Port of Brisbane Seagrass Monitoring Program 2019 – Final Report

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<tr><td colspan="2"></td></tr>
<tr><td colspan="3">Synopsis: Findings of the 2019 seagrass monitoring program at Port of Brisbane, Queensland.</td></tr>
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Executive Summary

Background

The Port of Brisbane is located adjacent to Waterloo Bay, which contains some of the largest seagrass meadows in western Moreton Bay. These meadows have outstanding ecological and fisheries resource values.

Port of Brisbane Pty Ltd (PBPL) conducts annual monitoring of seagrass meadows at Fisherman Islands and control locations at Manly and Cleveland. The seagrass monitoring program (SMP) incorporates remote-sensing and underwater video-based methodologies. Commencing in 2002, the SMP provides a long-term data-set of seagrass condition and assemblage. This provides a basis to assess trends in the condition of the seagrass meadows potentially affected by port activities.

Findings

The major findings of the 2019 SMP were:

- Consistent with previous years, five seagrass species were recorded: *Zostera muelleri*, *Halophila spinulosa*, *Halophila ovalis*, *Halophila decipiens* and *Halodule uninervis*. The structure of assemblages was consistent with previous surveys and is typical of meadows elsewhere in Moreton Bay and other Queensland estuaries.
- Intertidal and shallow subtidal areas were predominately composed of *Z. muelleri* meadows. These meadows were generally stable over time and space compared with deeper subtidal meadows dominated by *Halophila* species.

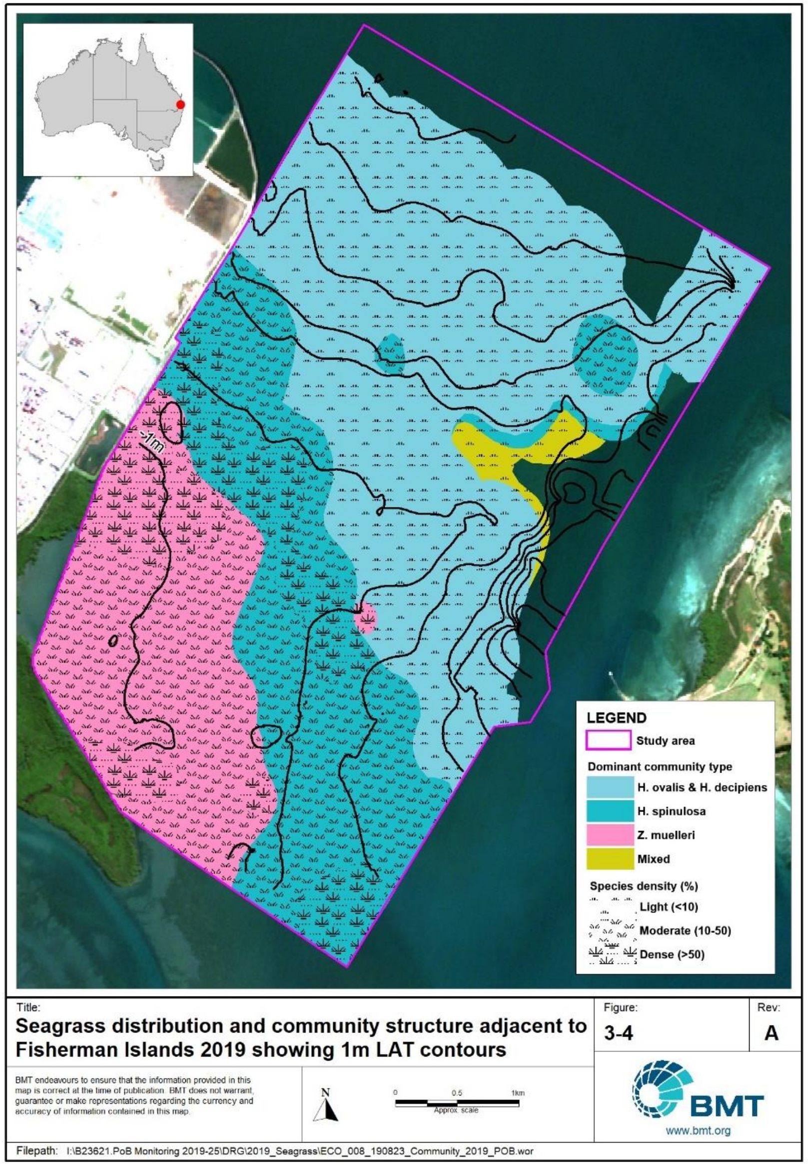

Figure 1 Seagrass distribution and community structure adjacent to Fisherman Islands 2019 showing 1m LAT contours

- There has been a long-term trend of seagrass meadow expansion at Fisherman Islands. This is consistent with the predictions of the Future Port Expansion Impact Assessment Study, which predicted that the reclamation would enhance seagrass local growing conditions.
- There has been year to year variability in composition and extent of seagrass meadows, with meadow expansion observed during the Millennium drought and retractions in 2011 and 2013 following major flooding events.
- There were localised contractions in *Z. muelleri* cover on the landward edge of Fisherman Islands meadows.

Figure 2 Intertidal Zostera muelleri at Fisherman Islands

- Seagrass depth range (SDR) is a function of water quality and availability of suitable substrates. Seagrass depth range was highest at Manly and lowest at Cleveland. Fisherman Islands SDR was stable since 2018. All transects remained equal to or above the SDR of 2013.
- *Environmental Protection Policy (Water*) sets out water quality objectives (WQO) for the protection of environmental values, which includes *Zostera muelleri* SDR as an ecological benchmark. Most transects met the SDR WQO, except for one transect at Cleveland. Notably, the SDR WQO was met at transect F of Fisherman Islands for the first year since 2010. WQO were met at more SDR transects than any previous survey, this is likely a result of prolonged drought that provides favourable seagrass growing conditions.

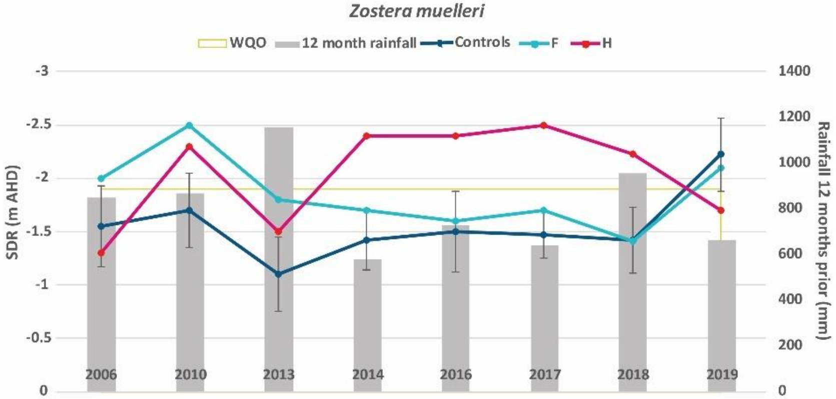

Figure 3 *Zostera* SDR at Fisherman Islands transect F and H, and the average (±SE) for control sites. Rainfall in the 12 months leading to the survey is also shown

- A variety of algae species were present in seagrass meadows. Filamentous algae were the most abundant algae group at all locations. *Caulerpa taxifolia* was a dominant component of the benthic community throughout the study area during the 2000's when El Niño (dry weather) conditions prevailed. However, no *C. taxifolia* was observed during the 2019 survey.
- Overall, the SMP demonstrates a long-term trend of increasing seagrass meadow extent at Fisherman Islands and recovery to pre-flood levels. The SMP demonstrates that seagrass meadows at Fisherman Islands continue to represent a critical ecosystem component in western Moreton Bay.

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1 Introduction

1.1 Background

Moreton Bay contains habitats, communities and populations that support outstanding ecological, social and economic values. In recognition of these values, parts of Moreton Bay are listed as an internationally significant wetland (Moreton Bay Ramsar Site) and Moreton Bay Marine Park (Figure 1-1).

The Port of Brisbane is located adjacent to Waterloo Bay, which contains some of the largest seagrass meadows in western Moreton Bay (Dennison and Abal 1999). The Port of Brisbane Pty Ltd (PBPL) has developed a Seagrass Monitoring Program (SMP) to provide information on the status and condition of seagrass meadows through time to identify if there are any signs of impact from port activity.

The extent and health of seagrass meadows is a useful indicator of water quality change, especially aquatic light climate (ANZECC/ARMCANZ 2000, p A3-79). The maximum depth at which seagrass grows is thought to mainly be a function of the availability of certain wavelengths of light[1] (Abal and Dennison, 1996). A reduction in light availability below the requirements of a particular seagrass species can reduce seagrass energy production (through the process of photosynthesis), typically resulting in the death of that seagrass. A reduction in light availability and associated loss of seagrass can therefore be manifested as a reduction in the vertical, and associated horizontal, distribution of seagrass.

Different species of seagrass vary in terms of their long-term light requirements and tolerances to transient periods of light deprivation. Therefore, the distribution, abundance and composition of seagrasses at any time in a region may be a function of both the long-term trends in light availability and by their ability to survive or regenerate after pulsed or seasonal (i.e. regular) turbidity events (Moore et al. 1997). For this reason, seagrass community monitoring also provides a basis for assessing long term changes in water quality.

1.2 Aims and Objectives

The aims of the SMP are to describe:

- Current broad-scale patterns in seagrass extent and species distribution at the Port of Brisbane (Fisherman Islands), and at the Manly and Cleveland control locations;
- Spatial variations in seagrass extent and species distribution occurring at the three monitoring locations; and
- Temporal trends in seagrass extent and species distribution at the monitoring locations.

The specific objectives of the SMP were to:

- Map the distribution and extent of seagrass meadows adjacent to Fisherman Islands;

[1] This assumes that levels of physical disturbance by waves/currents is within the tolerance limits of the seagrass under consideration

- Characterise spatial and temporal patterns in the vertical (depth, accuracy measured in tens of centimetres) distribution of seagrass meadows at the Port and at control areas;
- Determine whether broad-scale spatial and/or temporal patterns in seagrass extent are consistent among the Port and control areas; and
- On the basis of the above, identify possible broad-scale operational impacts of port activities on the distribution and extent of seagrass meadows.

1.3 Study Area

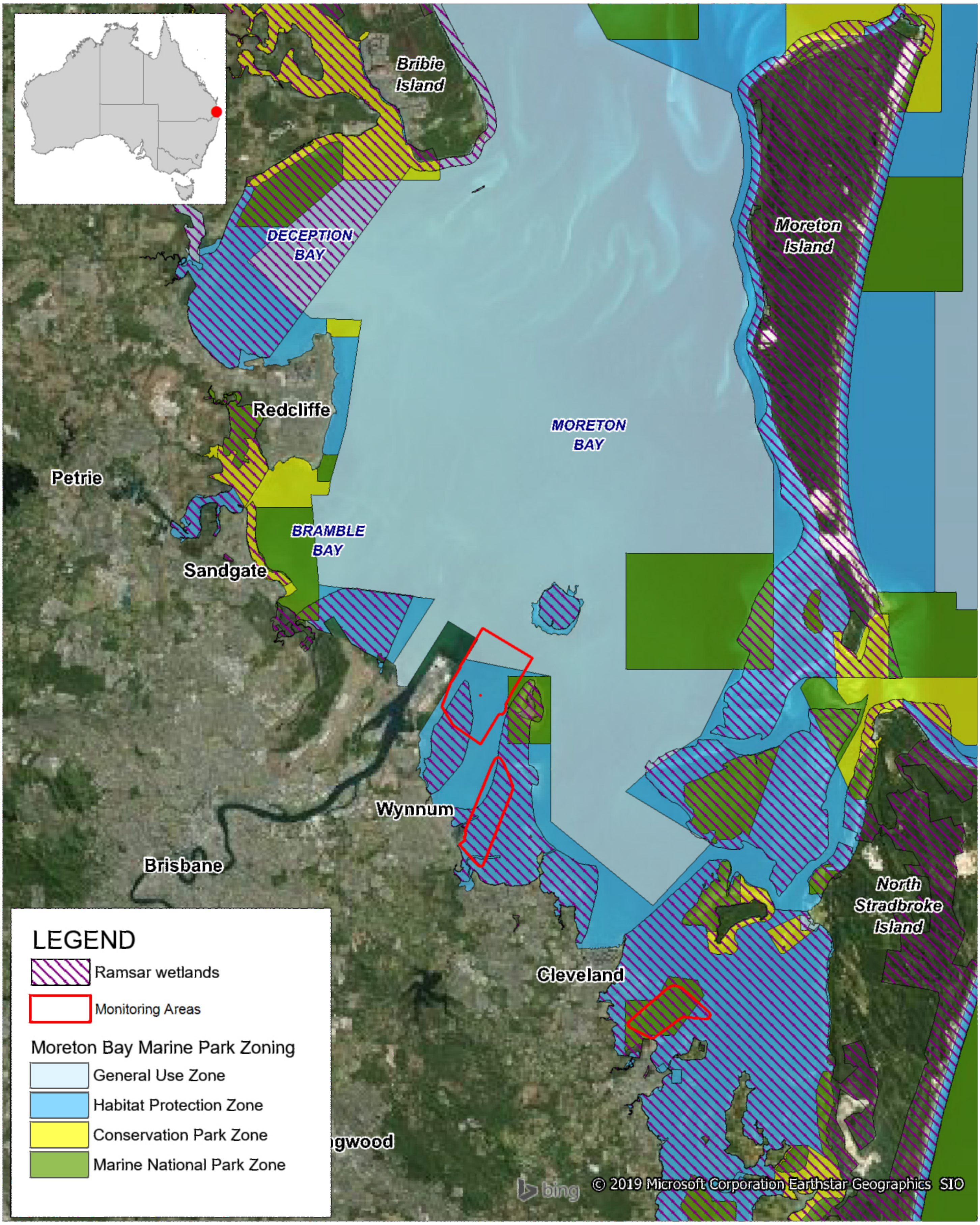
The Port of Brisbane is located on Fisherman Islands which is situated at the mouth of the Brisbane River on the western foreshore of Moreton Bay, Queensland.

Port facilities located at the Brisbane River mouth have been established on land reclaimed over a shallow sub-tidal river delta containing a series of low-lying mangrove islands, collectively called the Fisherman Islands. The area was reserved for harbour purposes in the 1940’s. Reclamation commenced in the late 1960’s and the decision was made to re-locate port facilities from the city reaches in the 1970’s. The Port of Brisbane is now Queensland’s largest container port facility and continues to expand by progressive filling within the existing perimeter bund.

Construction of the present-day port facilities over intertidal and subtidal areas has resulted in extensive changes to the environmental attributes of the Fisherman Islands area. However, significant areas of mangrove, saltmarsh and seagrass have also been retained, and form part of the Fisherman Islands wetland complex on the south eastern side of the Port of Brisbane. Moreton Bay Marine Park is situated to the south and east of the FPE seawall, this area is thought to contain one of the largest semi-contiguous seagrass meadows in western Moreton Bay. A Ramsar listed wetland is situated only kilometres to the south of the Port facilities, comprising intertidal portions of the Fisherman Islands wetland complex (Figure 1-1). The seagrass and mudflats of this Ramsar area are recognised for their importance to dugong, marine turtles and migratory and resident shorebirds (BMT WBM 2008).

On the northern side of the Port of Brisbane, dredging occurs within the shipping channel through the Bar Cutting, the Swing Basin and berth areas, which are presently maintained to a declared depth of 14m (relative to Port Datum – Lowest Astronomical Tide, hereafter referred to as LAT). The Port facilities are situated at the mouth of the Brisbane River, which comprises the largest river catchment in Moreton Bay, and experiences freshwater flows and ongoing inputs of sediments and contaminants derived from human activities in its catchment. Two major sewage treatment plants also have their sewage discharges within kilometres of the Port facilities (Luggage Point and Wynnum North wastewater treatment plant).

Control sites for the study are located adjacent to Manly and Cleveland on the western foreshore of Moreton Bay and to the south of the Fisherman Islands monitoring location (see Figure 2-2). At Manly, seagrass meadows extend from the intertidal areas adjacent to the Manly Boat Harbour and Fig Tree Point to the subtidal area close to Green Island. At Cleveland the seagrass habitat extends throughout the bay which is formed between Toondah Harbour and Coochiemudlo Island. Growing conditions at Manly and Cleveland are similar to those experienced at the Fisherman Islands and western Moreton Bay generally.



Title:

Moreton Bay Ramsar Wetlands and Marine Park Zoning

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2 Methodology

2.1 Timing

Field monitoring in 2019 was undertaken between the 18th and 26th of July and on the 15th of August. Tidal data from the Tidal Unit, Maritime Safety Queensland was obtained for the Brisbane Bar throughout this study period (Figure 2-1) and was used to correct depth soundings to Australian Height Datum (AHD).

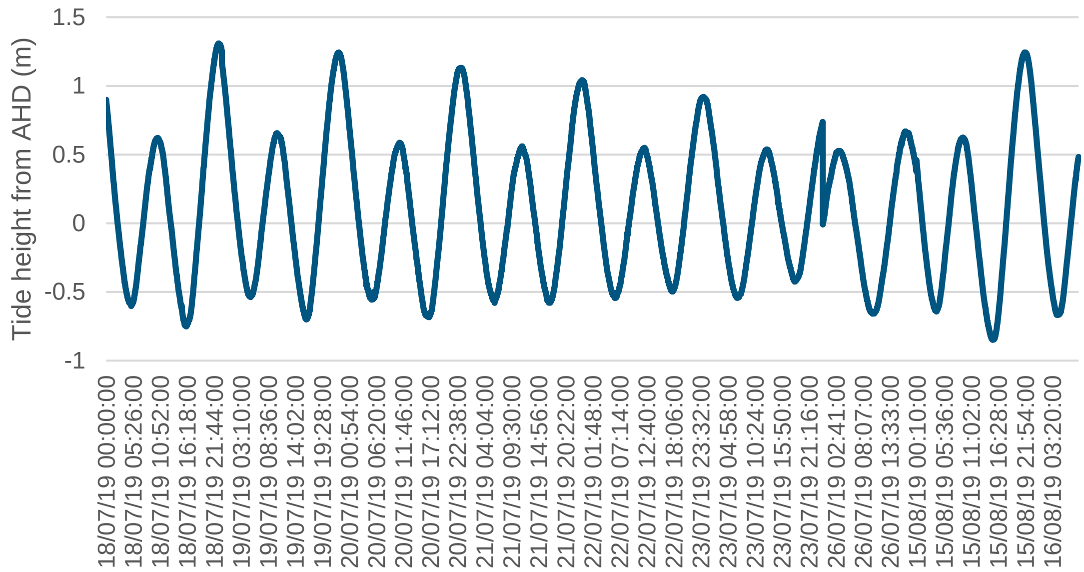


Figure 2-1 Tidal heights of Brisbane Bar during the 2019 survey

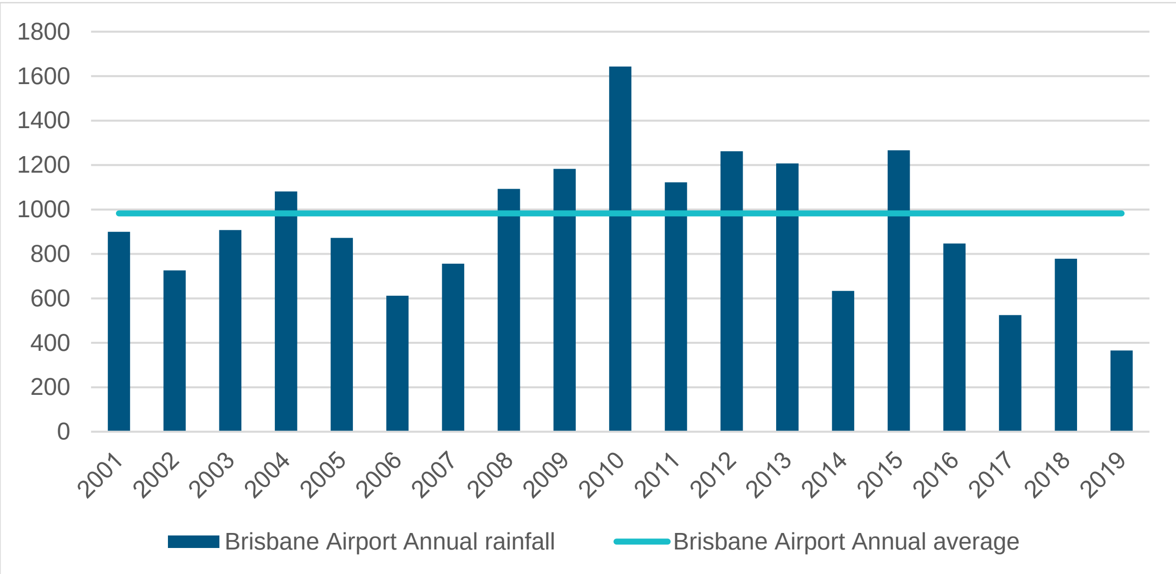


Figure 2-2 Annual rainfall from 2001 to 2018 and to date in 2019 at Brisbane Airport (Source: BoM station: 040842)

2.2 Survey Vessel and Positioning

All sampling was carried out using the BMT research vessel 'Seagrass.' Location and navigation to sites was undertaken using a Garmin GPS.

2.3 Monitoring Sites and Approach

Monitoring sites for this survey were based on those previously used for the Port of Brisbane seagrass monitoring program which was developed in 2002 (WBM Oceanics Australia 2002). Sampling locations were at Fisherman Islands (putative impact or test), Manly (control) and Cleveland (control). Since its development in 2002 the monitoring program has evolved from edge of bed monitoring to a systematic grid sampling approach. This has developed to utilise remote sensing advances and to allow the mapping of the extent and composition of both intertidal and subtidal seagrass meadows. The seagrass depth profile transects have been maintained to allow consistency in long-term comparisons.

2.3.1 Ground-truthing

Mapping information generated from remote sensing data were ground-truthed using a systematic grid style sampling approach. 500 m survey grids were developed at each study area and are shown in Figure 2-3 (Fisherman Islands), Figure 2-4 (Manly) and Figure 2-5 (Cleveland).

At each point in the survey grids the following parameters were recorded: time, water depth (using the survey vessel's sounder), position (GPS), seagrass species present and macroalgae community composition (a video image was recorded at each point). The depth at each point was converted to Australian Height Datum to enable comparisons between locations.

In addition, single beam bathymetry was also collected throughout the field campaign and used to develop a DEM specific to each of the study areas. This data was converted to Australian Height Datum based on tidal predictions and tidal planes from the Australian Hydrographic Service.

Ground truthing data were then used along with remote sensing data to develop mapping of the extent and composition of seagrass meadows at Fisherman Islands (Figure 3-4).

2.3.2 Seagrass Depth Profiles

Seagrass depth profiles are used to monitor any variations in seagrass depth distribution and extent of seagrass species at each of the study locations. Depth profiles were originally monitored on a six-monthly basis throughout the FPE project but were unable to be completed in 2004 due to adverse weather conditions. Subsequent sampling has occurred in 2005, 2006, 2010, 2013, 2014, 2016, 2017 and 2018.

Two depth profile transects occur at each survey location and run approximately perpendicular to the shoreline (Figure 3-3 to Figure 3-5). At each point along the profile transect, the following parameters were recorded: time, water depth (using the survey vessel's sounder), position (GPS), seagrass species present and macroalgae community composition (a video image was recorded at each point). The depth at each point was converted to Australian Height Datum to enable comparisons between locations.

The alignments of the two Manly depth profiles were adjusted in May 2003 to ensure each profile extended beyond the outer edge of the seagrass meadows. These alignments end near Green Island, which acts as a natural barrier to seagrass distribution.

2.4 Data Analysis

2.4.1 Seagrass Assemblages

Seagrass assemblages were determined according to species composition within a meadow. A standard nomenclature system based on Carter and Rasheed (2016) was to assign the community types to each of the sampling sites (Table 2-2). Assemblages correspond with percent composition that each seagrass contributes to the meadow.

Table 2-1 Nomenclature for seagrass community classes

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 C	Species A is <40%

2.4.2 Seagrass Abundance

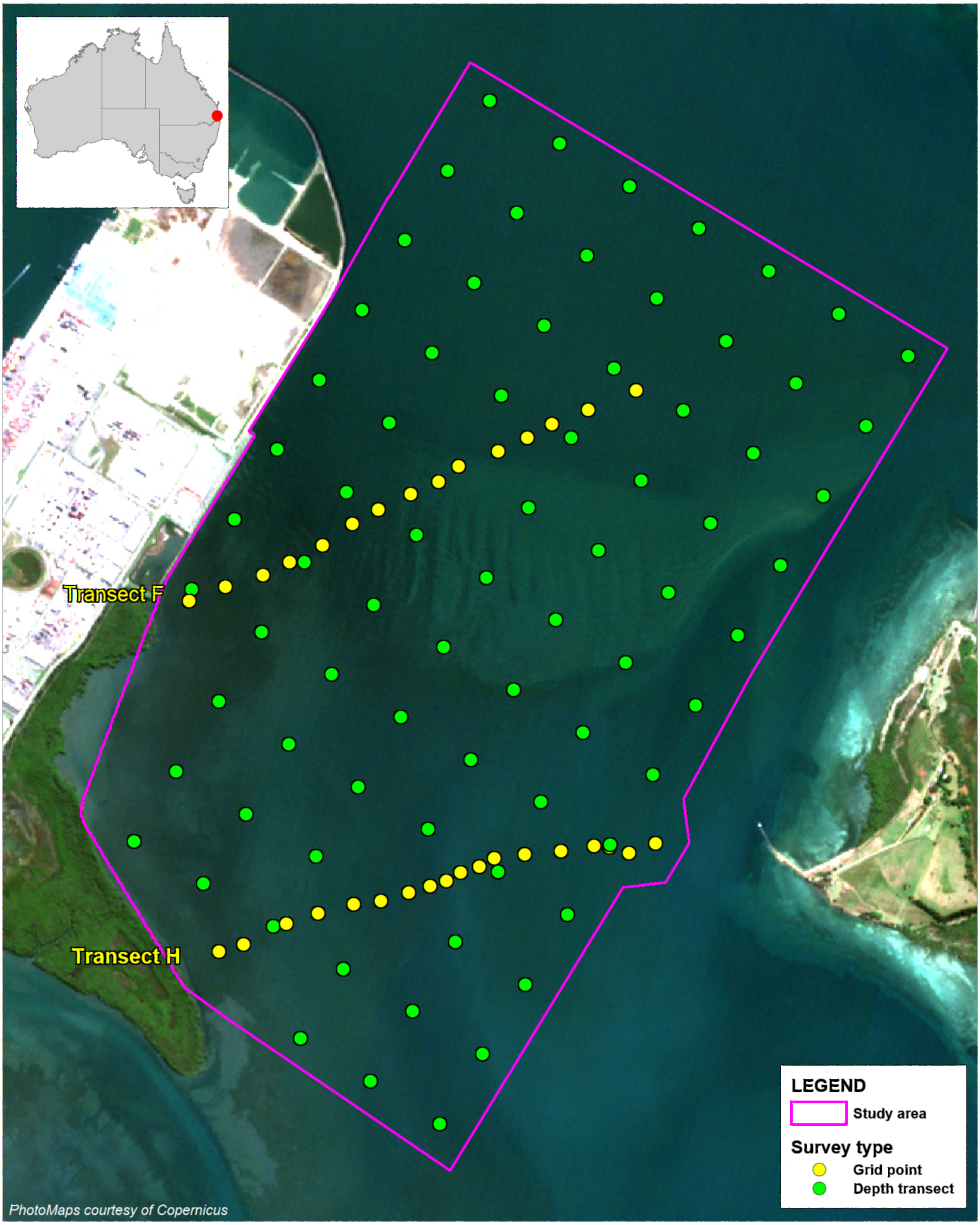
Consistent with previous monitoring, seagrass species at each survey site was assigned to abundance categories according to overall seagrass percent cover, as described in Figure 3-1 to Figure 3-3. In addition, groupings of overall seagrass cover were used to provide context to the broad community categories described in Section 2.4.1 (Table 2-2).

Table 2-2 Broad seagrass density categories

Density Category	Overall Cover (%)
Light	0-10%
Moderate	10-50%
Dense	>50%

2.4.3 Algae

Algae abundance was estimated for two functional groupings: (i) filamentous algae including epiphytic and turfing algae; (ii) other macroalgae (non-filamentous).



Title:

Survey points used to map the distribution of seagrass at Fisherman Islands, adjacent to the Port of Brisbane

Figure: **2-3**

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0 0.5 1km

Approx. scale

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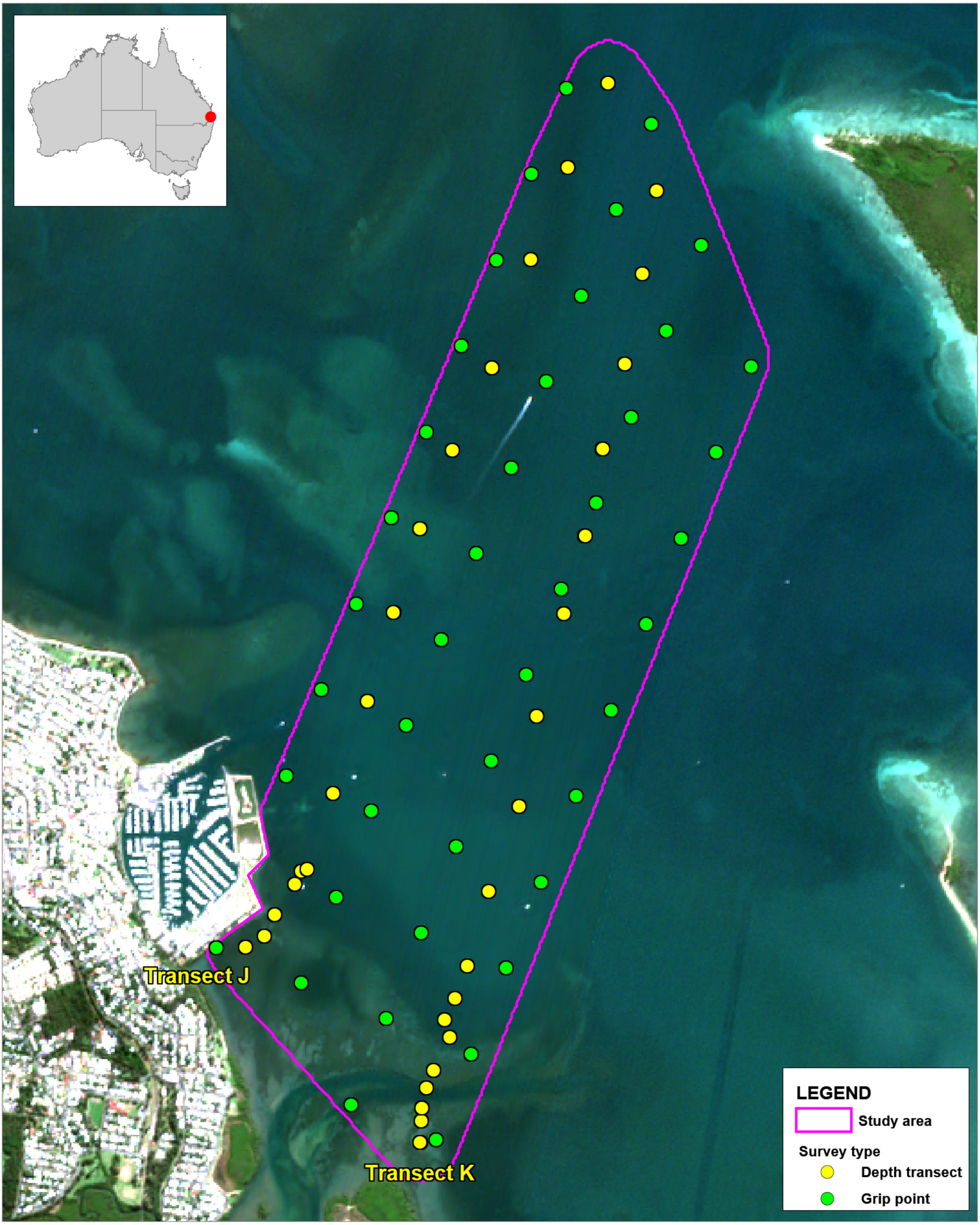

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Survey points used to map the distribution of seagrass adjacent to Manly

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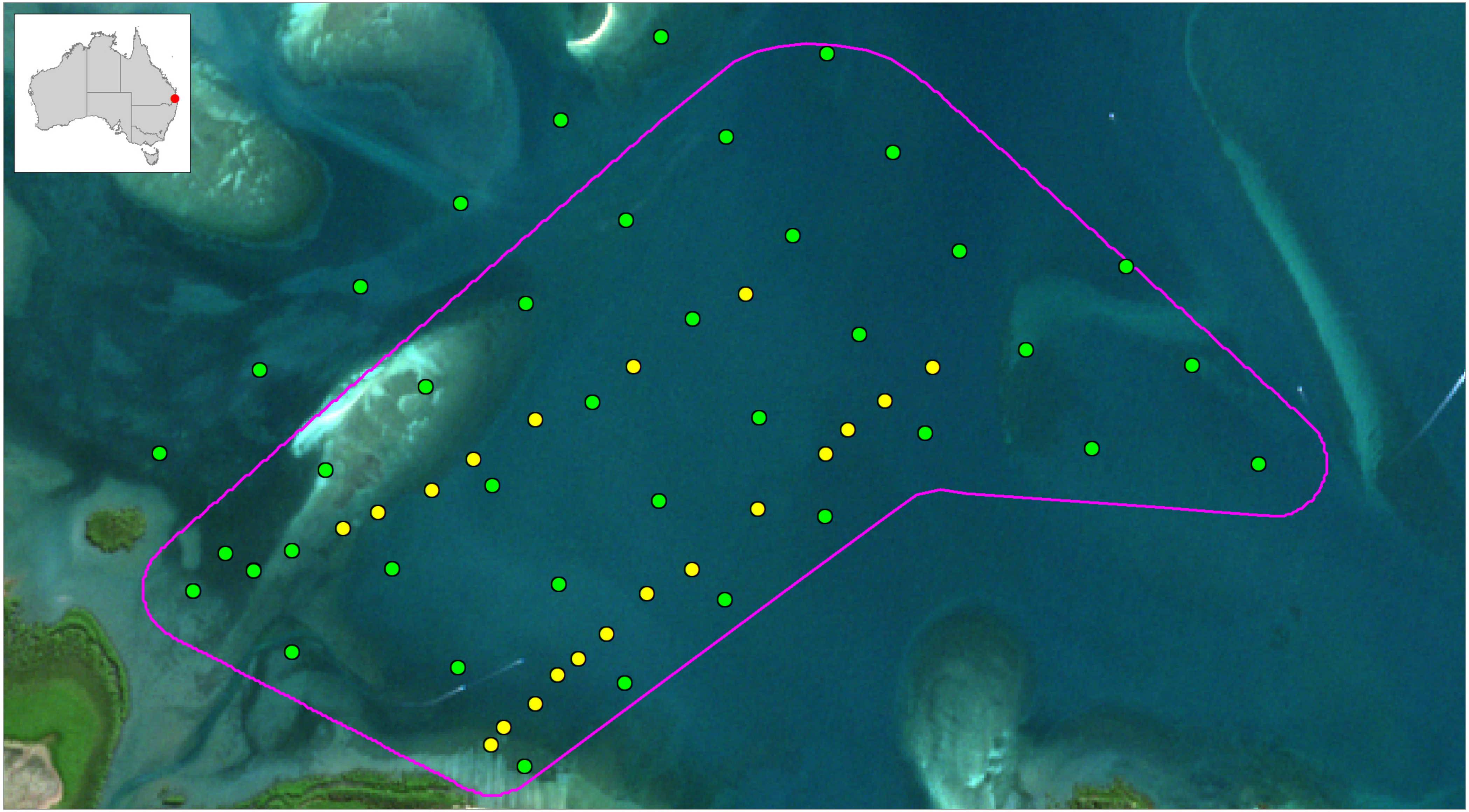

LEGEND

Study area

Grid points

Depth transects

Title:

Survey points used to map the distribution of seagrass adjacent to Cleveland

Figure: **2-5**

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3 Results

3.1 Seagrass Spatial Distribution and Percentage Cover

Five of the eight seagrass species known to occur in Moreton Bay were recorded in the 2019 survey: *Zostera muelleri (*subsp*. capricorni), Halodule uninervis, Halophila ovalis, Halophila spinulosa* and *Halophila decipiens.*

Maps showing the spatial distribution of each seagrass species recorded during the 2019 survey are shown in Figure 3-1 to Figure 3-3 . Seagrass assemblage types at Fisherman Islands derived from survey data, interpretation of Sentinel satellite data and high-resolution aerial photography (Nearmap) is presented in Figure 3-4.

In 2019 there was a general pattern of assemblage structure across the different habitat depths (Figure 3-4):

- The shallow intertidal area was numerically dominated by *Z. muelleri;*
- The transitional zone between intertidal and subtidal areas was numerically dominated by *H. spinulosa*;
- Subtidal areas were numerically dominated by sparse *H. ovalis* and *H. decipiens*.

In comparison to previous surveys there was an overall decrease in *Z. muelleri* dominated communities and an increase in *H. spinulosa* dominated communities (Appendix B). The following describes trends in species distribution and cover.

3.1.1 Species Distribution

The findings from the 2019 survey were largely consistent with the 2018 survey and are as follows:

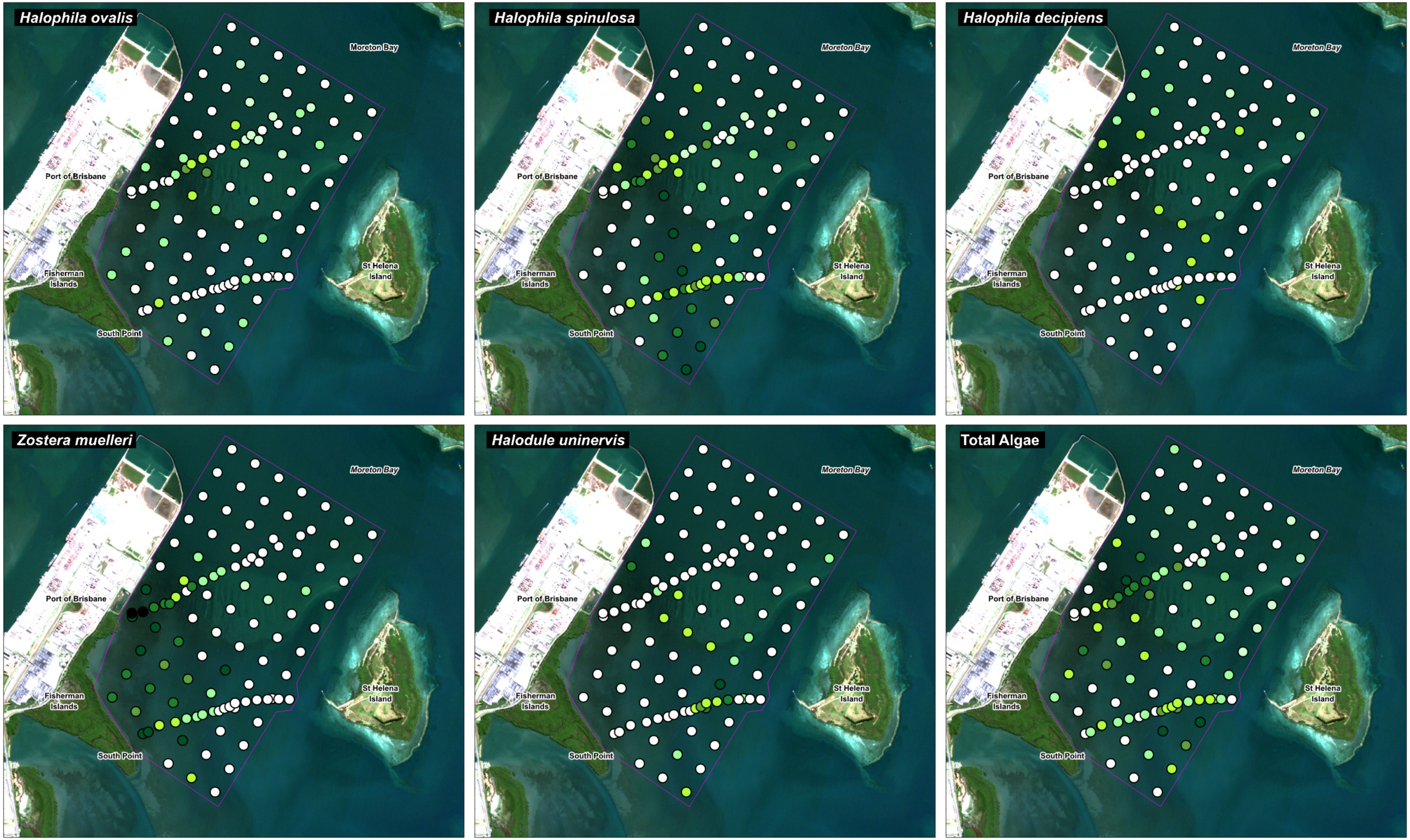
- Seagrass was present at 85% of the Fisherman Island sites (*n* = 110), 96% of Manly sites (n = 75) and 88% of Cleveland sites (n = 59). The frequency of seagrass detections was higher in 2019 than 2018 (86%, 91% and 80% of the sites at Fisherman Islands, Manly and Cleveland respectively).
- *Halophila. spinulosa* and *H. ovalis* were the most frequently recorded species at Fisherman Islands, occurring at 49% and 39% of sites, respectively. *Zostera. muelleri* was observed at 24% of sites which is a decrease from 49% in 2018. The most frequently recorded species at Cleveland and Manly were also *H. ovalis* (68% and 45%) and *H. spinulosa* (49% and 39%).
- *H. uninervis* was present at 20 sites at Fisherman Islands and was mainly limited to subtidal areas. *H. uninervis* was recorded at two of the Cleveland sites.
- *Z. muelleri* dominated meadows were mainly located within the intertidal zone, extending from above LAT at the landward edge into shallow subtidal areas (X m LAT). Intertidal meadows were mostly comprised of dense mono-specific stands of *Z. muelleri* with occasional patches of *H. ovalis* and/or *H. spinulosa*. Mixed meadows were more common within subtidal areas.
- Isolated patches of *H. ovalis* and *H. decipiens* were recorded in exposed areas with predominately sandy substrate. The frequency of *H. decipiens* detections decreased at Fisherman Islands and

Cleveland compared to 2018, but highest abundance remained within the deeper subtidal zone. *Halophila ovalis* also decreased in distribution between 2018 and 2019 at Fisherman Islands, predominately in the shallower subtidal area.

- The distribution of *H. spinulosa* has remained relatively consistent, with a slight increase in cover.
- Macroalgae coverage generally decreased at all sites, and were numerically dominated by filamentous algae.

3.1.2 Seagrass Cover

Temporal patterns in seagrass cover varied among species and locations (Figure 3-5). The main trend of seagrass cover was a decrease in percentage cover in the shallow intertidal areas with the subtidal areas having both areas of increasing and decreasing percentage cover.



LEGEND

Species density (%)

- 75 to 100
- 50 to 75
- 25 to 50
- 15 to 25
- 5 to 15
- 1 to 5
- <1
- 0

Study area

Title:

Species Distributions at Fisherman Islands, adjacent to the Port of Brisbane in 2019

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Figure: 3-1

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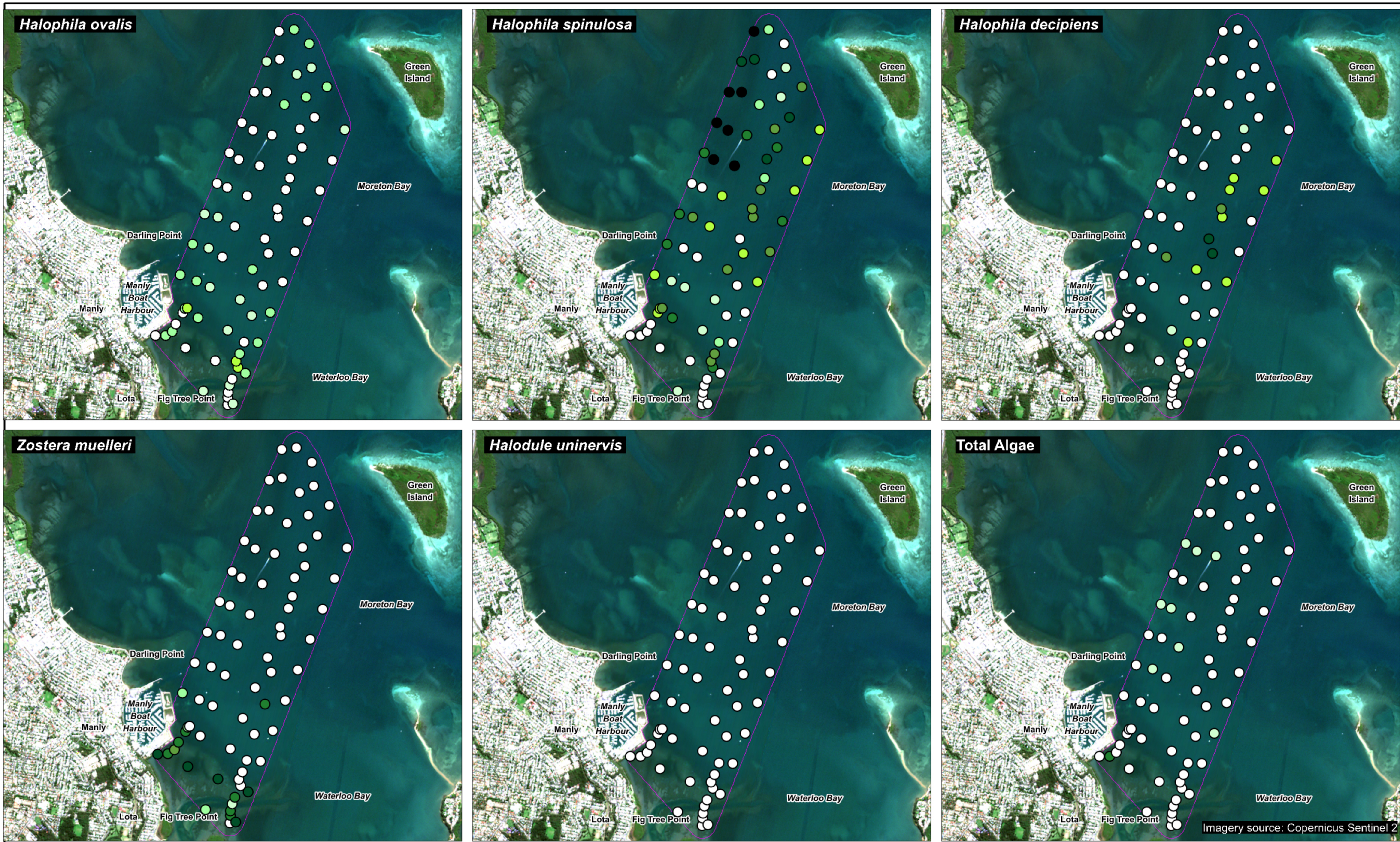

LEGEND

Species density (%)

- 25 to 50
- 15 to 25
- 5 to 15
- 1 to 5
- <1
- 0

Study area

Title:

Species Distributions at Manly, Waterloo Bay in 2019

Figure: **3-2**

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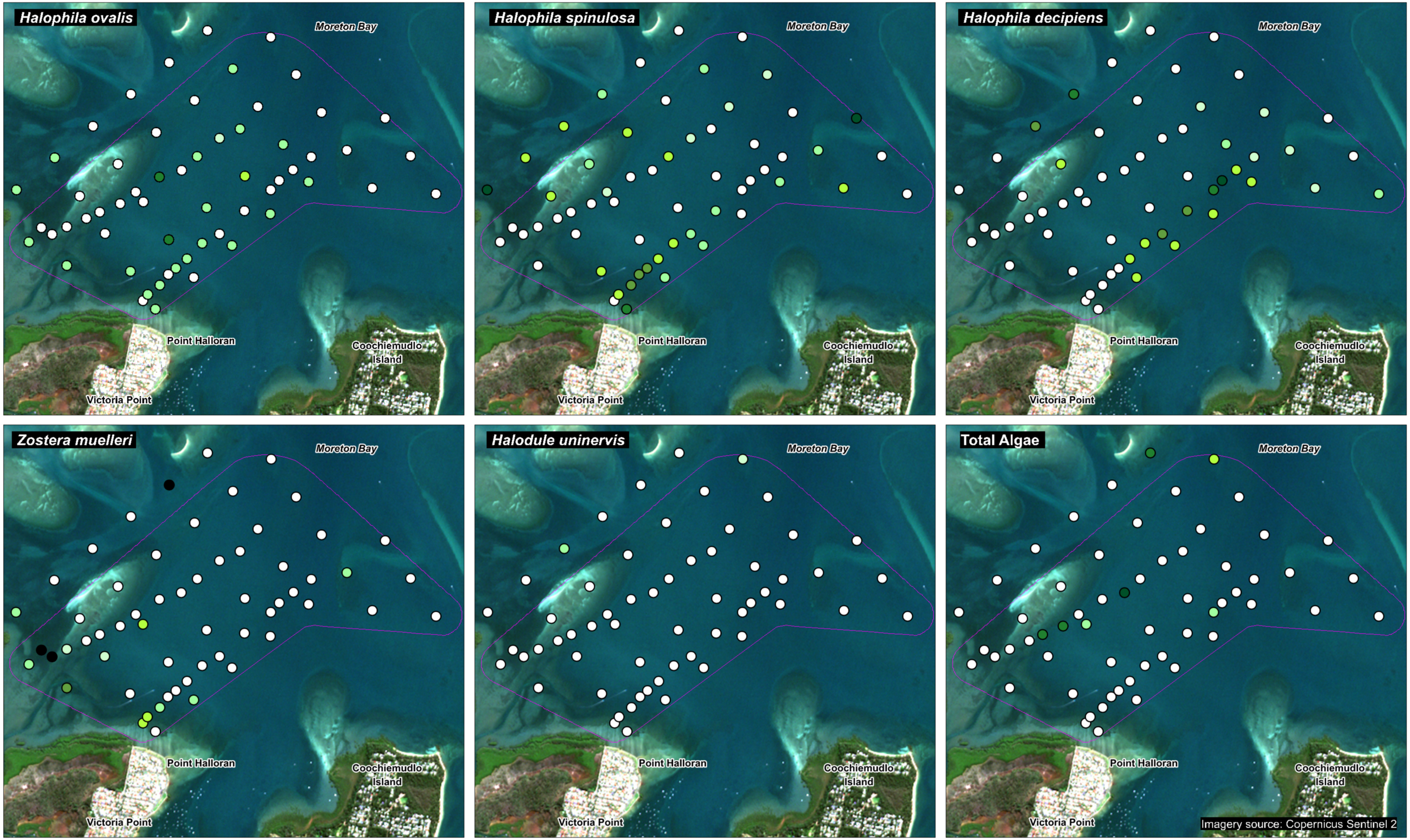

LEGEND

Species density (%)

75	to	100
50	to	75
25	to	50
15	to	25
5	to	15
1	to	5
0.1	to	1
0	to	0.1

Study area

Title:

Species Distributions at Cleveland, Moreton Bay in 2019

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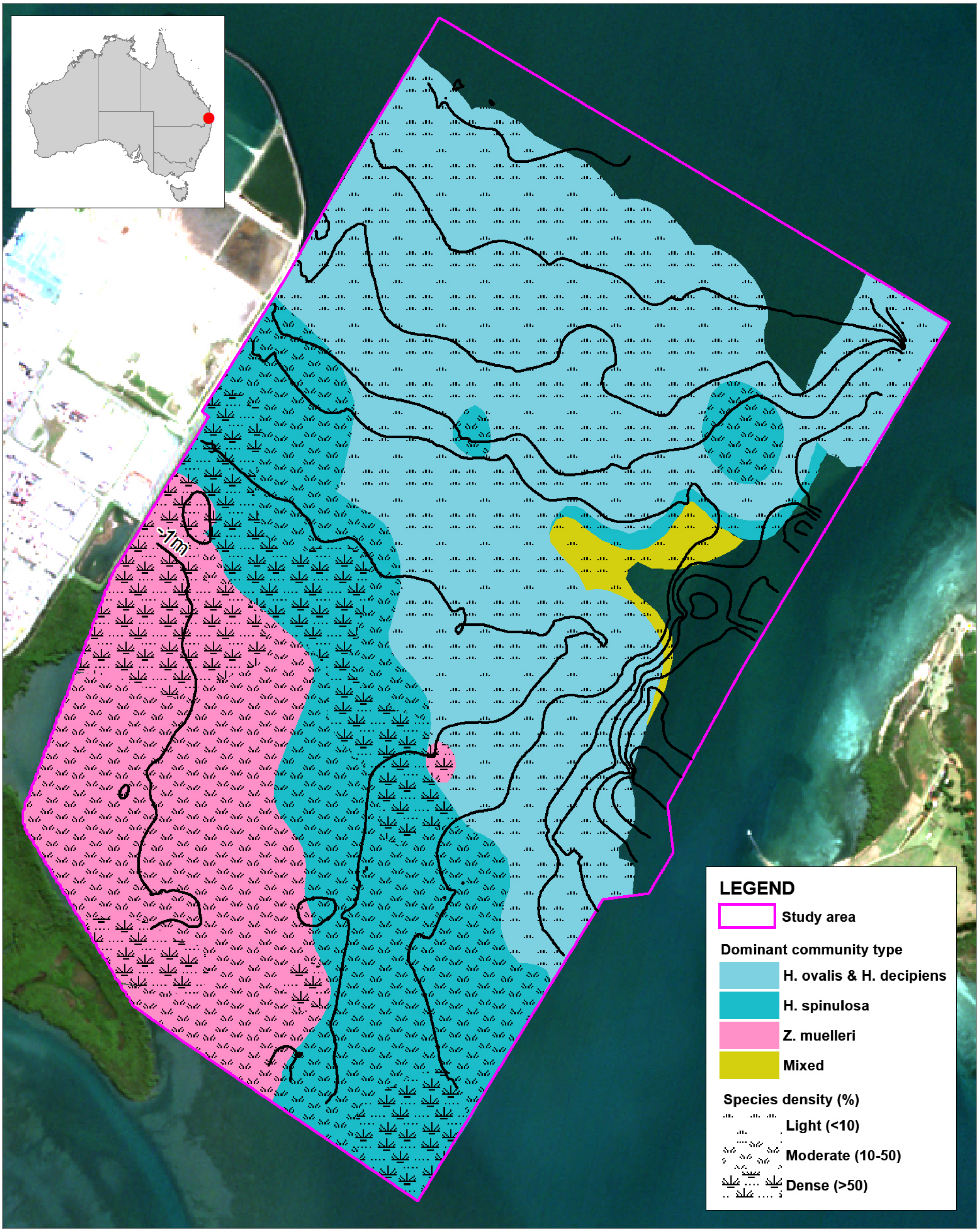

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Seagrass distribution and community structure adjacent to Fisherman Islands 2019 showing 1m LAT contours

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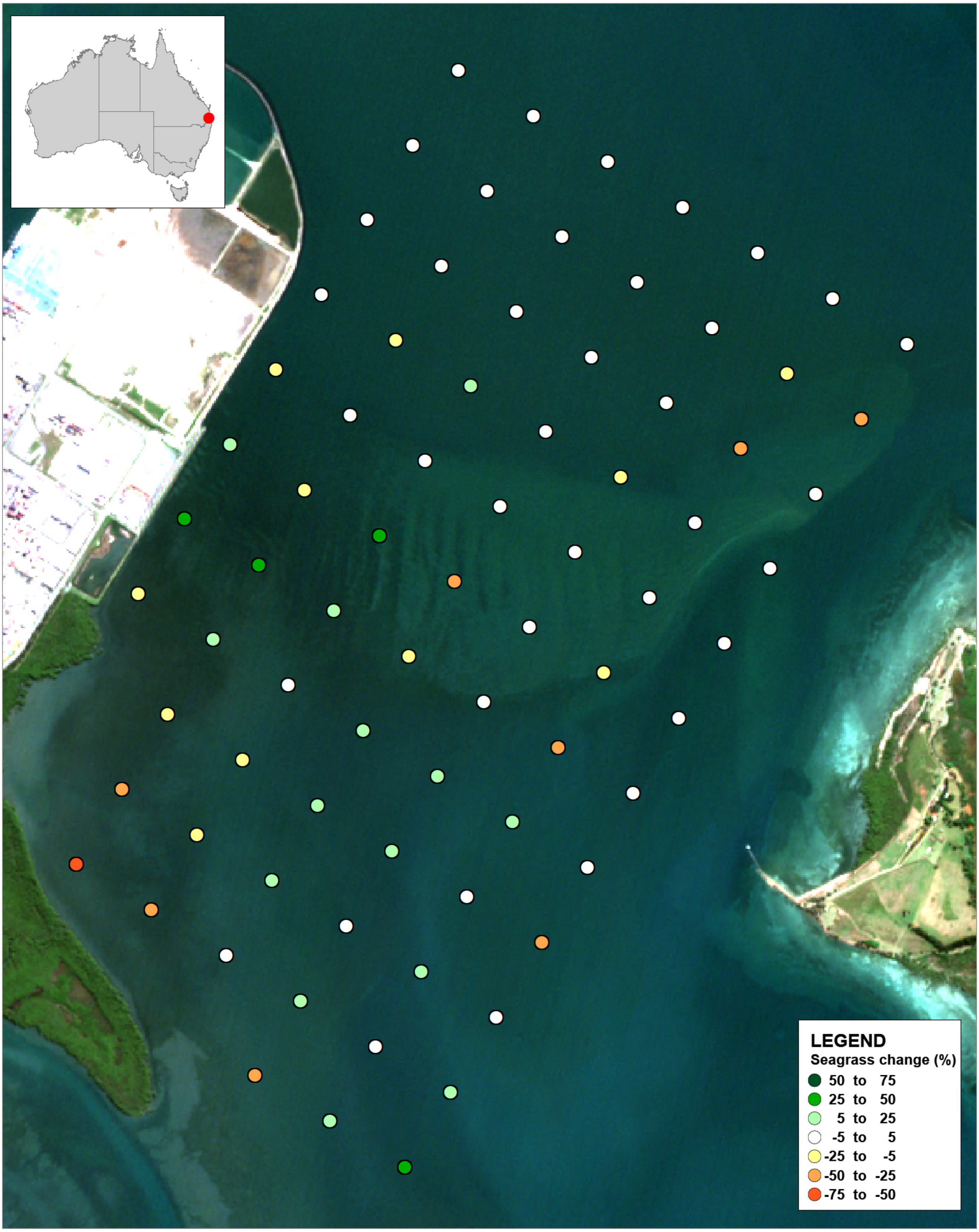

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Changes in total seagrass cover between 2018 and 2019 Fisherman Islands

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3.2 Seagrass Depth Range (SDR) and Assemblages Structure

Table 3-1 presents the maximum recorded depths of seagrass species (seagrass depth range – SDR) on depth transects in the period 2006 to present, along with a rating based on the SDR for each period relative to the historical maximum recorded SDR. The mean and coefficient of variation (CoV) is also displayed. Note that as *H. ovalis* and *H. decipiens* were grouped together prior to 2013, the SDR rating for these species is based on the maximum value recorded SDR for either of these species.

Conceptual diagrams showing changes in seagrass meadow assemblages and extent along each transect are provided in Appendix D. The percentage cover of seagrass species at each location (i.e. grid and depth transect sites) against depth categories are shown in Appendix E.

3.2.1 Spatial Patterns in 2019

Key patterns in seagrass composition and distribution along depth transects are as follows:

- *Z. muelleri* was observed at all locations, with the maximum depths at Fisherman Islands, Cleveland and Manly of -3 m, -3.6 m and -2.1 m (AHD) respectfully. At both Fisherman Islands and Manly, average cover was highest within intertidal meadows (above LAT) than subtidal meadows (below LAT). Within individual depth categories, average cover at depths below <0.5 m AHD were higher at Fisherman Islands (~60%) than the control locations (~45% and 0% at Manly and Cleveland respectively). *Z. muelleri* cover was highest between -0.5 m and 1 m AHD at all locations. The greatest depth recorded for *Z. muelleri* was -3.5 m AHD at Fisherman Islands. *Z. muelleri* formed mono-specific meadows or mixed assemblages with *H. spinulosa*.
- *H. uninervis* was found at both Cleveland and Fisherman Islands predominately between -1 m and -2 m LAT. This species occurred both as the major species or minor species in mixed communities. The sites where *H. uninervis* was present had ~10% cover on average which is a decrease from 2018. Note that *H. uninervis* was previously not recorded at Cleveland.
- *H. spinulosa* was observed at moderate densities at all locations with a maximum depth of -4.5 m, -7 m and -8 m AHD at Fisherman Islands, Cleveland and Manly respectively. This species was present at a variety of depths and community compositions, found predominately between -1 m and -2 m AHD at Fisherman Islands and predominately deeper than - 3 m at Manly.
- *H. ovalis* was present at all sites in a range of depths and formed predominately mixed communities with *Z. muelleri* and *H. spinulosa*. The depths that had *H. ovalis* present were: 0 m to -6 m, -0.2 m to -9 m, 0 m to -5 m AHD at Fisherman Islands, Manly and Cleveland respectively. The highest densities were generally found between -1 m and -3 m AHD.
- *H. decipiens* was observed at all locations and the maximum depth range was -8 m, -4 m and ~- 7 m AHD at Fisherman Islands, Manly and Cleveland respectively. *H. decipiens* generally occurred between -3 m and -4 m AHD. The coverage was predominately sparse (<10% cover) and formed mixed communities with *H. spinulosa*.

3.2.1.1 Temporal Patterns

Table 3-1 shows SDR values for each species over time on permanent transects. A condition rating has been provided with reference to the maximum SDR values recorded historically for each species on each transect.

Zostera muelleri SDR, a key indicator of long-term patterns in water quality, showed complex spatial and temporal patterns. Figure 3-6 shows that:

- The SDR on Transect H rapidly recovered between 2013 and 2014, and continued to improve over time. However, the SDR was slightly lower in 2019 than 2018.
- The SDR on Transect F increased between 2018 and 2019, reversing the declining trend observed in the period 2013-2018, and was only slightly less than the SDR recorded prior to the 2013 flood.

The coefficient of variation (CoV) was calculated to assess the degree of temporal variability in seagrass SDR within transects (Table 3-1). Consistent with 2018, the CoV for SDR was generally higher at Manly (-16 to -80%) compared to the other locations. Fisherman Islands and Cleveland reported similar CoV's of <50%. This indicates that SDR was typically more stable at Fisherman Islands and Cleveland than at Manly.

3.2.1.2 SDR Water Quality Objective

The *Z. muelleri* SDR water quality objective (WQO) for Waterloo Bay (Figure 3-6) was used as a benchmark[2] to assess seagrass condition. Compliance with the WQO varied over time and at a variety of spatial scales. Transects that met the WQO were (Table 3-1):

- Fisherman Islands Transect H (2010, 2014, 2016, 2017 and 2018) and F (2006, 2010 and 2019);
- Manly Transect J (2006, 2010, 2016, 2018 and 2019) and K (2006, 2010, 2014, 2016, 2017 and 2019); and
- Cleveland Transect P (2019).

In 2019 the SDR met WQO at more transects than any other previous survey year.

[2] the WQO was derived based on the median value using reference site data. While the WQO applies only to High Ecological Value waters in the State Protection Policy, it has been adopted here as a general benchmark of seagrass condition

Table 3-1 Comparison of SDRs (Maximum Recorded Depth in Meters relative to AHD) of Seagrass Species on Permanent Transects at each Location from 2006 to 2018

Location	Transect	Species*	2006	2010	2013	2014	2016	2017	2018	2019	Mean	CoV
Cleveland	P	Ho	-5.9	-6.4	-6.2	-4.8	-3.6	-3.3	-2.1	-3.6 (↑)	-4.5	-35
		Hd			-5.1	-6.4	Absent	Absent	-4.4	Absent (↓)	-5.6	-15
		Hs	Absent	-3.4	-3.5	-4.8	Absent	-0.9	Absent	-3.1 (↑)	-3.1	-45
		Zm	-1.3	-0.8	-0.6	-0.7	-0.7	-0.9	-1.7	-1.9 (↑)	-1.1	-46
	Q	Ho	-5.7	-6.2	-5.7	-2.7	-2.5	-5	-2.4	-2.8 (↑)	-4.1	-41
		Hd			-4.6	-4.6	-5.9	Absent	-5.6	-5.8 (↑)	-5.5	-12
		Hs	-3.2	Absent	-3.7	-4	-2.9	-3.3	-2.6	-3.1 (↑)	-3.3	-14
		Zm	-0.6	-1.5	-1.8	-1.4	-1	-1.4	-1.2	-1.8 (↑)	-1.3	-30
Manly	J	Ho	-2.2	-4.9	-4.5	-2	-2.1	-2.9	-2.1	-3.3 (↑)	-3.0	-38
		Hd			-4.5	-4.4	-3.5	-4.8	-4.5	Absent (↓)	-4.1	-23
		Hs	-2.6	-4	-3.4	-3.4	-4.1	-3.4	-4.5	-4.8 (↑)	-3.8	-19
		Zm	-2.2	-2.3	-1.6	-1.5	-2.1	-1.6	-2.1	-1.9 (↑)	-1.9	-16
	K	Ho	-0.4	-8.8	-5	-2.1	-2.2	-2.4	-1.8	-7.9 (↑)	-3.8	-80
		Hd			-5	-3.7	-4	-5.3	-7.7	-4.1 (↓)	-4.9	-53
		Hs	Absent	-4.4	-4	-3.9	-2.2	-2.3	-3.9	-8 (↑)	-4.1	-47
		Zm	-2.1	-2.2	-0.4	-2.1	-2.2	-2	-0.7	-3.3 (↑)	-1.9	-49
Fisherman Islands	F	Ho	-3.8	-5.7	-2.2	-2	-1.8	-4.7	-1.6	-5.1 (↑)	-3.4	-50
		Hd			Absent	-4	-4.1	-4.3	-4.1	-4.2 (↔)	-4.3	-15
		Hs	-3.8	-4.3	-2.2	-1.6	-1.8	-3.8	-2.0	-5.1 (↑)	-3.1	-44
		Zm	-2	-2.5	-1.8	-1.7	-1.6	-1.7	-1.4	-2.1 (↑)	-1.9	-18
		Hu	Absent	Absent	Absent	Absent	Absent	Absent	-2.0	-1.6 (↓)	-1.8	-14
	H	Ho	-2.6	-4.6	-2.5	-2.4	-2.4	-5.5	-2.2	-4.4 (↑)	-3.3	-39
		Hd			-2.9	-5.1	-5	Absent	-7.2	Absent (↓)	-5.1	-35
		Hs	-2.5	-2.3	-2.5	-2.4	-3	-2.5	-3.9	-4.7 (↑)	-3.0	-29
		Zm	-1.3	-2.3	-1.5	-2.4	-2.4	-2.5	-2.2	-1.7 (↓)	-2.0	-23
		Hu	Absent	Absent	Absent	Absent	Absent	Absent	Absent	-2.8 (↑)	-2.8	N/A
12-month Rainfall (mm)[1]			850.6	870.6	1158.6	582	731.2	642.8	955.6			

SDR relative to historical maximum:

Max	99-80% max	79-50% max	49-20% max	<20% max	Not applicable

Trend since 2018: ↑ improvement, ↔ stable (within 0.1 m of 2018), ↓ decline

* Ho *Halophila ovalis*, Hd *Halophila decipiens*, Hs *Halophila spinulosa*, Zm *Zostera muelleri*. Note video transects in 2006-10 did not provide sufficiently detailed imagery to discern *H. ovalis* and *H. decipiens*, and were therefore grouped together

Red text – SDR does not achieve the SDR WQO for HEV waters in Waterloo Bay of -1.9m AHD (generic benchmark for the purpose of this study)

1 – Rainfall data sourced from BoM station 040913 (Brisbane)

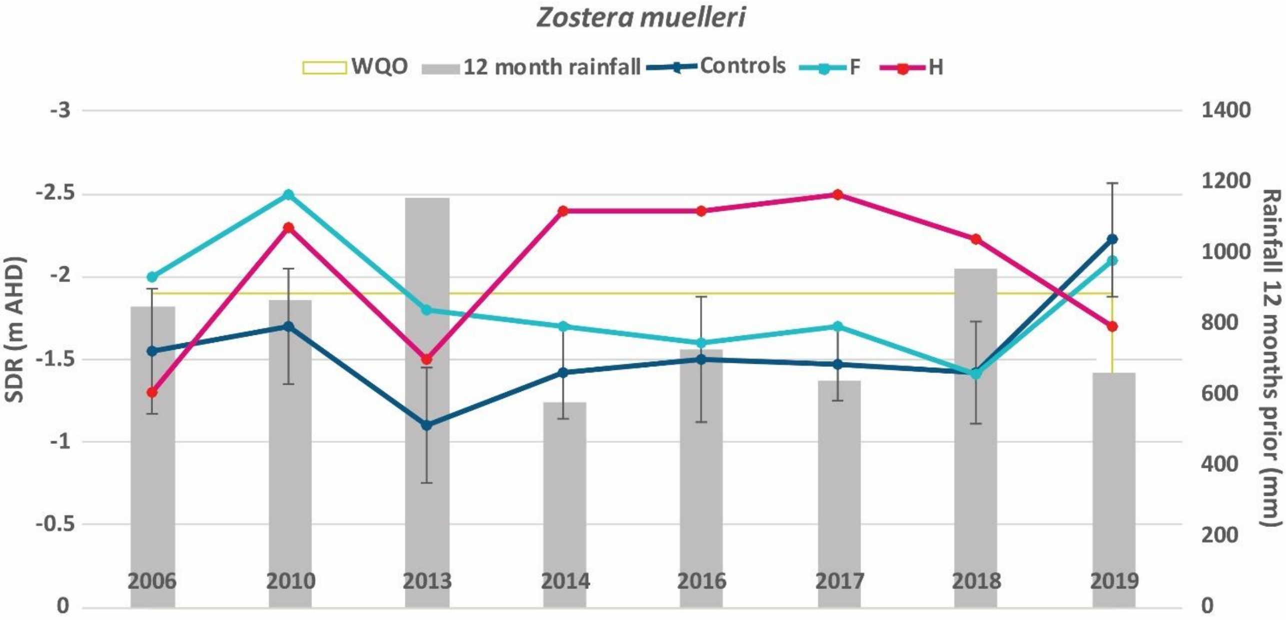


Figure 3-6 *Zostera muelleri* **seagrass depth range for Transect F and H at Fisherman Islands and the average (±SE) for control sites. Rainfall in the 12 months leading to the survey is also shown (BoM station number 040913 – Brisbane)**

4 Discussion

4.1 Overview

Consistent with 2018 results, the SMP provides the basis to draw out five general principles about the ecology of seagrass meadows at Fisherman Islands and western Moreton Bay. These are:

(1) Meadows are numerically dominated by a core set of widely distributed tropical and tropical-temperate species. Tropical vagrants occur from time to time but are uncommon.

(2) All species have adaptations that allow rapid recovery following disturbance.

(3) *Zostera muelleri* is restricted to shallow waters (<2 m below LAT), forming dense meadows that are comparatively stable over time in subtidal waters, but more dynamic near the landward margin.

(4) Sparse *Halophila* species and *Halodule uninervis* meadows extend to depths down to -8 m below LAT and show great variability in assemblage structure among years.

(5) Seagrass meadows show cyclic changes in extent in response to flood-drought cycles. There has been a long-term expansion in overall seagrass meadow extent at Fisherman Islands, with 2019 representing the maximum recorded extent to date (Figure 4-1).

These are described in the following section.

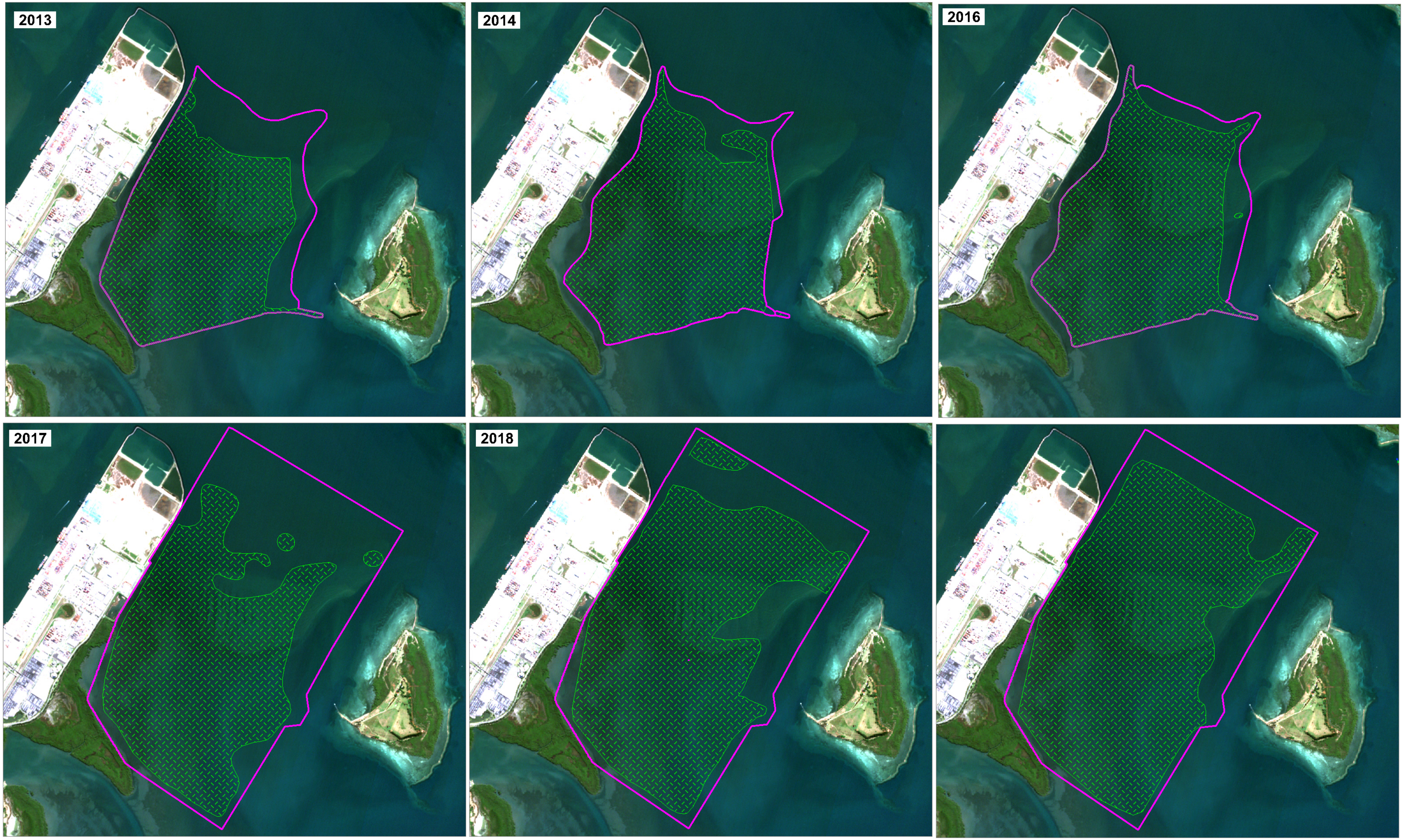
4.2 Species Composition

Eight seagrass species have been reported within broader Moreton Bay (Young and Kirkman 1975; Hyland *et al*. 1989, Davie 2011): *Zostera muelleri (subsp. capricorni), Halophila ovalis, Halophila decipiens, Halophila spinulosa, Halodule uninervis, Cymodocea serrulata, Syringodium isoetifolium* and *Halophila minor.*

Cymodocea serrulata, Syringodium isoetifolium and *Halophila minor* have not been recorded in the Port of Brisbane SMP. Moreton Bay is the southern-most distribution limit of *S. isoetifolium*, *H. uninervis*, *H. spinulosa C. serrulate* and *H. minor* (Kirkman, 1997). *Halophila minor* has only been recently discovered in Broadwater, Gold Coast in 2006 by GHD and is considered uncommon, possibly having a similar disjunct geographical distribution as *C. serrulata* and *S. isoetifolium* (Davie and Phillips 2008). *Halophila minor* is a pioneering species and if present would have likely formed mono-specific communities following the Brisbane River floods in 2013. No additional species compared to previous studies were recorded in the 2019 study.

4.3 Spatial and Temporal Patterns in Assemblages

Overall, seagrass meadows at Fisherman Islands increased in area by approximately one square kilometre from 13.7 km^2 to 14.8 km^2. This continues an apparent long-term trend of seagrass meadow expansion at this location (Figure 4-1), notwithstanding changes to study area boundaries and survey methodologies over time.



LEGEND

Study Area

Seagrass Meadow Extent

Title:

Seagrass Meadow Extent between 2013-19

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0 1 2km

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4.3.1 *Halophila* and *Halodule*

In 2019, there was an overall contraction in *H. ovalis* at Fisherman Islands but an increase at Manly and Cleveland. *H. decipiens* showed a contraction between 2018 and 2019 at all sites. *H. spinulosa* showed an increase in extent and overall density across all the areas surveyed. There was an overall increase in distribution of *H. uninervis* at Fisherman Islands and a presence noted at Cleveland.

Halophila species are among the least tolerant species of seagrass to reductions in light availability, with declines occurring during sustained wind events and sediment re-suspension, events which are common in western Moreton Bay. These species are also primary colonisers that can rapidly colonise deep water areas during extended periods of clear water, or high light availability (Longstaff *et al.* 1999). Overall, Halophila and Halodule species were variable between the 2018 and 2019 surveys.

There was also a high degree of small-scale heterogeneity in the distribution of different *Halophila* species (i.e. differences among transects within locations). Several processes can interact to control small-scale heterogeneity in seagrass meadows, most notably biological interactions including competition for space with other seagrass species and macroalgae, and grazing (by dugongs and green turtles). Differences in TSS concentrations (and light availability) can also occur among transects, varying in response to proximity to channels and sand banks.

4.3.2 Zostera

Zostera muelleri predominately occurred in intertidal and shallow waters of the study area (landward of 2.5 m AHD). *Z. muelleri* has a high light requirement compared to other seagrass species found within the study area (e.g. Abal and Dennison, 1996; Collier and Waycott 2009). This limits *Z. muelleri* to intertidal and shallow subtidal habitats where it is a dominated species.

SDR was found to vary among the site locations, ranging from 0 m to -3 m AHD adjacent to Fisherman Islands, -0.5 m to -3.5 m AHD at Cleveland and 0 m to -3.3 m at Manly. *Z. muelleri* expanded its depth range landward and seaward at all three locations in the 2019 survey compared to the 2018 survey. Differences in SDR among locations are likely to reflect:

- Differences in the availability of suitable (and stable) habitat - Physical habitat conditions, including hydrodynamic processes and substrate stability, are key controls on seagrass meadows. Fisherman Islands has broad intertidal and subtidal sand and mud banks, within the preferred depth zone of *Z. muelleri*. By contrast, Manly and Cleveland have short and steep intertidal/shallow subtidal shore profiles and coarse sediments, and therefore less potential *Z. muelleri* habitat. A consequence of this has been that the depth distributions among locations may reflect changes in sediment quality and other factors (e.g. exposure to wave re-suspension/ boat wash and channels) as well as being driven by the availability of light in deeper waters.
- Differences in water quality conditions among (and possibly within) locations. The three sampling locations are influenced to different degrees by river flows and wave-generated sediment resuspension.

SDR along the depth transects is varied between years at both Fisherman Islands and the control sites. Within the 2019 survey it was observed that each site had an increase in SDR along one depth transect and a decrease along the other. In the case of Fisherman Islands' meadow the F transect observed an increase in SDR while the H transect observed a decrease.

Z. muelleri depth range is more stable at Fisherman Islands (CoV -14 to -23) than both Cleveland (CoV -30 to -46) and Manly (CoV -16 to -49). This suggests that Manly is more prone to disturbance compared to the other sites, which differs from the 2018 survey where Cleveland had the greatest coefficient of variation. SDR trends on transect H have differed from all other transects since 2014, where depth range increased on transect H and while the other transects remained relatively consistent. In 2018 the patterns of SDR at transect H also differed as depth range was decreasing while the other transects observed increasing depth range. This may be caused by a variety of factors, the major one being that transect H has a different bathymetric profile to the other transects. Transect H also extends towards St Helena Island which has a different sediment type, this may cause changes in the deeper extent of seagrass. Competition and differentiation during identification of *Z. muelleri* and *H. uninervis* may also be a contributing factor.

4.3.2.1 Decrease in Nearshore *Z. muelleri*

The landward and seaward margin of some *Z. muelleri* meadows at Fisherman Islands retracted between 2019 and 2018, but there was expansion in other areas. *Halophila* species also colonised deeper areas where Zostera losses occurred. Potential drivers and stressors that can lead to seagrass meadow loss are summarised in .

The main *Zostera* losses occurred in the shallowest section of Fisherman Islands. An inspection of historical aerial photography suggests that seagrass extent in this area is highly variable at time scales measured in months to 10s of months. This is a dynamic area that is subject to multiple stressors including wave-generated disturbance, desiccation (in the intertidal area) and high water temperatures leading to heat stress. Intertidal areas are also targeted by bait worm diggers.

There was little evidence to support most of the potential drivers, the possible exception being heat stress. Shields *et al*. (2019) observed temperature-driven *Zostera marina* die-off events that resulted in a community switch from a slower growing, large climax species (*Z. marina*) to a faster growing, small pioneer species (*Ruppia maritima*). This same pattern was observed in the present study, with the fast growing *Halophila* replacing *Zostera*. Further work would be required to test the influence of heat stress and/or other drivers on seagrass meadow condition.

Table 4-1 Evaluation of potential causes of the decrease in *Z. muelleri* percent cover

Driver and stressors	Analysis undertaken and result	Potential contribution	Subsequent assessment
Wind → turbidity and physical disturbance	• Wind can affect seagrass through physical disturbance by wind-waves, and by turbidity generated by sediment resuspension • A wind rose was created for July 2018 to July 2019. Data for the period were compared to a long-term average. • Wind direction and speed in the year preceding the survey was similar to long-term averages. • *Halophila* is more sensitive to reduced light than *Zostera*, and would be expected to decline if turbidity was the main driver of change. There was no contraction in *Halophila* meadows.	Unlikely	Analysis of turbidity data using satellite imagery could be undertaken to assess long term changes
Rainfall and runoff → turbidity and physical disturbance	• Stressors generated by floods (i.e. reduced salinity, increased turbidity, scour) are a key driver of seagrass meadows in Moreton Bay • No flood events occurred in the period 2018-19	Unlikely	Not required
Temperature → direct physical stress	• The landward margin of seagrass meadows is ultimately controlled by stressors including desiccation and high temperatures. High temperatures and UV combined during low tides would represent a stress. • The area of observed seagrass loss mostly occurred in water depths <0.5 m LAT, which would be most prone to high temperatures • Average temperatures during summer 2018-19 and autumn 2019 were well above average, and several heatwaves recorded.	Possible	Further assessment of tides and climate processes could be undertaken
Bait worm diggers → direct physical disturbance and habitat modification	• High resolution Near-map imagery was used to query whether areas of seagrass retraction coincided with bait worm diggings • There was no evidence of bait worm diggers in the affected areas. Extensive areas of bait worm digging were observed but outside the area of observed changes.	Unlikely	Not required
Macroalgae → light reductions	• High macroalgae and filamentous algae loads can reduce light availability for seagrass photosynthesis • No change in algae cover observed between 2019 and 2019 surveys	Unlikely	Not required
Sediment release/incidents from Port operations	• No spills or other environmental incidents with the potential to cause seagrass loss were recorded by PBPL in the period	Unlikely	Not required

4.3.3 Filamentous Algae and Other Macroalgae

The dominant algae type observed across the survey locations was filamentous algae, other macroalgae observed included *Hydroclathrus clathratus*, *Hypnea* and *Sargassum*. Filamentous algae can proliferate under nutrient enriched conditions, leading to reductions in available light and loss of seagrass (Han and Liu 2014). Fisherman Islands is located directly adjacent to several major nutrient sources (i.e. Luggage Point WWTW, Wynnum WWTW and catchment inflows from the Brisbane River), which likely to promote filamentous algae productivity at this location. Like seagrass, different macroalgae species show great variation in distribution and cover over time and space.

The median macroalgae cover was highest at Cleveland (40% coverage) compared to Fisherman Islands (5%) and Manly (0.5%). However, the Fisherman Islands had the greatest proportion of sites with a recorded presence of macroalgae (70%) compared to both Cleveland and Manly (11% and 12% respectively). Macroalgae was present at a variety of depths at Fisherman Islands (0 m to -8 m AHD), Cleveland (-1 m to -4 m AHD) and Manly (0 m to -4 m AHD).

Cleveland has the greatest amount of hard substrate habitat in shallow water habitats that relate to the abundance of reef associated species such as *Sargassum*, *Hydroclathrus clathratus* and *Laurencia majuscule.* Fisherman Islands has shell and rubble fragments that provide substrate for macroalgae while Manly has the least macroalgae as a result of the absent of hard substrates.

The most notable temporal change observed over time has been cyclic changes in the green alga *Caulerpa taxifolia. C. taxifolia* was a dominant component of the benthic community throughout the study area during the 2000's when *El Niño* conditions prevailed, and sewage discharges were of a poorer quality than present day. The distribution and density of *C. taxifolia* declined across the study area post-2010. *C. taxifolia* was not recorded at any of the sites in the 2019 survey, despite prolonged drought conditions.

4.4 Existing Seagrass Condition

Seagrass meadow condition was assessed with reference to:

- SDR water quality objective (WQO) for Waterloo Bay (State Protection Policy – HEV waters for Waterloo Bay)
- Local 'reference' value; in this instance, the maximum recorded SDR for each species on individual transects.

Based on the SDR (WQO) of -1.9 m AHD, only the Q depth transect at Cleveland did not comply during the 2019 survey. Manly had the highest rate of compliance to the SDR WQO (63% followed by Fisherman Islands (50%) and Cleveland (6%). The non-compliance of Fisherman Islands is most likely due to local hydrodynamic conditions on the F transect, which is not favourable for *Z. muelleri* growth. The low compliance of Cleveland suggests that habitat quality for *Z. muelleri* is low.

WQO were met on more transects across the SMP than during any previous seagrass survey, this is most likely a result of prolonged drought that provides favourable seagrass growing conditions.

4.5 Impacts of the FPE Seawall

The results of the SMP again indicate an overall long-term trend of a net expansion in seagrass meadow extent at Fisherman Islands since the FPE seawall construction (see BMT WBM 2016 for details). Consistent with the predictions of the FPE IAS (WBM 2000), the results of the Port of Brisbane SMP suggest that port expansion activities (both the FPE and previous reclamations at

Fisherman Islands) have led to localised alterations to hydrodynamic processes that favour the development of seagrass meadows. Key controlling processes are expected to include:

- Enhanced protection from northerly waves. The FPE seawall provides more protection from prevailing wind generated waves from the northerly direction.
- Deposition of fine sediment. The extension of the FPE seawall appears to be enhancing the deposition of fine sediments within the embayment north and east of Fisherman Islands (BMT WBM 2010; 2015; 2016; 2017). The effects of fine sediment deposition on the ambient light climate and nutrients availability, and flow on effects to seagrass, remains unresolved.
- Separation from the Brisbane River. The seawall extension has effectively moved the mouth of the Brisbane River further from the Fisherman Islands seagrass meadows, possibly enhancing water clarity and reducing the impacts of low salinity flood waters.

4.6 Program Review

A review of the SMP was undertaken in the context of two aspects:

- Whether the monitoring program design was still appropriate in the context of meeting the study objectives
- Consideration of additional methodologies that could improve the SMP in terms of:
  - the ability to more accurately map seagrass meadows and associated with this, the ability to detect change
  - defining the biodiversity values of seagrass meadows, which to date have focussed entirely on marine plants.

4.6.1 SMP Survey Design

In 2018, the survey design was modified to better characterise spatial patterns in seagrass meadow extent and structure. The survey design was modified to a grid-based approach to: (i) allow more robust measurements of temporal changes within sites, and (ii) improve map interpolation methodology. The revised design has allowed the detection of temporal changes in nearshore *Zostera* meadows which were not possible with the previous design.

The SMP compares spatial and temporal patterns at test and control locations as a means for detecting potential impacts. This approach is dependent on control sites being representative of environmental conditions at the test location. While assemblage structure is broadly consistent among control and test locations, there are differences in benthic habitat conditions which confound comparisons. In particular, the Cleveland control location has more hard structure and a steeper gradient than Fisherman Islands, which results in different spatial patterns in seagrass assemblages.

The inclusion of an additional control location site could improve the ability to detect changes relative to ‘background’ variability. A potential control location that could be considered the seagrass meadows at Deception Bay. Deception Bay has a gradient like that found at Fisherman Islands. There are two main seagrass meadows found at Deception Bay, one in the northern portion and another in the southern portion. The University of Queensland (2011) found the northern meadows of Deception Bay to be composed of *Z. muelleri*, *H. ovalis* and *H. spinulosa* which makes this meadow an appropriate control site. Seagrass cover in the northern Deception Bay meadow ranges from dense in the shallower areas to sparse in the deeper communities (Roelfsema *et al.* 2009).

4.6.2 Supplementary Methods

4.6.2.1 Remote Sensing

The availability of medium to high spatial resolution satellites at relatively high capture frequencies allows the ease of identification of seagrass meadow extent across large areas in optically shallow or turbid intertidal environments (Roelfsema et al. 2009). Remote sensing allows the relative ease of analysis over large areas through time however, the collection of reliable ground-truthing data is critical to the accuracy of remote sensing. The field data collected during the 2019 field campaign was used in combination with Sentinel-2 Satellite imagery collected on the 24th of July 2019 to create a seagrass percentage cover map adjacent to Fisherman Islands.

When comparing the remotely sensed seagrass cover (Figure 4-2) and an interpolated grid of the field data (Figure 4-3) it is evident that a similar cover classes are observed across the study area. The major difference between the two is the increased area of dense seagrass cover in the intertidal region, this is most likely an artefact of depth. As seen in the classification of the Sentinel-2 image remote sensing is an effective method of creating seagrass coverage maps when reliable field data is available. However, due to the similarity in reflectance's between different seagrass species satellite imagery cannot be used to accurately differentiate seagrass species or assemblage types. Algae coverage may interfere with remote sensing of seagrass as some species of algae have similar reflectance as seagrass, this is evident around the northern end of the Fisherman Islands.

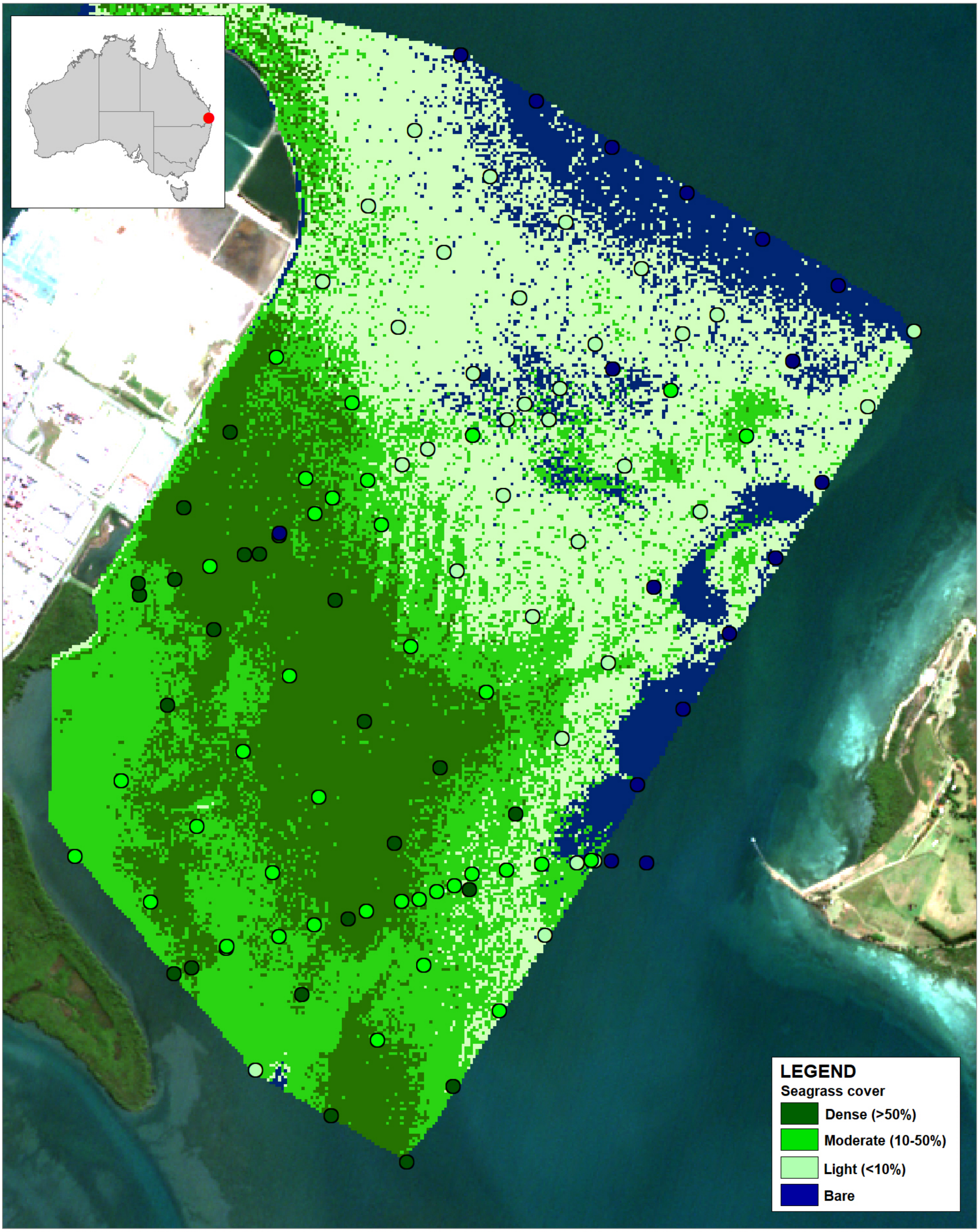
Remote sensing is beneficial for monitoring seagrass adjacent to Fisherman Islands as it provides a continuous percentage cover mapping for the entirety of the study area and therefore allows more detailed change assessments and better comparison through time. Ground-truthing data required for remote sensing is already collected during the current surveys and an additional four days of post processing would be needed to acquire, correct and classify the satellite imagery.

4.6.2.2 Acoustic surveys

There are a number of acoustic techniques that can be used to determine seagrass distribution, these include Single Beam Echo Sounders (SBES), Multi Beam Echo Sounders (MBES), Acoustic Doppler Current Profile (ADCP) and Side Scan Sonar (SSS) (Gumusay et al. 2019).

SSS is a low-cost method that has wide swath coverage and high-resolution backscatter (Gumusay et al. 2019). During the 2019 survey SSS data was collected to investigate the potential of SSS to assess seagrass coverage. Seagrass was able to be visualised on the side scan swaths however, it needs to be ground-truthed with site observations and also requires substantial post-processing.

A small pilot program could be undertaken in parallel with the existing program to trial this approach. This could be done over a one-day period with three days post processing.



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Seagrass density categories derived satellite imagery Fisherman Islands 2019

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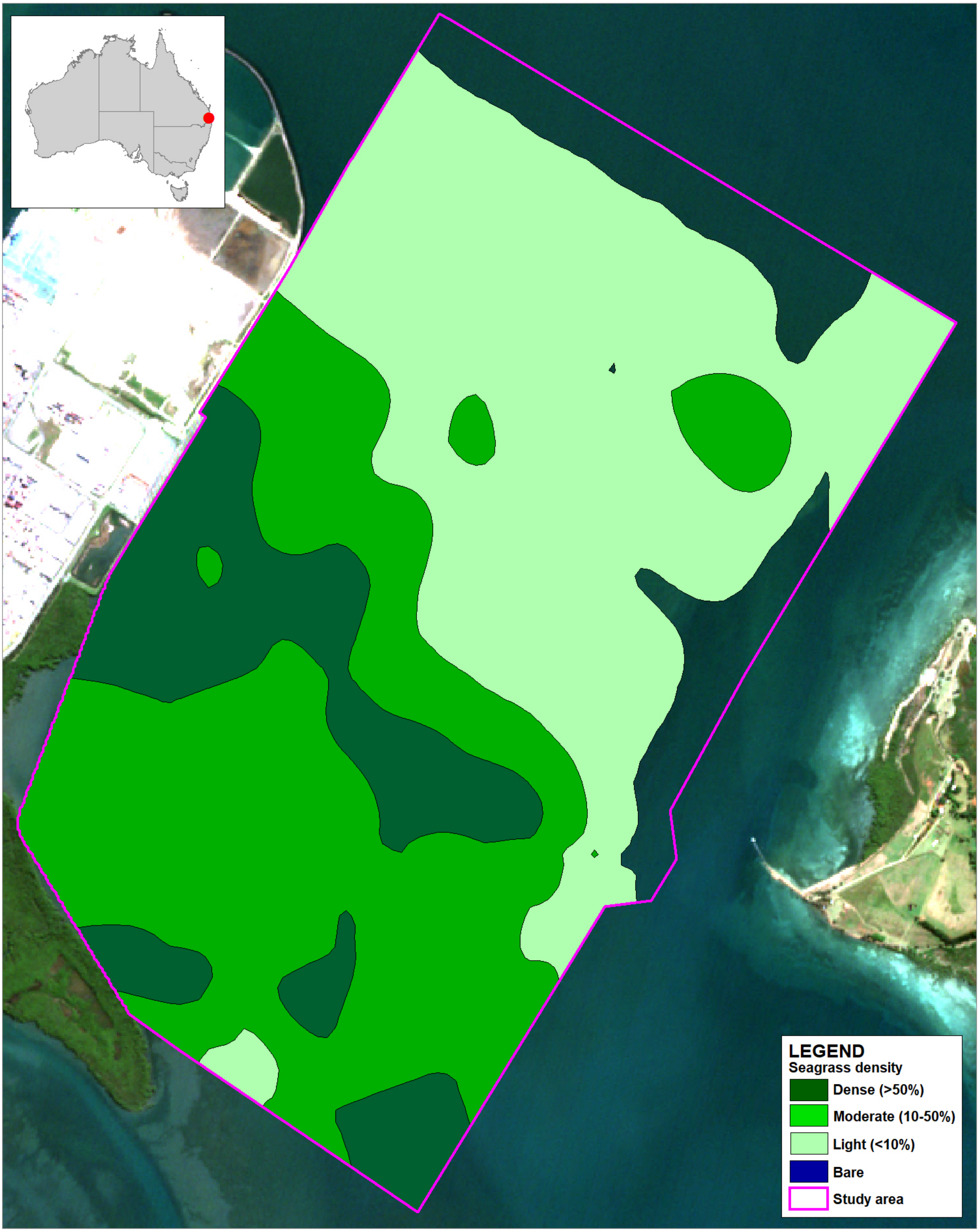

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Seagrass density categories derived from field data
Fisherman Islands 2019

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4.6.2.3 Biodiversity Values

The SMP does not presently characterise the fauna habitat values of the seagrass meadows. This gap could be filled through a number of rapid assessment methods:

- Baited Remote Underwater Video (BRUV) – BRUVs provide a cost-effective means for quantifying patterns in fish assemblages. The deployment of BRUV stations in representative seagrass assemblage classes will provide quantitative counts and diversity measures to be measured and compared in time and space (Kriggins *et al.* 2018). A pilot level assessment could involve an additional two days field work (x 2 people) and two days analysis and reporting.
- Analysis of Existing Video Imagery – a review of existing underwater imagery collected in the SMP identified several sessile fauna groups (soft corals, sponges etc.) within the seagrass meadows. It is recommended that incidental observations of sessile fauna are recorded and quantified. There is no additional cost for field work and one day of effort for data analysis and reporting.

5 Conclusions

The key findings of the 2019 are:

- Seagrass community composition remains relatively consistent with previous surveys, with *Z. muelleri* dominating intertidal habitat and *H. spinulosa* and *H. ovalis* dominating subtidal areas.
- Overall meadow extent increased approximately one square kilometre at Fisherman Islands, partially as a result of the low rainfall during the previous year.
- SDR was variable between 2018 and 2019 among and between sites.
- *Zostera muelleri* SDR WQO for Waterloo Bay was used as a benchmark to assess seagrass condition. Most transects complied with the WQO, the exception being Cleveland depth transect Q. This indicates that seagrass meadows are in good condition. It is likely that the prolonged drought conditions provide favourable seagrass growing conditions, as also observed during the Millennium drought.
- *Caulerpa taxifolia* was abundant during the 2000's when *El Niño* conditions prevailed. Despite the dry conditions over the last year, there is no evidence of *Caulerpa taxifolia* proliferation in the study area.
- Filamentous algae was the most numerically abundant function group of algae at all sites, with a number of macroalgae species also present at the majority of sites.
- The results of the Port of Brisbane SMP to date do not suggest that Port activities have resulted in seagrass meadows loss at Fisherman Islands. Rather, the overall long-term trend to date has been a net expansion in seagrass meadow extent at Fisherman Islands. This trend is consistent with the predictions of the FPE IAS (WBM 2000) that port expansion activities (both the FPE and previous reclamations at Fisherman Islands) have led to localised alterations to hydrodynamic processes that favour the development of seagrass meadows.

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Appendix A Photo Plates

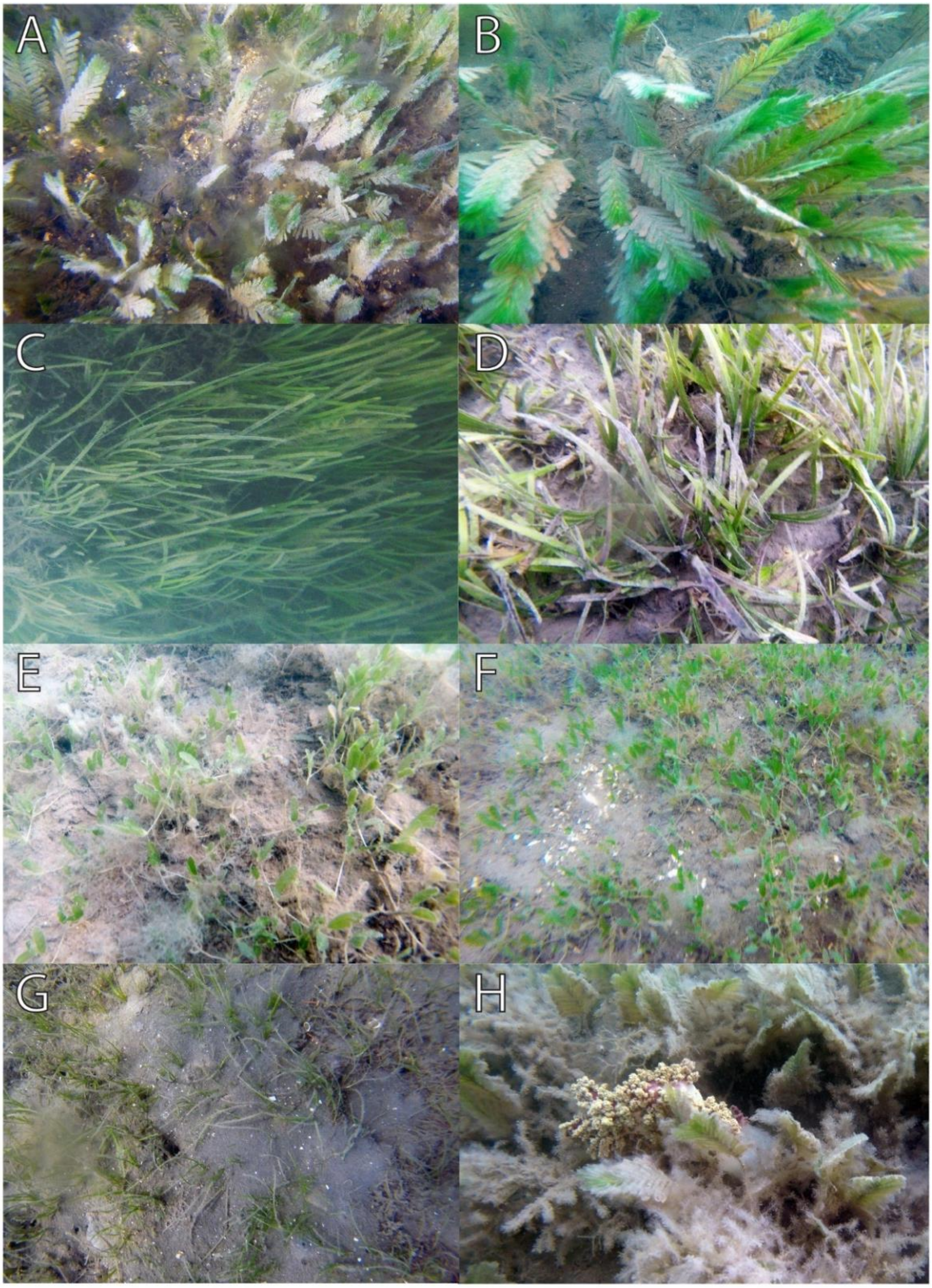


Figure A-1 Seagrass species *Halophila spinulosa* (A) at Manly, *Halophila spinulosa* at Manly (B), dense *Zostera muelleri* adjacent to Fisherman Islands(C), moderate density *Zostera muelleri* adjacent to Fisherman Islands (D), *Halophila ovalis* at Cleveland (E), *Halophila decipiens* at Cleveland (F), *Halodule uninervis* (G) and soft coral surrounded by macroalgae and *H. spinulosa* adjacent to Fisherman Islands (H).

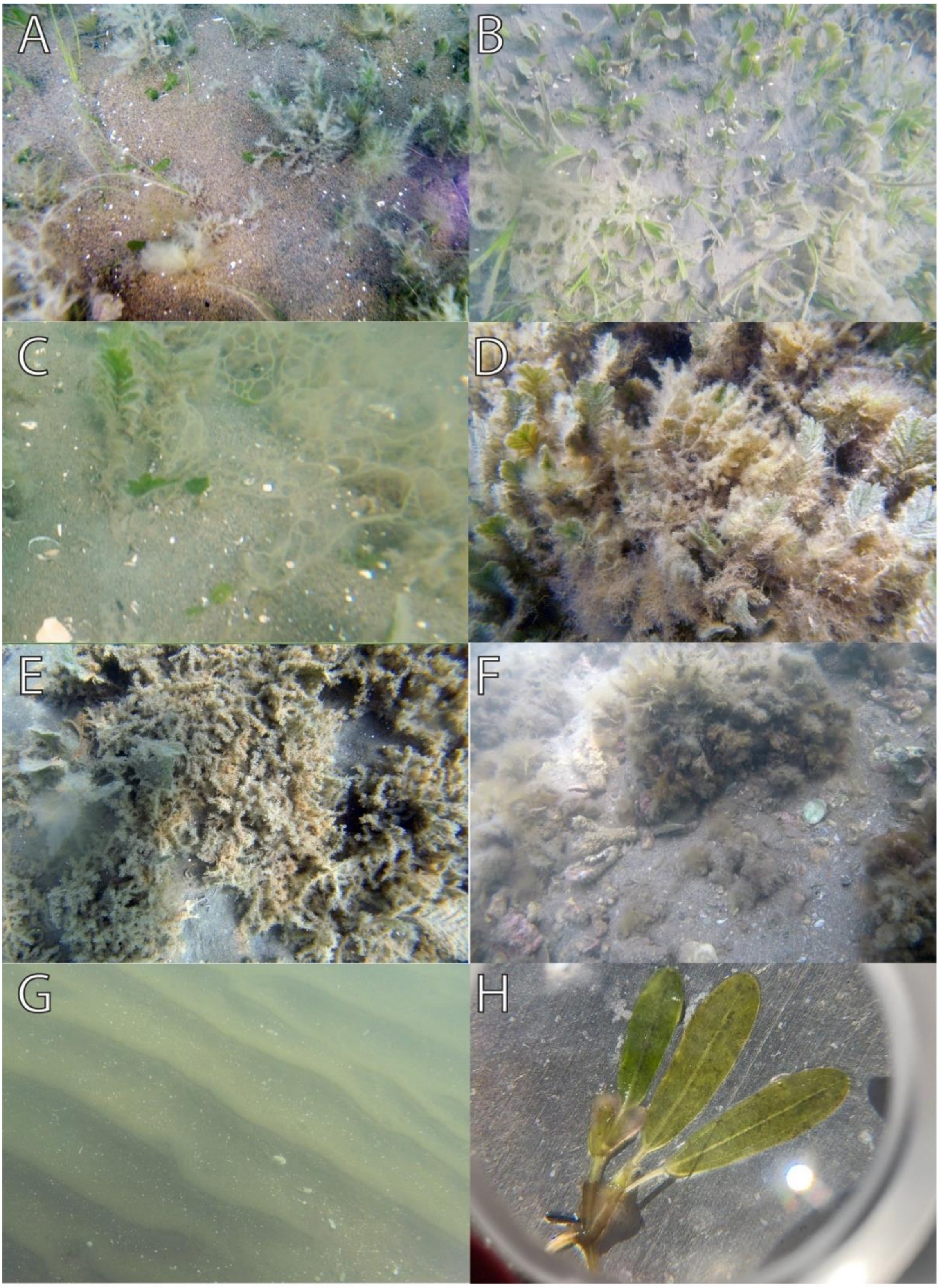
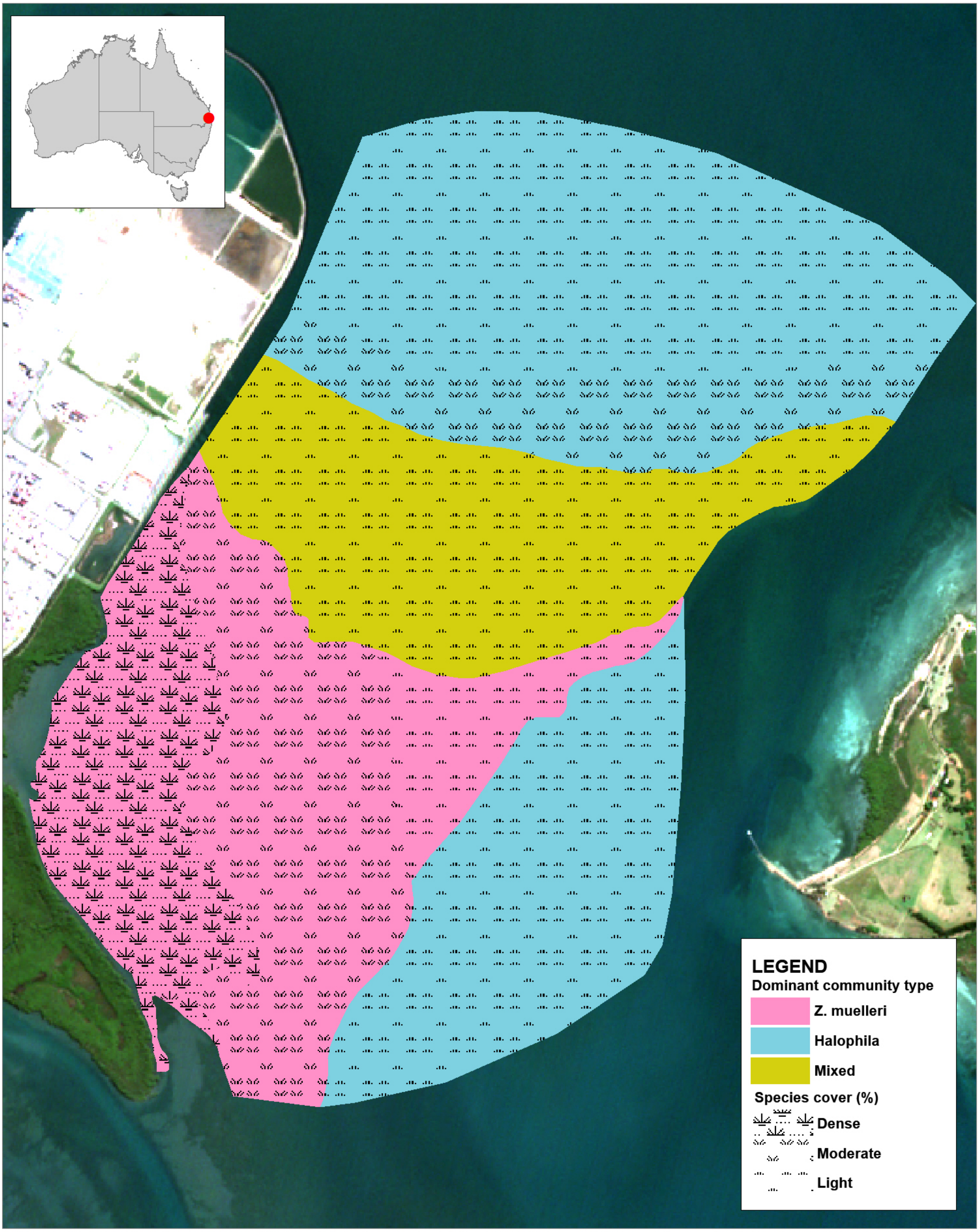


Figure A-2 Mixed community and macroalgae adjacent to Fisherman Islands (A), mixed community with *H. ovalis* adjacent to Fisherman Islands (B), mixed community with *Hydroclatharus* (C), H. spinulosa and macroalgae adjacent to Fisherman Islands (D), Hypnea covered in epiphytic algae adjacent to Fisherman Islands (E), rocky habitat at Cleveland (F), bare substrate at Fisherman Islands (G) and field sample of *H. decipiens* (H).

Appendix B Broad scale patterns in seagrass species distribution at the Port of Brisbane 2010, 2013, 2014-2018



Title:

Seagrass distribution and community structure adjacent to Fisherman Islands 2010

Figure: **B-1**

Rev: **A**

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Approx. scale

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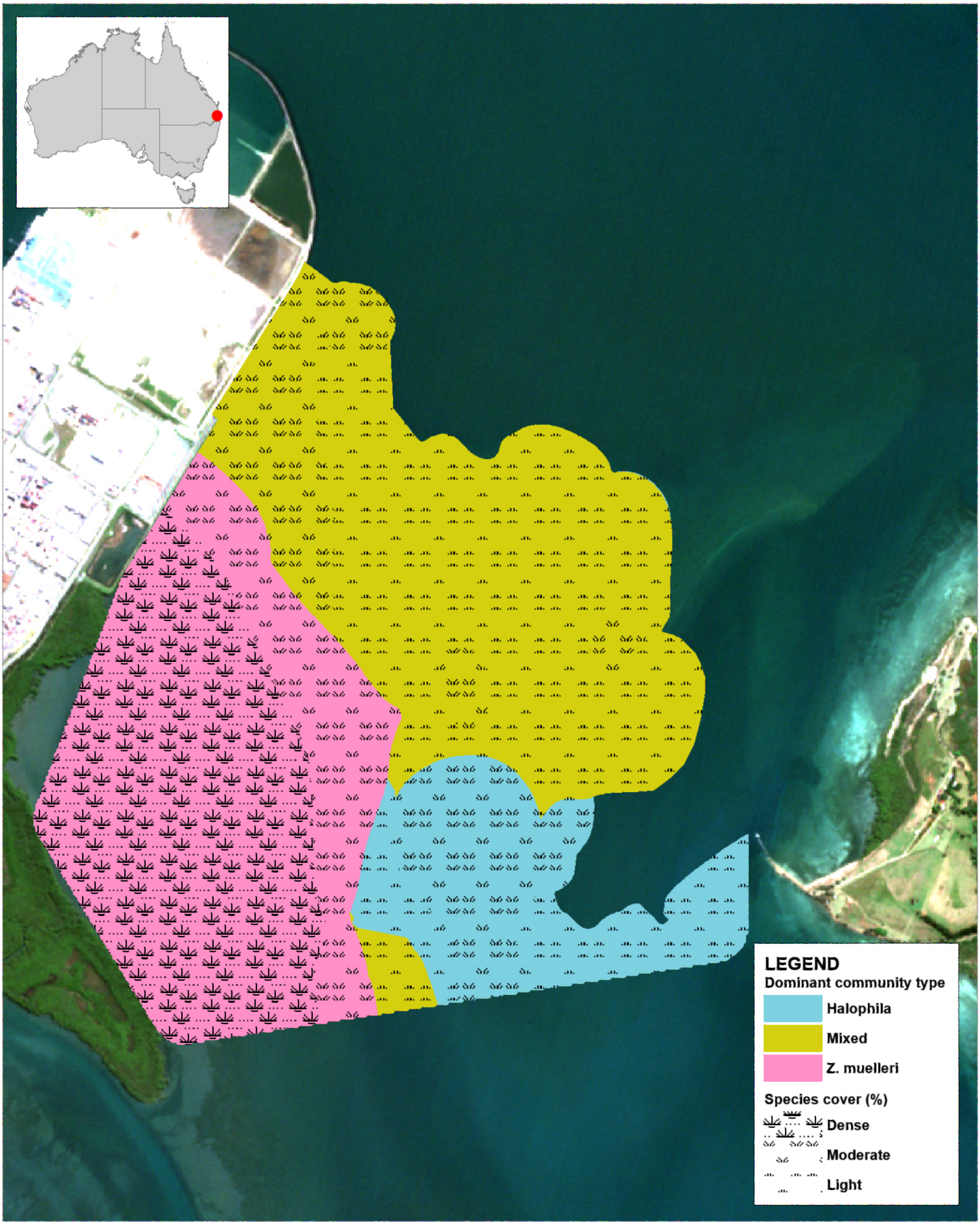

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Seagrass distribution and community structure adjacent to Fisherman Islands 2013

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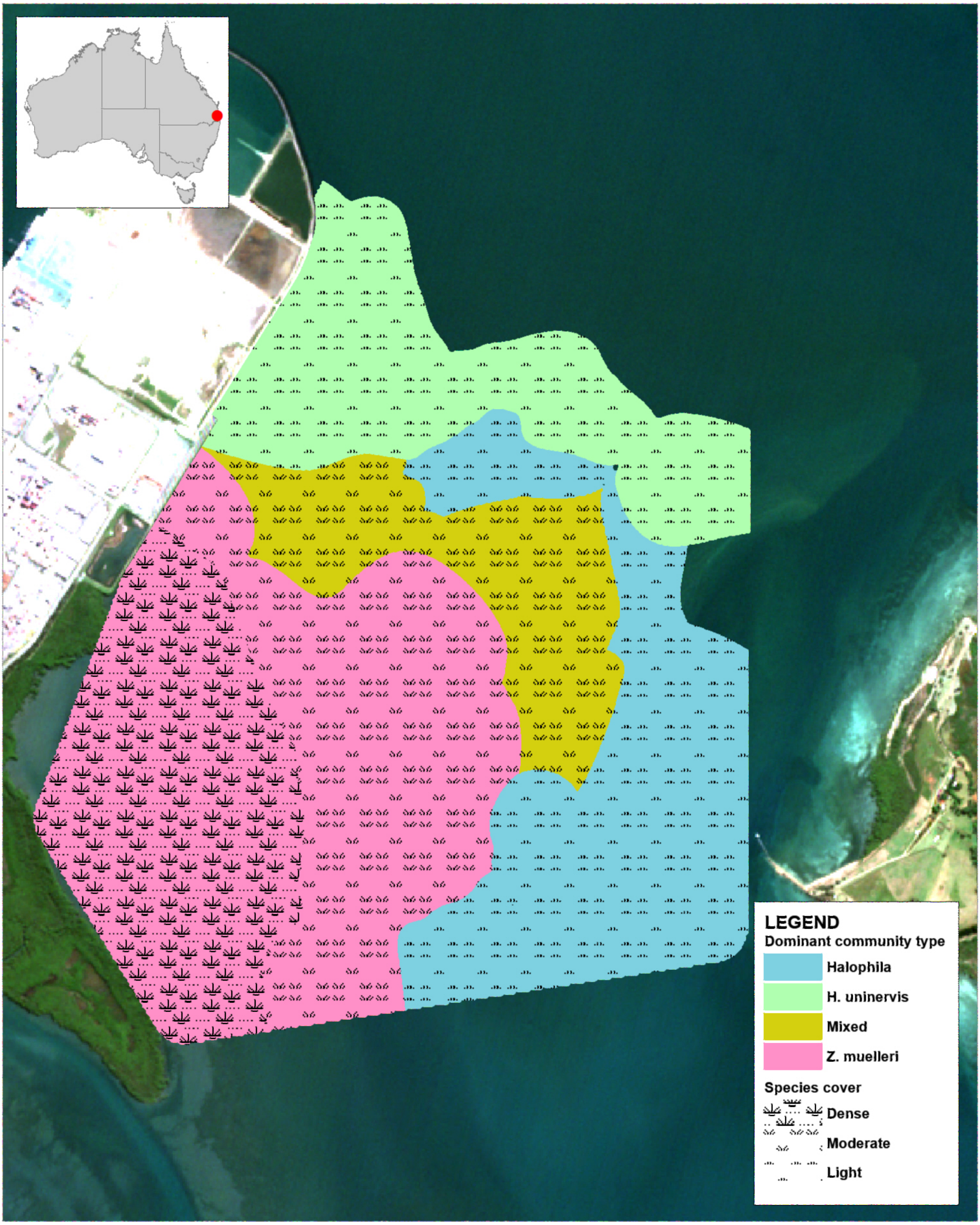

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Seagrass distribution and community structure adjacent to Fisherman Islands 2014

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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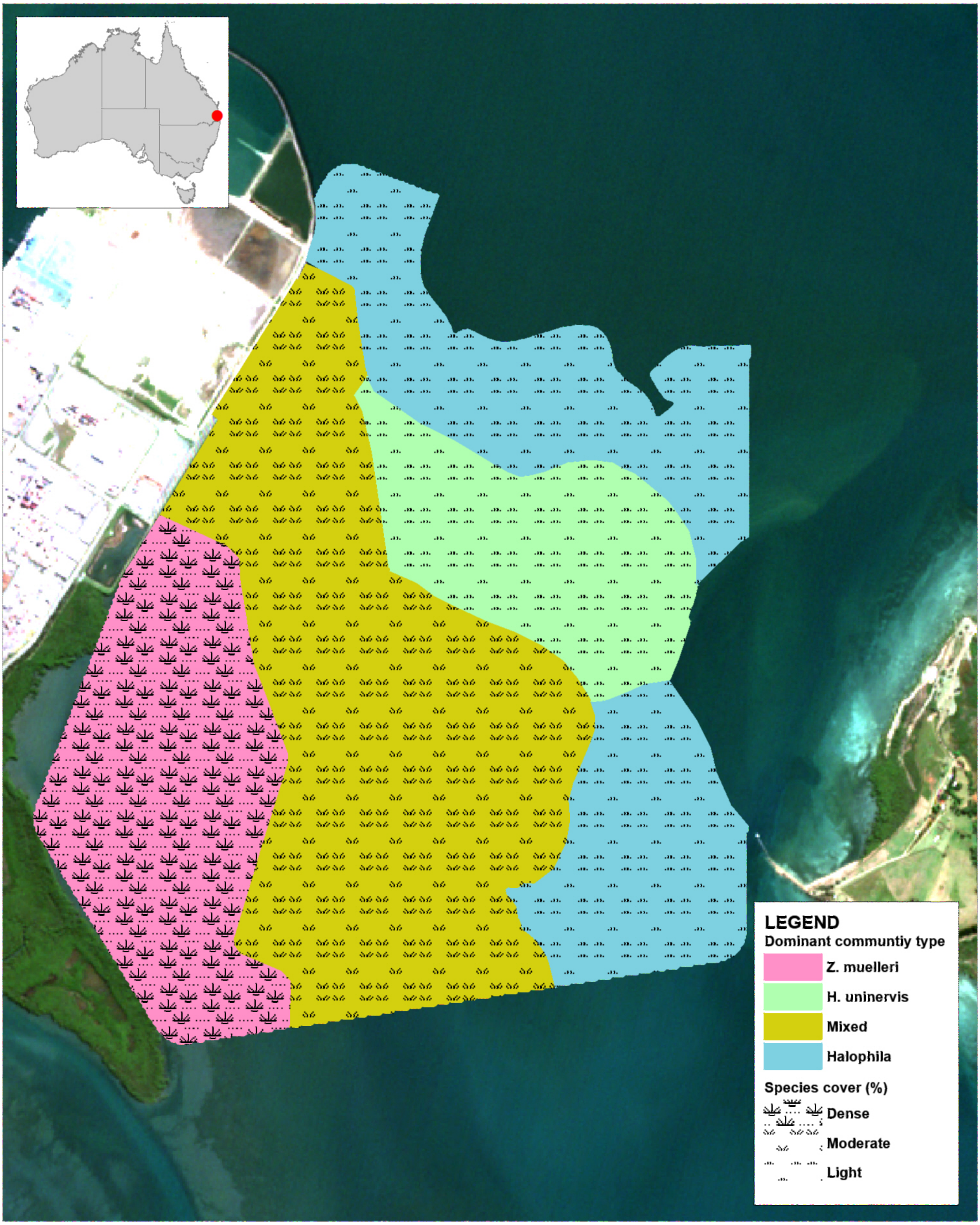

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Seagrass distribution and community structure adjacent to Fisherman Islands 2016

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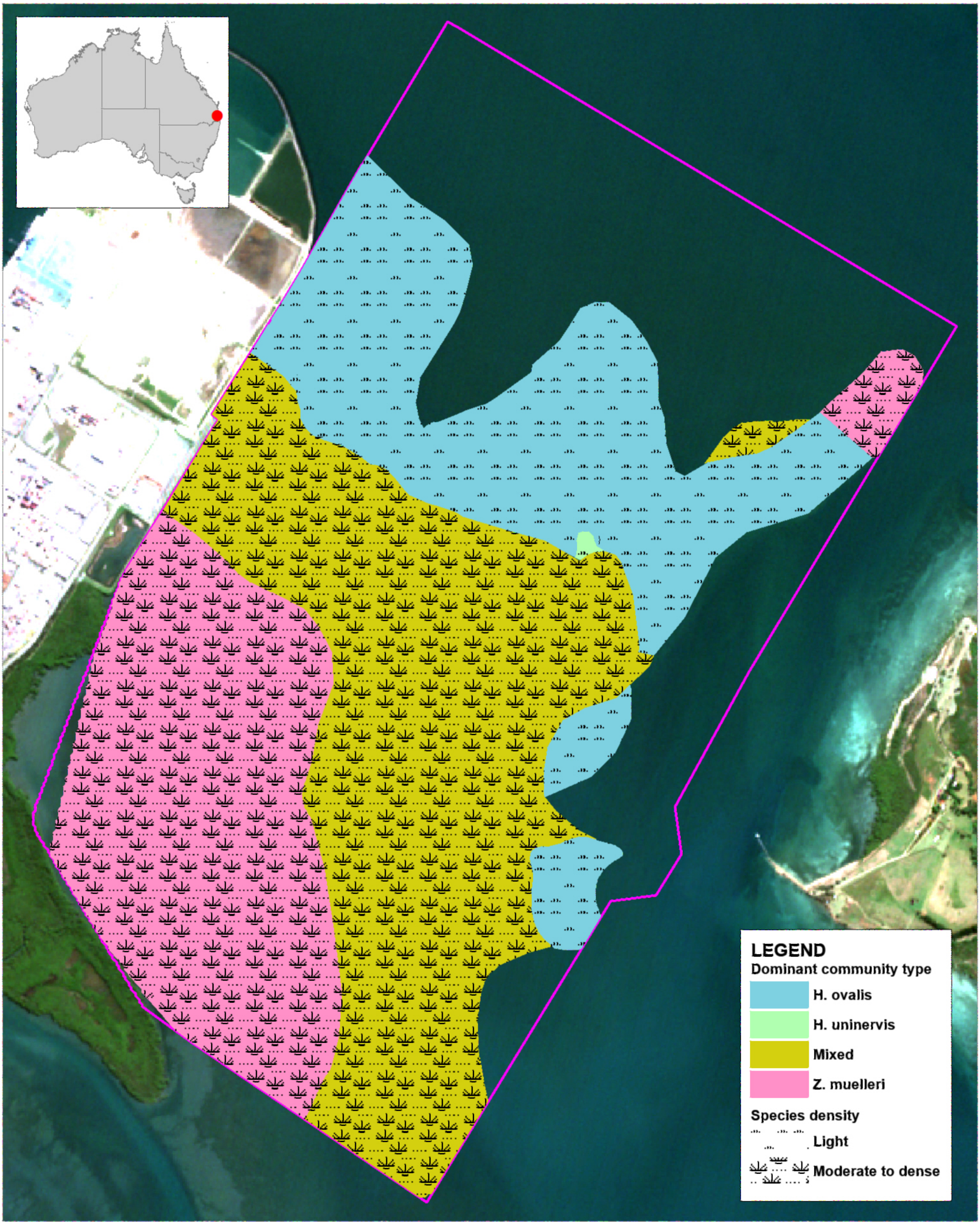

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Seagrass distribution and community structure adjacent to Fisherman Islands 2017

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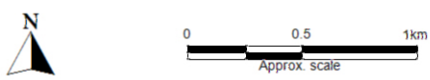

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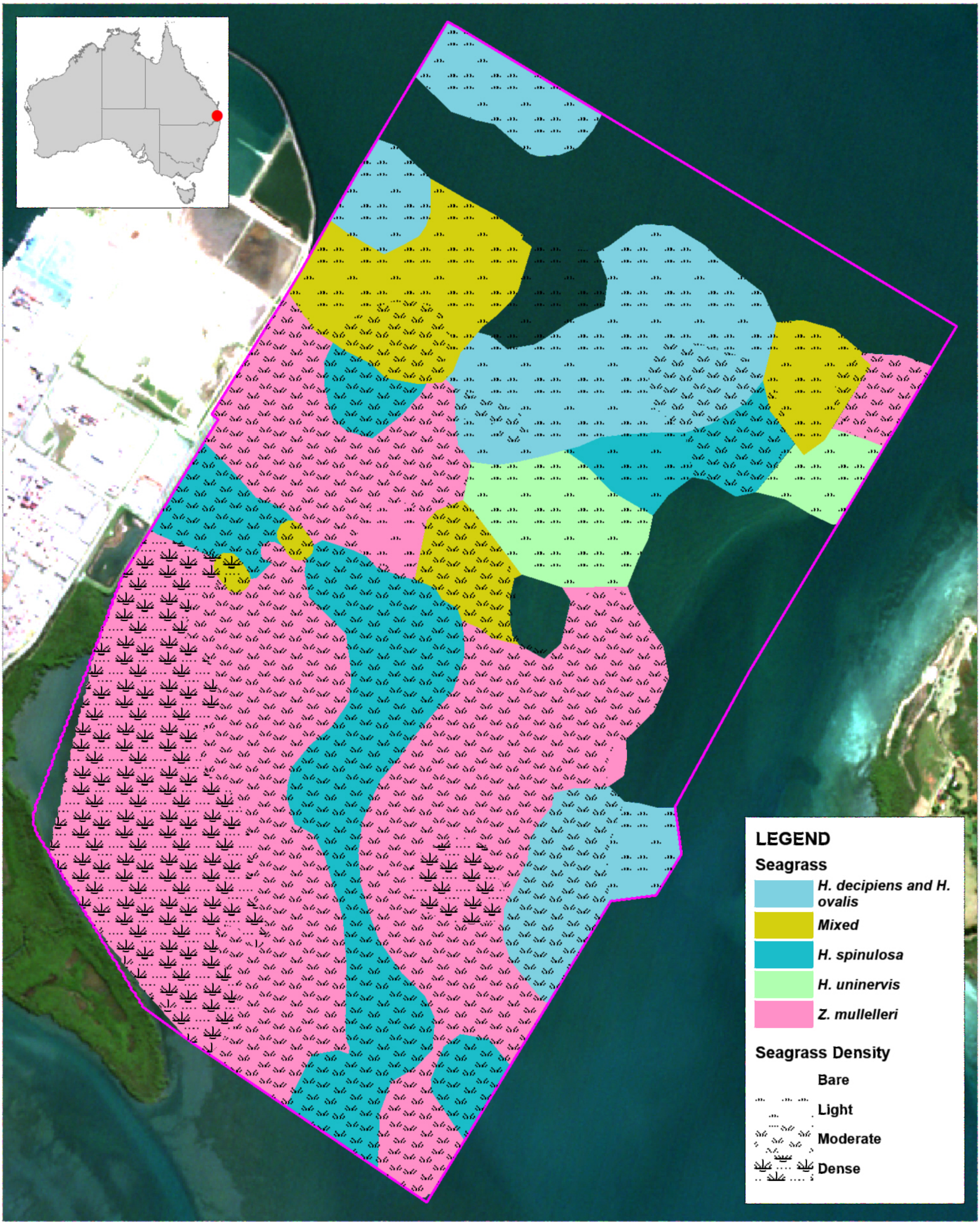

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Seagrass distribution and community structure adjacent to Fisherman Island, 2018

Figure: **B-6**

Rev: **A**

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Appendix C Seagrass videos

Figure C-1 Field footage of *Z. muelleri* adjacent to Fisherman Islands

Figure C-2 Field footage of mixed communities adjacent to Fisherman Islands

Seagrass videos

Figure C-3 Field footage of *H. spinulosa* at Manly

Appendix D Conceptual seagrass illustrations

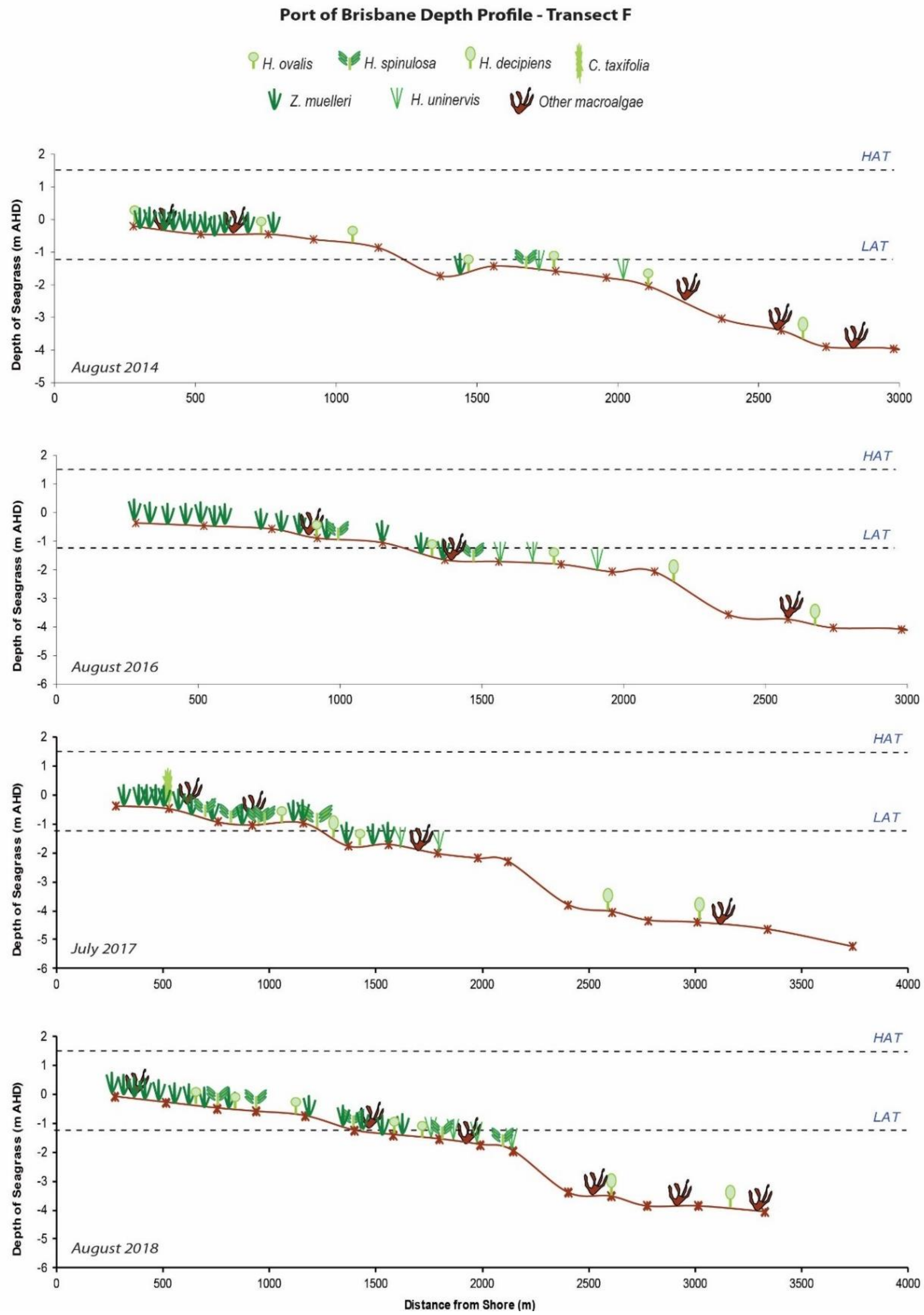

Figure D-1 Schematic representation of seagrass species distribution from 2013 to 2014 and 2016 to 2018 at depth profiling transect F, Fisherman Islands

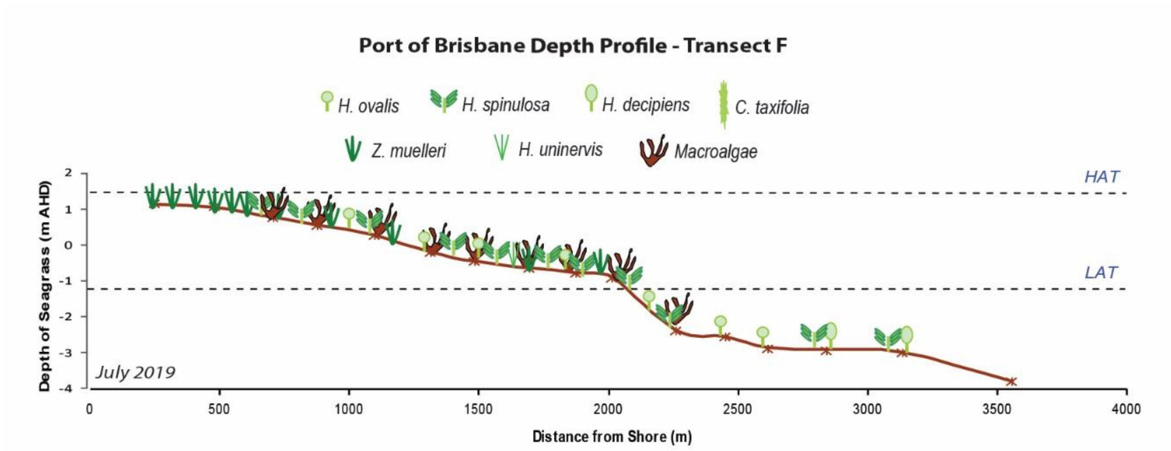

Figure D-2 Schematic representation of seagrass species distribution in 2019 at depth profiling transect F, Fisherman Islands

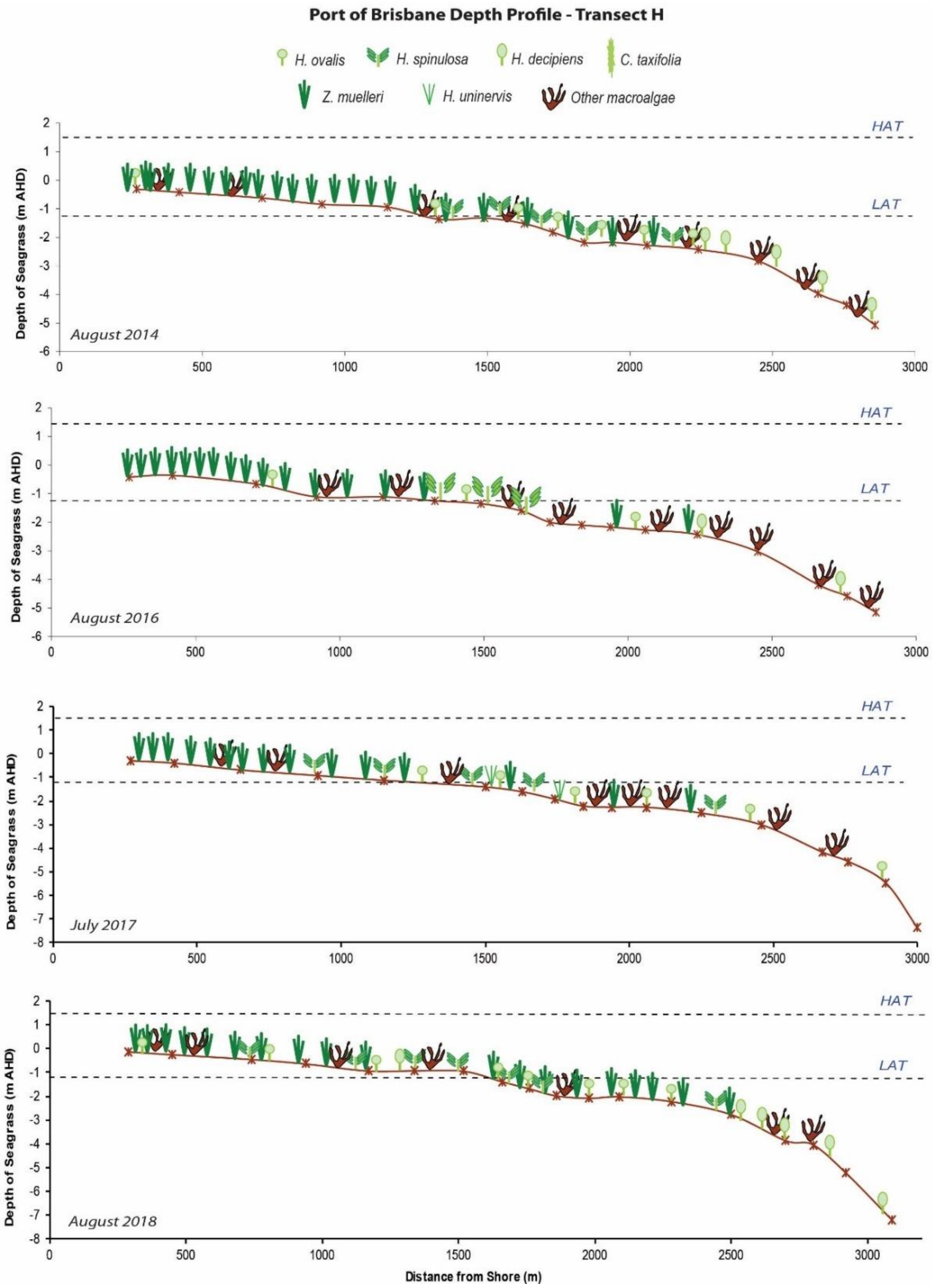

Figure D-3 Schematic representation of seagrass species distribution from 2013 to 2014 and 2016 to 2018 at depth profiling transect H, Fisherman Island

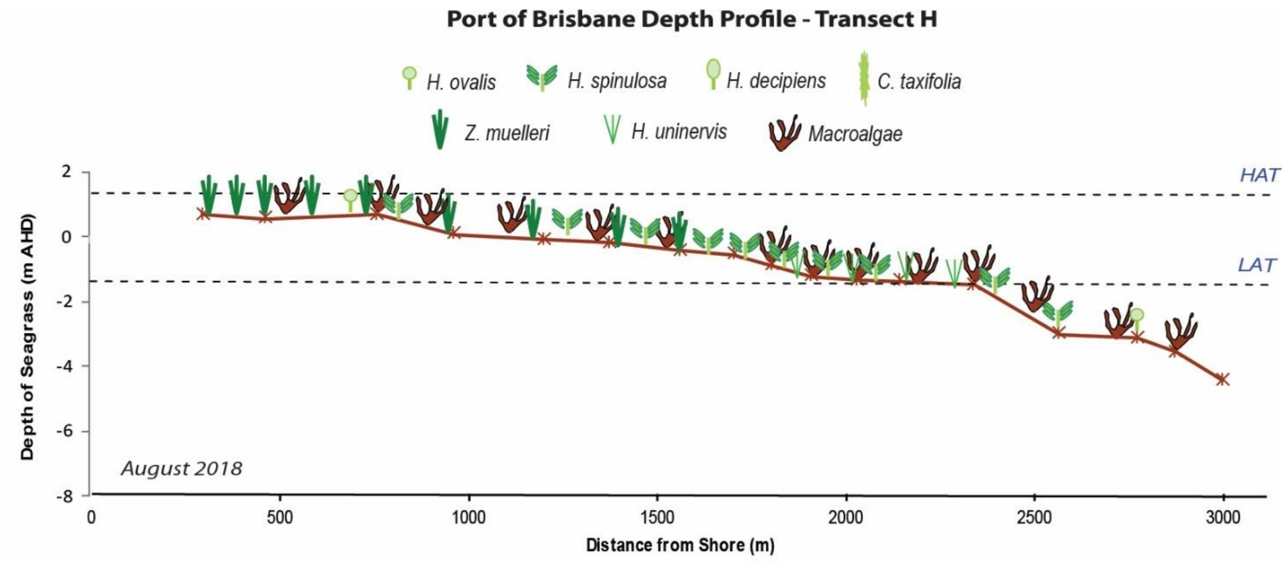

Figure D-4 Schematic representation of seagrass species distribution in 2019 at depth profiling transect F, Fisherman Island

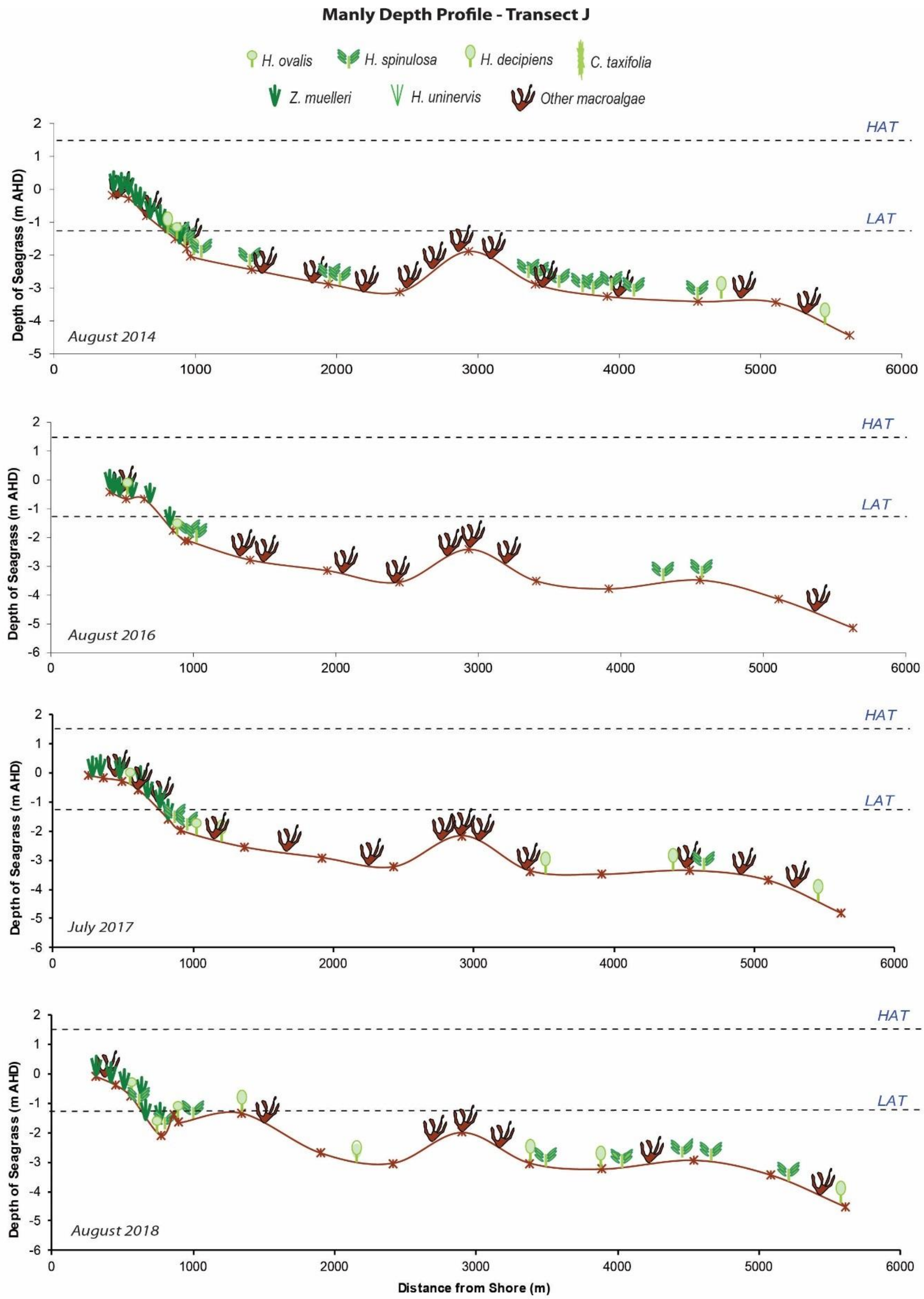

Figure D-5 Schematic representation of seagrass species distribution from 2013 to 2014 and 2016 to 2018 at depth profiling transect J, Manly

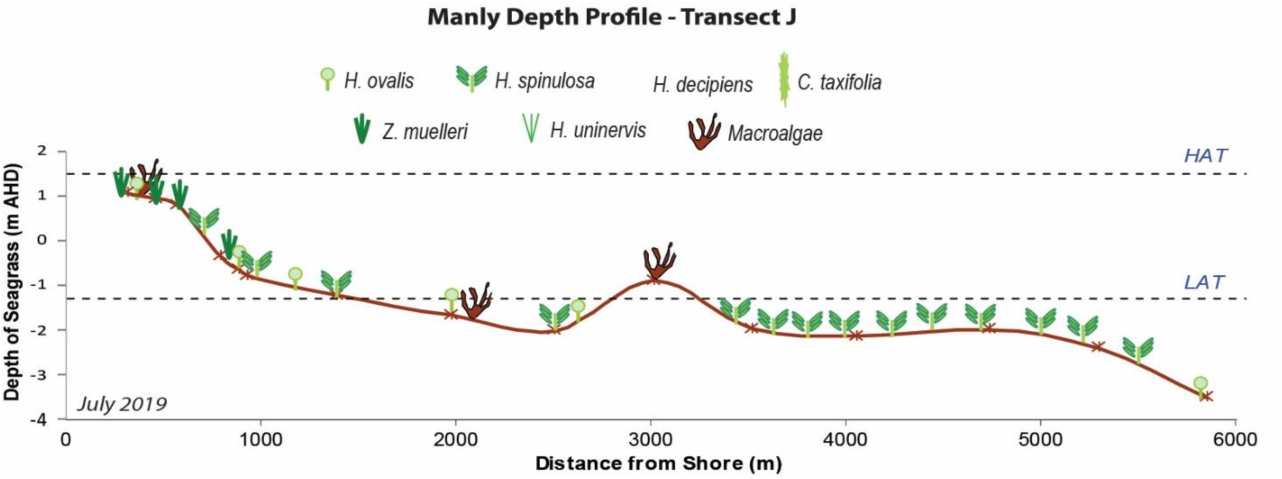

Figure D-6 Schematic representation of seagrass species distribution in 2019 at depth profiling transect J, Manly

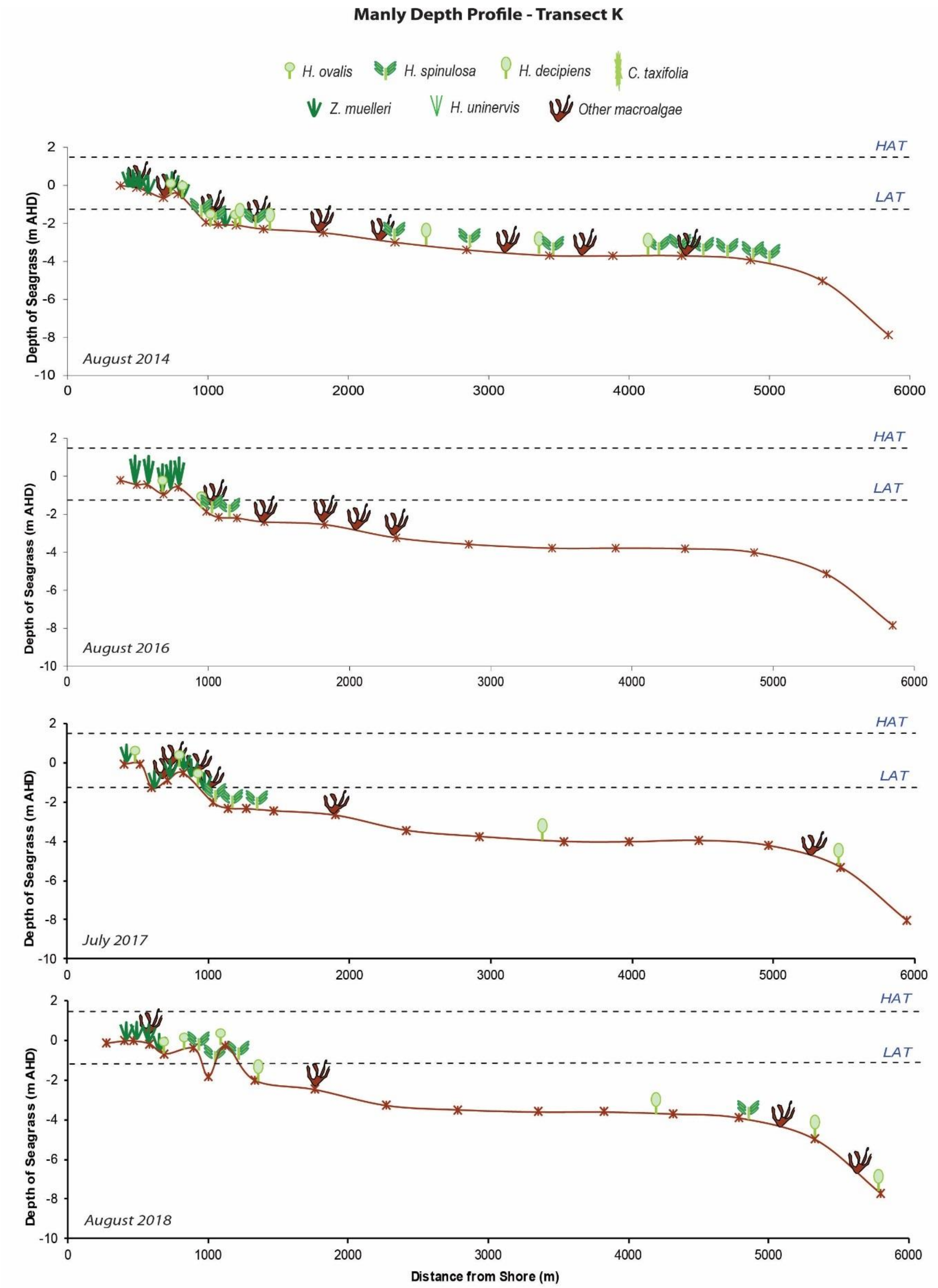

Figure D-7 Schematic representation of seagrass species distribution from 2013 to 2014 and 2016 to 2018 at depth profiling transect K, Manly

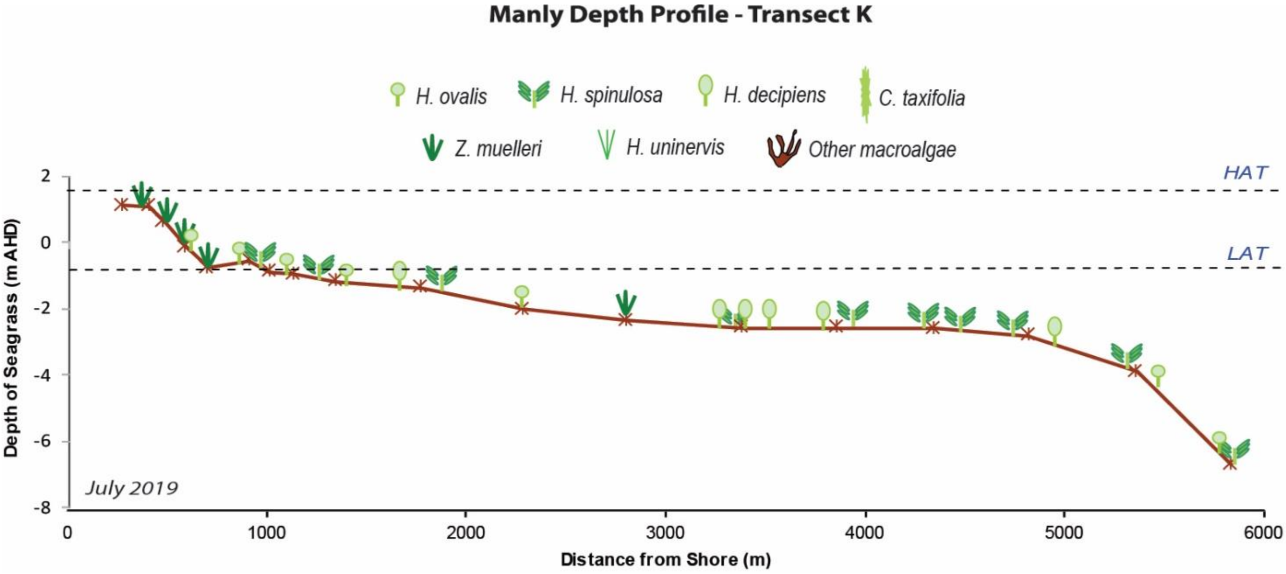

Figure D-8 Schematic representation of seagrass species distribution in 2019 at depth profiling transect K, Manly

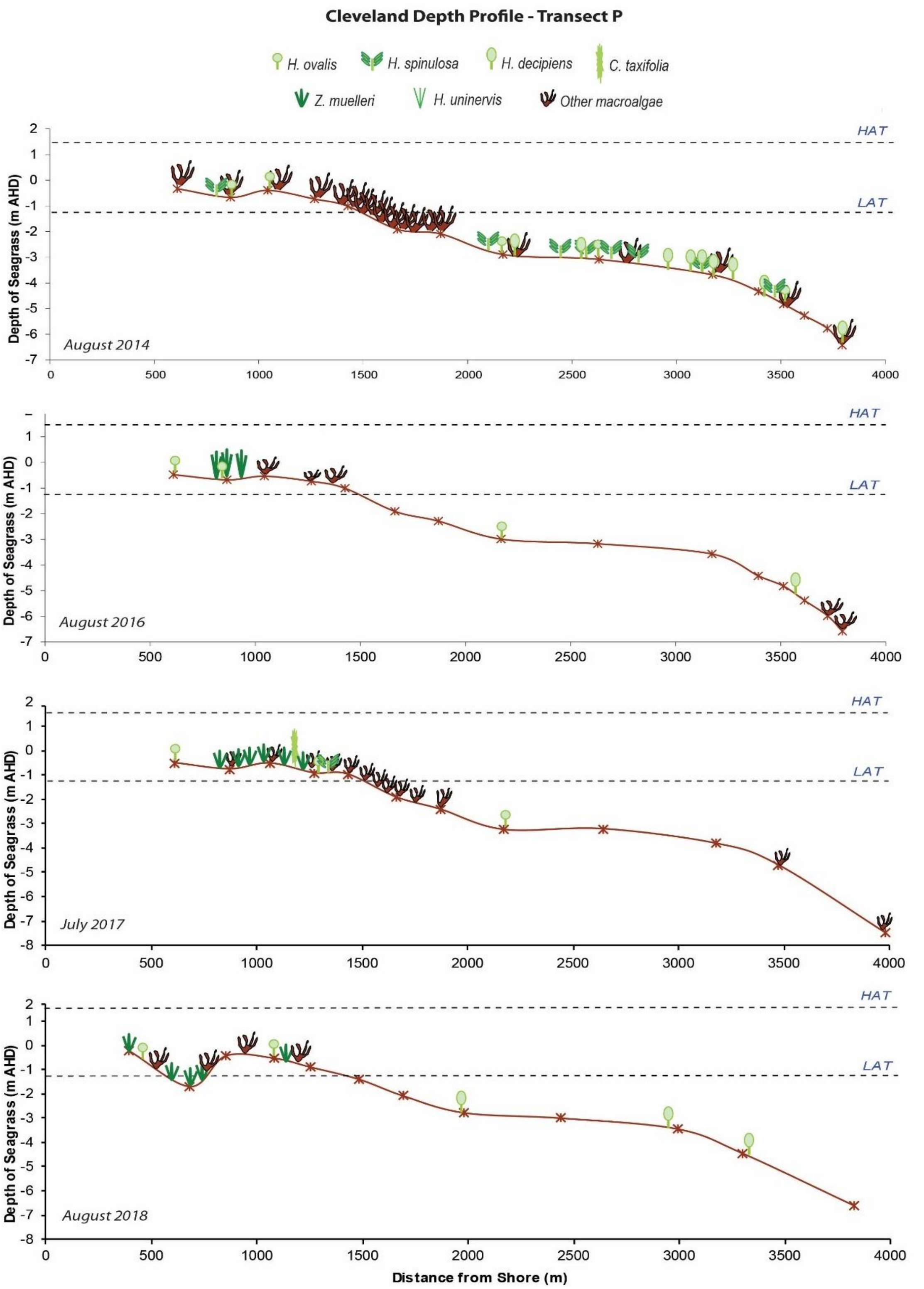

Figure D-9 Schematic representation of seagrass species distribution from 2013 to 2014 and 2016 to 2018 at depth profiling transect P, Cleveland

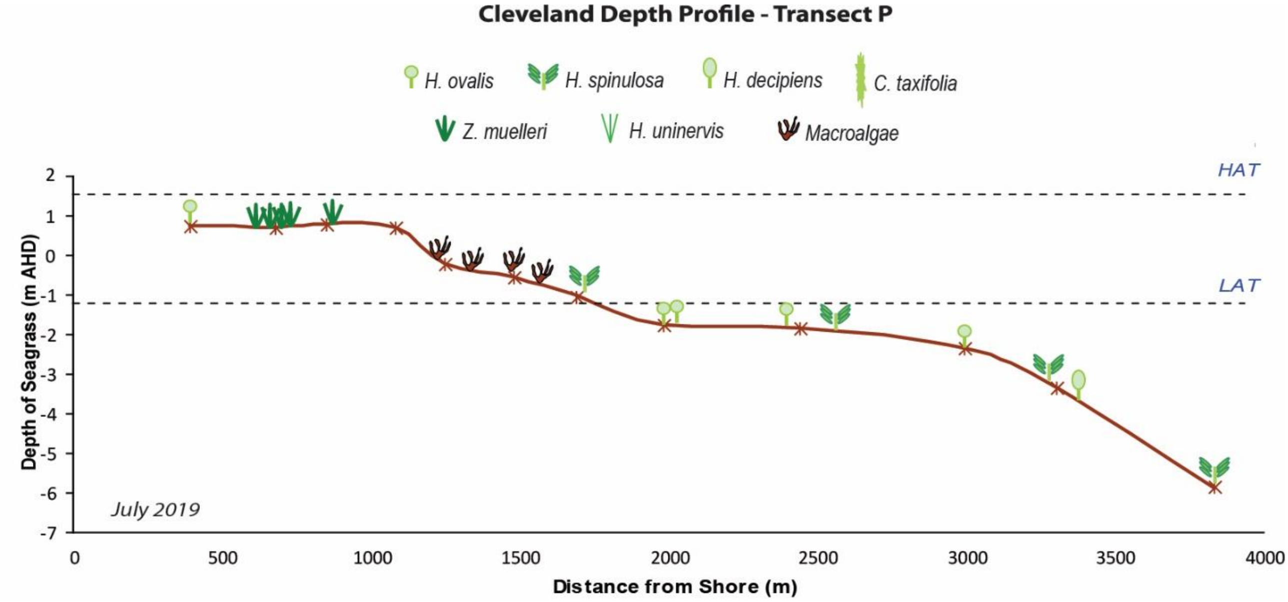

Figure D-10 Schematic representation of seagrass species distribution in 2019 at depth profiling transect P, Cleveland

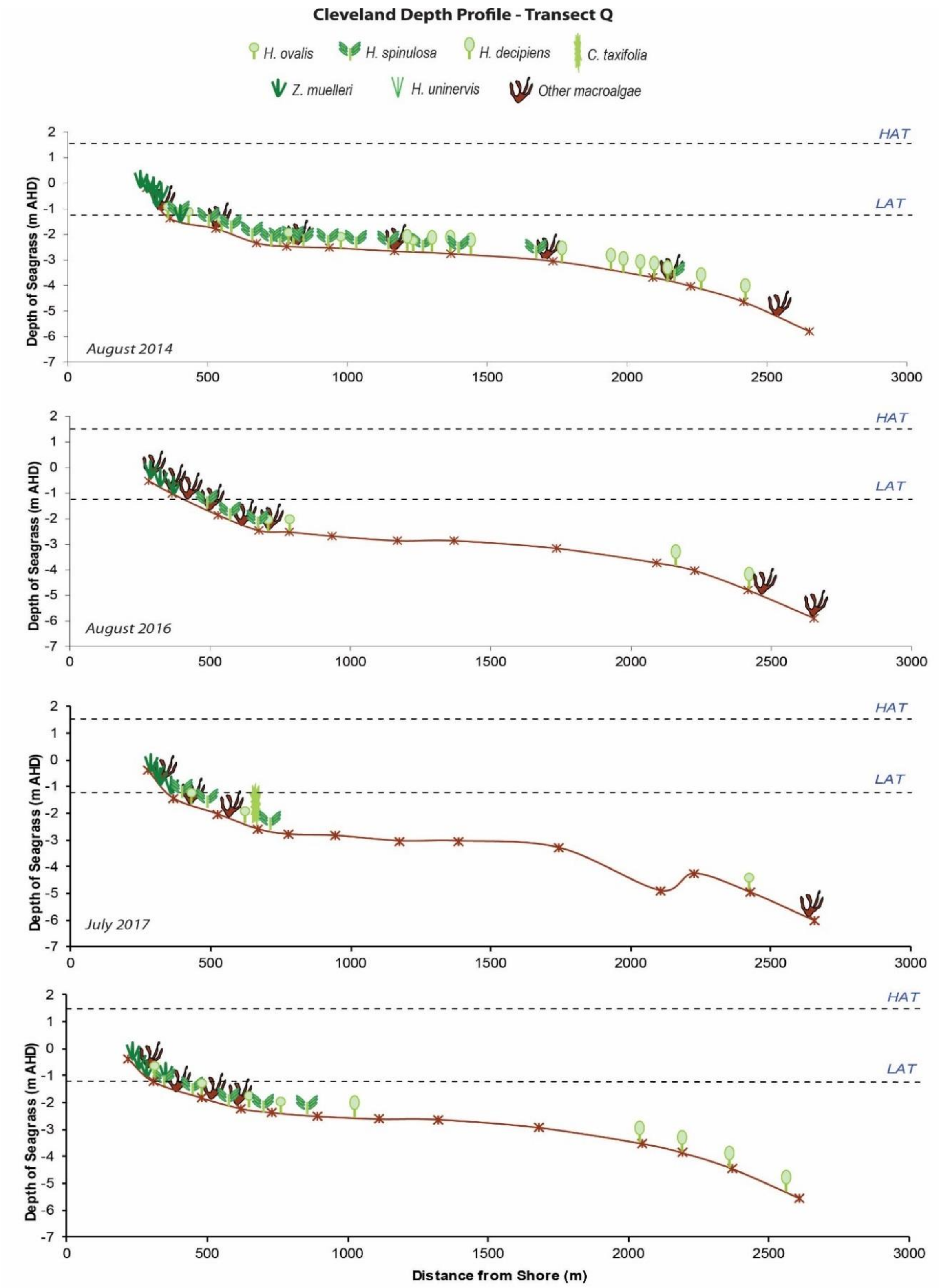

Figure D-11 Schematic Representation of seagrass species distribution from 2013 to 2014 and 2016 to 2018 at depth profiling transect Q, Cleveland

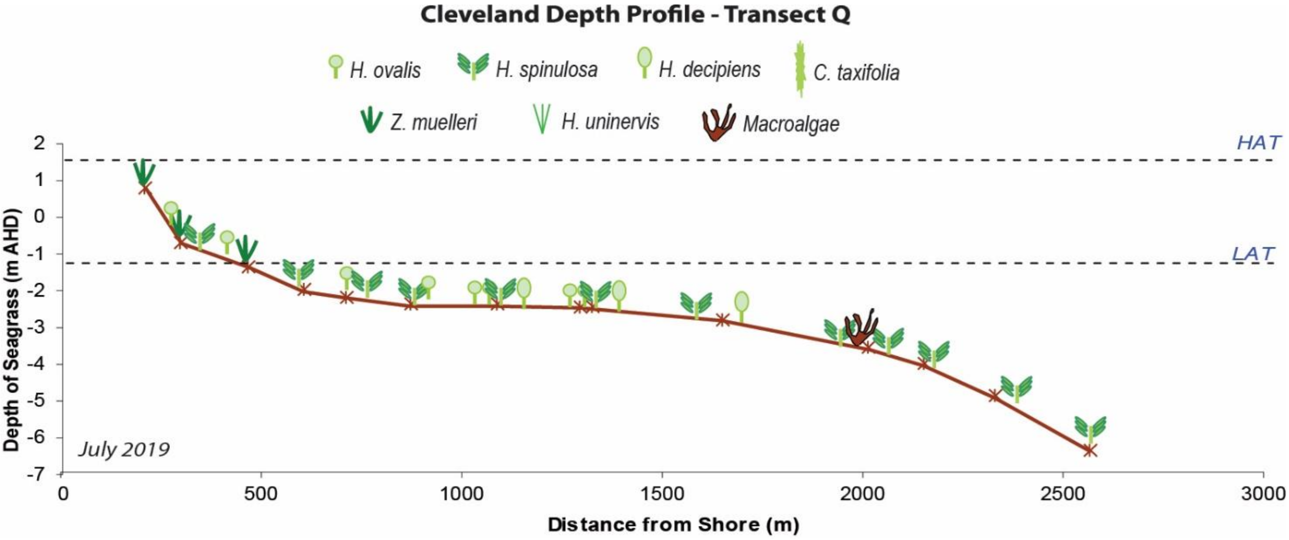

Figure D-12 Schematic Representation of seagrass species distribution from in 2019 at depth profiling transect Q, Cleveland

Appendix E Seagrass percentage cover – depth categories

Seagrass percentage cover – depth categories

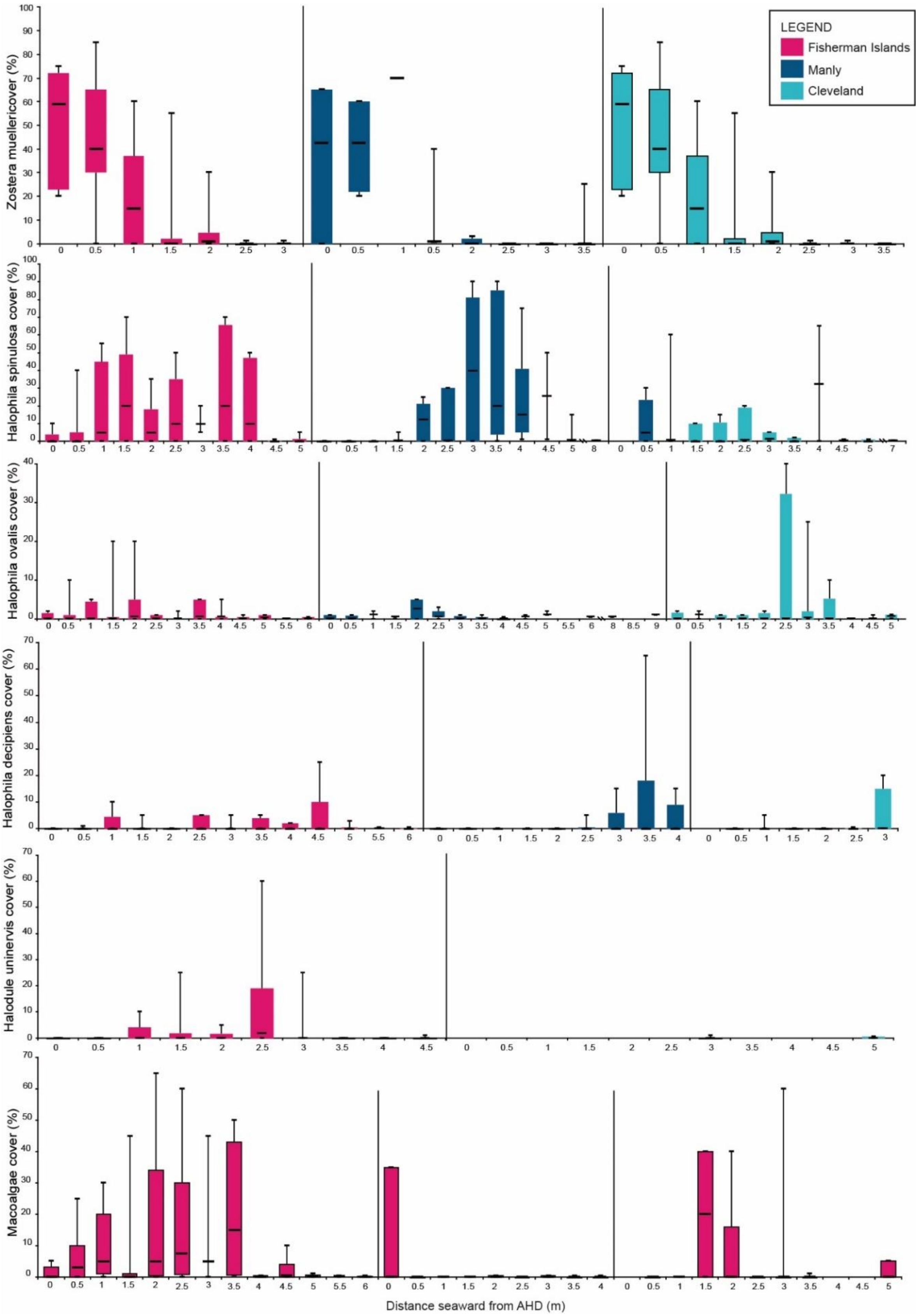

Figure E-1 Percentage cover of species at each location and depth category

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