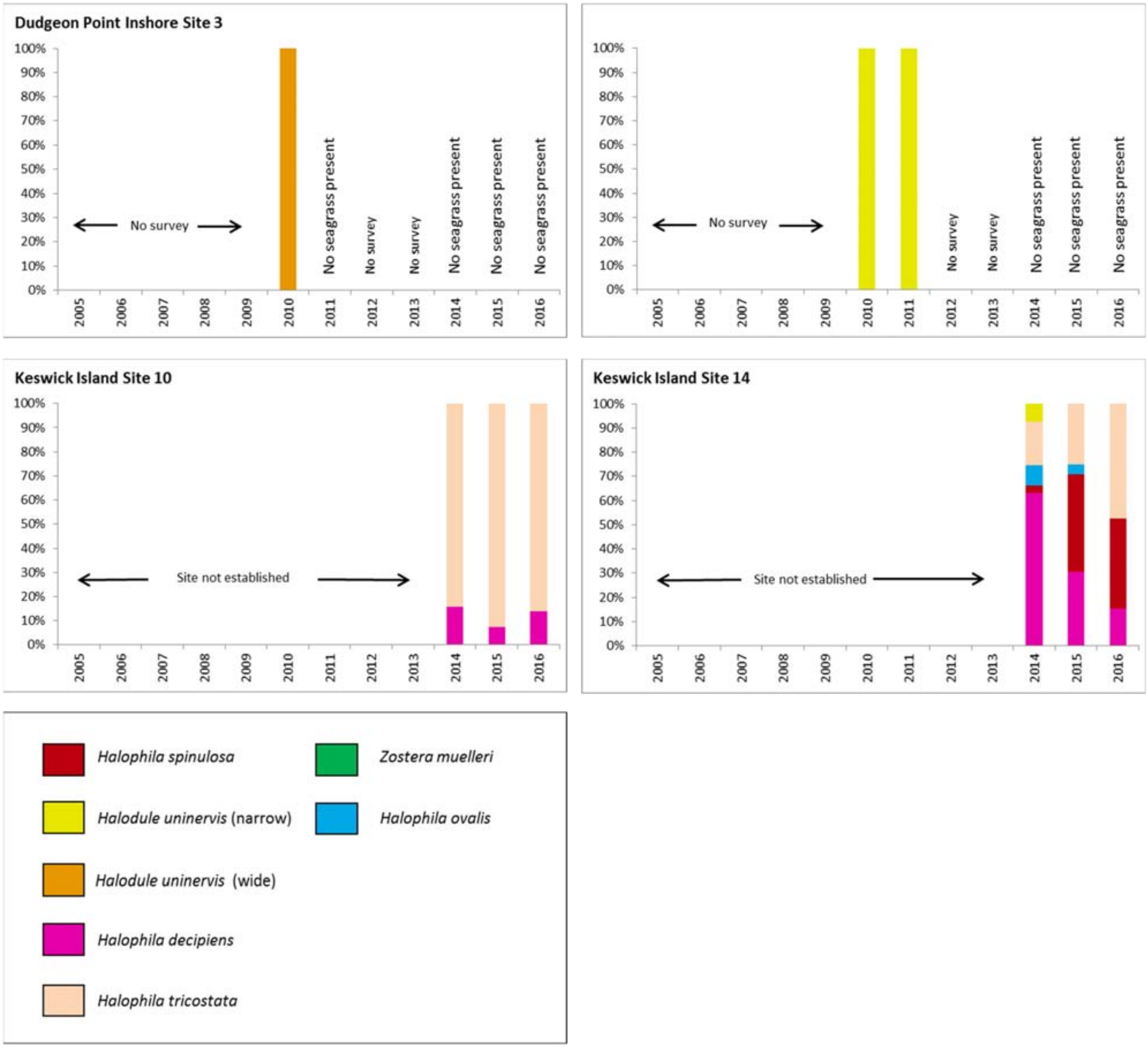











Dudgeon Point Inshore Site 3
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
No survey
No seagrass present
No survey
No survey
No seagrass present
No seagrass present
No seagrass present
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
No survey
No survey
No survey
No seagrass present
No seagrass present
No seagrass present
Keswick Island Site 10
Site not established
Keswick Island Site 14
Site not established
Halophila spinulosa
Zostera muelleri
Halodule uninervis (narrow)
Halophila ovalis
Halodule uninervis (wide)
Halophila decipiens
Halophila tricostata