Port of Brisbane Seagrass Monitoring Program Report 2023

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Executive Summary

This report describes the approach and findings of the Port of Brisbane Seagrass Monitoring Program (SMP) 2023 sampling event. The SMP monitors meadows at Fisherman Islands and control locations of Cleveland, Manly and Deception Bay using field-based (underwater video transects) and remote (aerial imagery) methodologies.

- There has been a long-term continuous 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.

- Species composition: A core set of species occurred at all locations over time: the eelgrass *Zostera muelleri*, the paddle-weeds *Halophila ovalis*, *Halophila spinulosa* and (typically) *Halophila decipiens*. All four seagrass species were observed in the 2023 field surveys. A fifth species, the narrow-leaf seagrass *Halodule uninervis,* is an ephemeral species that was also recorded in 2023. A sixth species, Cymodocea serrulata was previously recorded in the 2021 survey, however not in 2022 or 2023.

- Spatial Patterns: Figure 1 is a map of seagrass meadows at Fisherman Islands in 2023. Intertidal and shallow subtidal areas were numerically dominated by *Zostera muelleri*, either as monospecific meadows or a mixed meadow with one or more *Halophila* species sub-dominant. Subtidal meadows were comprised of mixed communities of *Halophila* and macroalgae species. Similar pattens in structure have been observed since the commencement of seagrass mapping in the 1980s.

- Subtidal Meadow Expansion in 2022-23: The seaward boundary of *Halophila* seagrass meadows expanded at all sites between 2022 and 2023 surveys. The 2022-23 period was drier that 2021-22, providing suitable conditions for seagrass recolonisation and partial recovery following the 2022 flood event.

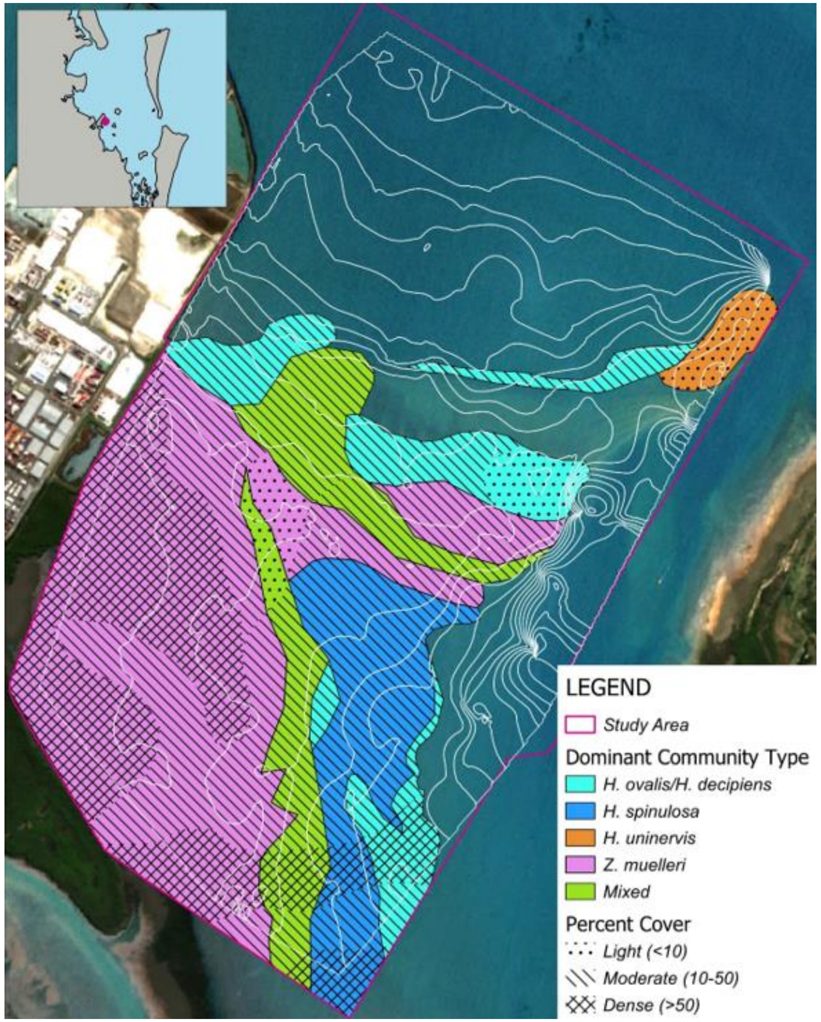


Figure 1. Seagrass Distribution and Composition Adjacent to Fisherman Islands 2023, Showing 1 m LAT Contours

- *Zostera* Depth Range Variations in 2022-23: The maximum seagrass depth range (SDR) of *Zostera mulleri* expanded at the following sites: Manly (Transects J and K), Fisherman Island (Transect F only) and Cleveland (Transect Q only). SDR contracted at all other sites. Based on trends between 2013-21 (Figure 2), *Zostera* meadow recovery would be expected to occur in the order of 2-6 years after the 2022 flood event (in the absence of further flood events). Increases in *Zostera mulleri* SDR at some sites in 2023 indicate that the meadows have begun to recover.

- Upper Limit of Seagrass Meadows. The landward margin of *Zostera muelleri* meadows expanded at Fisherman Islands between 2022 and 2023. It is hypothesised that lower than average maximum temperatures provided favourable seagrass growing conditions in shallow waters during 2022-23.

- Macroalgae Beds. A variety of macroalgae species were recorded in seagrass meadows. The brown algae *Padina* being the most abundant, followed by *Hydroclathrus and Sargassum*. The native green alga *Caulerpa taxifolia* replaced large areas of seagrass in western Moreton Bay during 2000s, but has been sparse to absent since 2009. This species is intolerant of low salinity, and its disappearance from the study area coincided with major flood events (2010 and 2013).

- FPE Seawall Effects. Since the construction of the FPE, there has been a long-term trend of seagrass meadow expansion at Fisherman Islands. The long-term trend of seagrass meadow expansion is consistent with predictions of the Future Port Expansion Impact Assessment Study, which suggested that land reclamation would enhance growing conditions for nearby seagrass meadows.

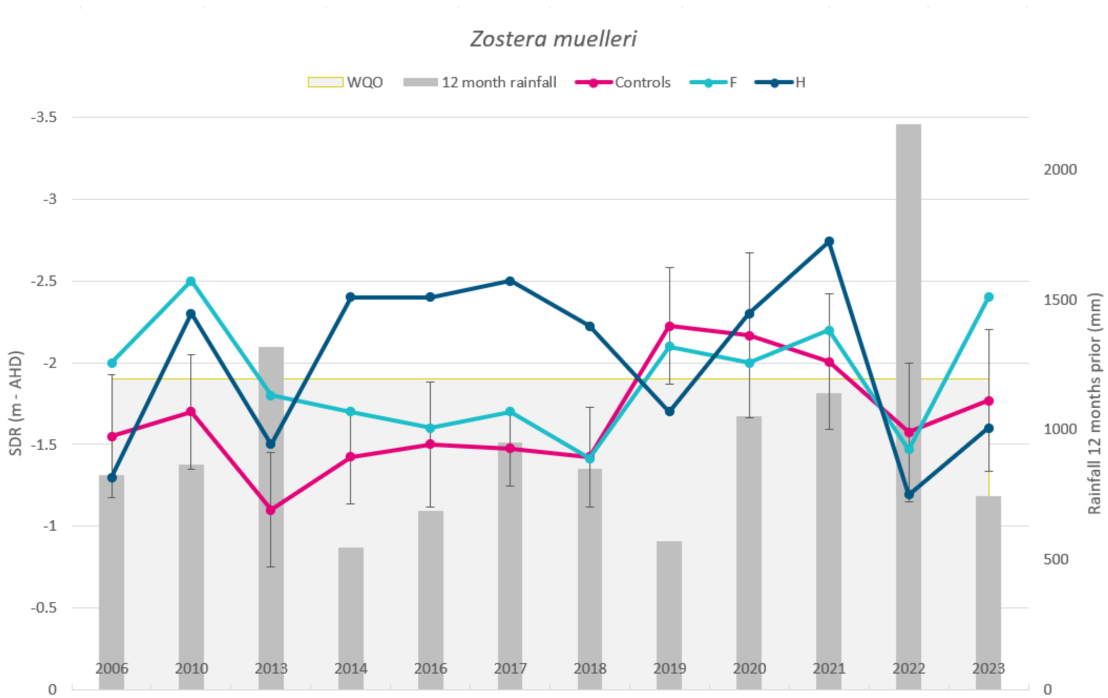


Figure 2. *Zostera* seagrass depth range at Fisherman Islands transect F and H, and the average (±SE) for control sites. The Water Quality Objective (WQO) is shown for Waterloo Bay. Rainfall in the 12 months leading to the survey is also shown (BOM, 2023)

Contents

1 Introduction

1.1 Background

Moreton Bay contains a mosaic of marine habitats supporting 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 like dredging or shipping.

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, Cleveland and Deception Bay (western Moreton Bay) control locations;
- Spatial variations in seagrass extent and species distribution occurring at the four 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;
- 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;

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

- 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 Morton 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 southeastern 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).

The control sites for the study, named western Moreton Bay sites (Manly, Cleveland and Deception Bay),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. Deception Bay was included as an additional site in 2020. Previous surveys of Deception Bay have characterised this seagrass community as light to moderate coverage consisting of the following species: Zostera muelleri (subsp. capricorni), Halodule uninervis, Halophila ovalis and Syringodium isoetifolium (Kirkman 1995; OzCoasts 2004).

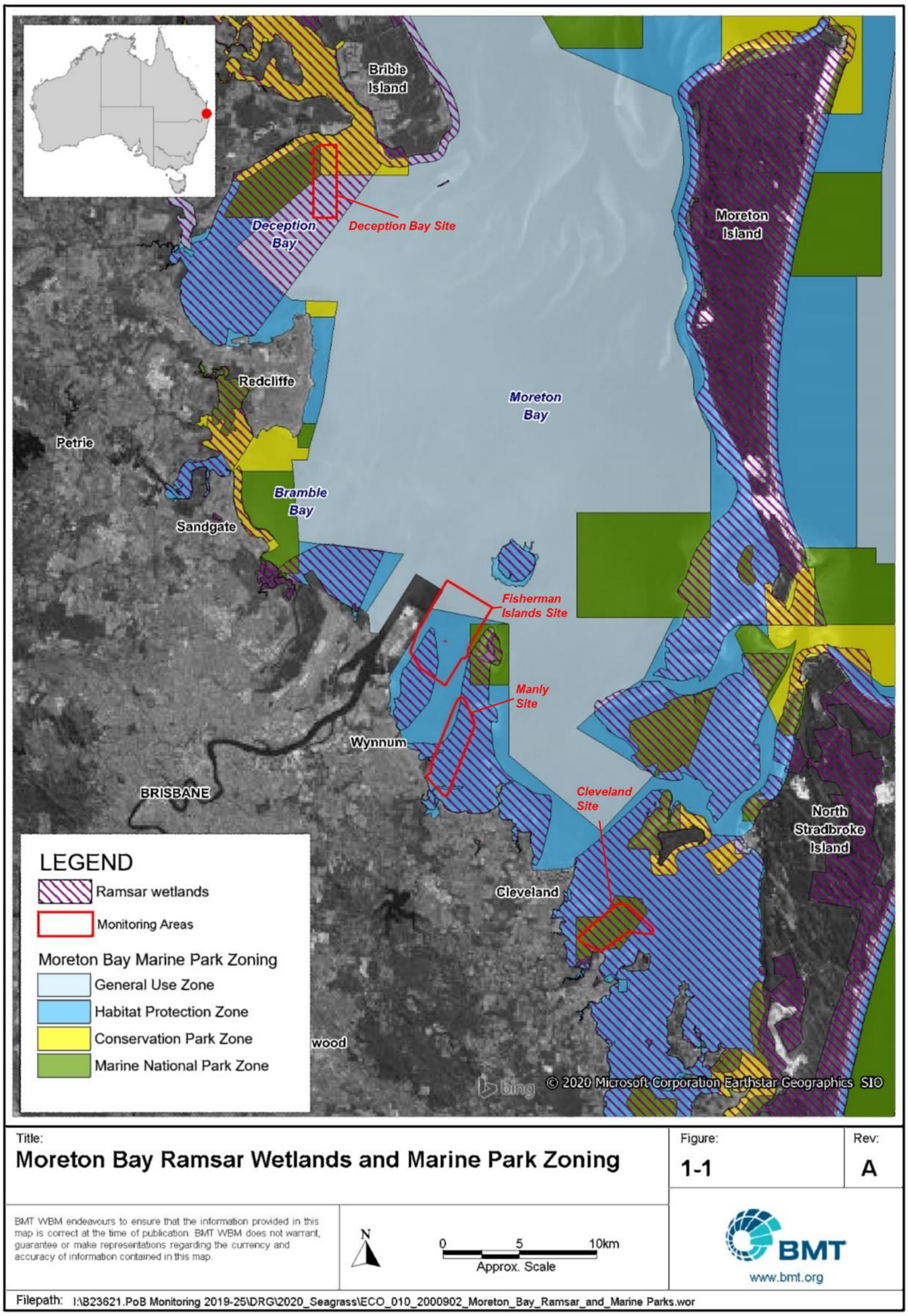


Figure 1.1 Moreton Bay Ramsar Wetlands and Marine Park Zone

2 Methodology

2.1 Timing

Field sampling in 2023 was undertaken between the 20th of July to the 1st of August 2023. Tidal data from the Tidal Unit, Maritime Safety Queensland was obtained for the Brisbane Bar throughout this study period (Figure 1.2) and was used to correct depth soundings to Australian Height Datum (AHD).

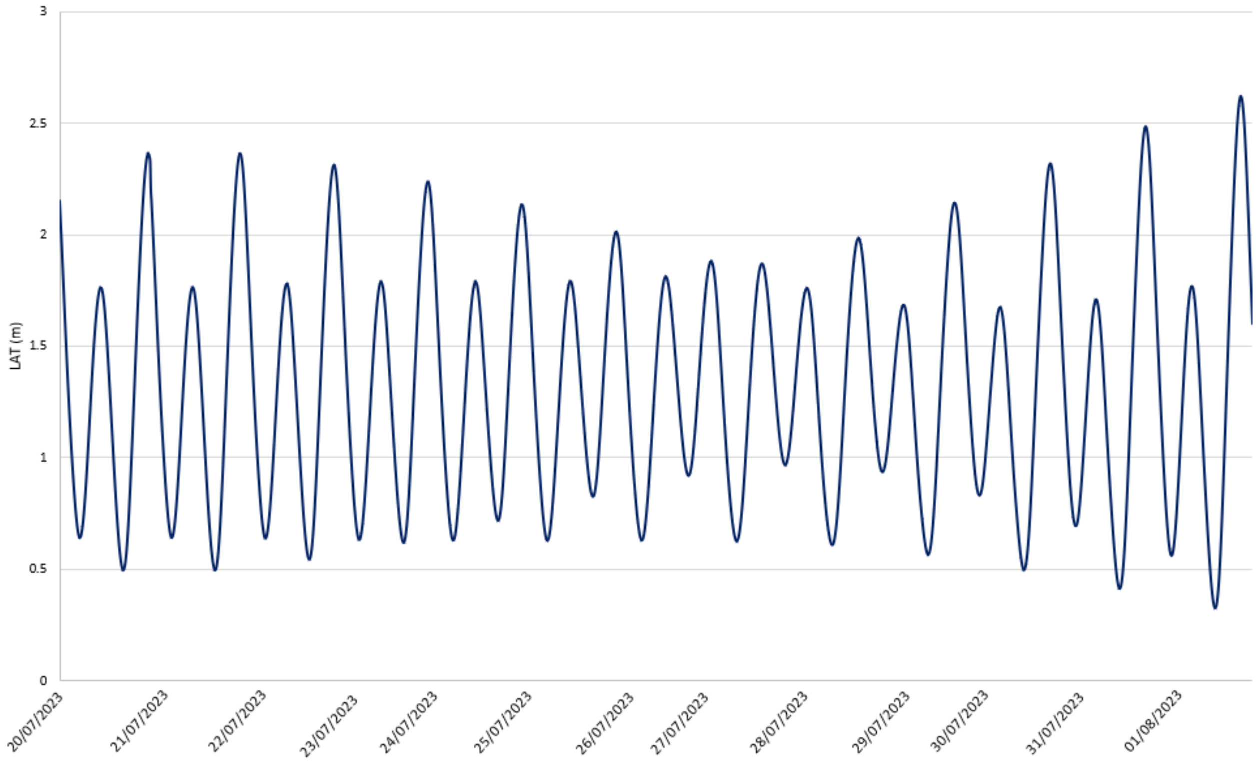


Figure 2.1 Tidal Heights at Brisbane Bar

Figure 2.2 shows: (i) Average annual rainfall; (ii) Annual rainfall for 2001-2023, and (iii) monthly rainfall, for the period 2001-23, together with mean annual maximum temperature for the period 1995-23. Key trends include monthly and annual rainfall spiking in La Niña events.

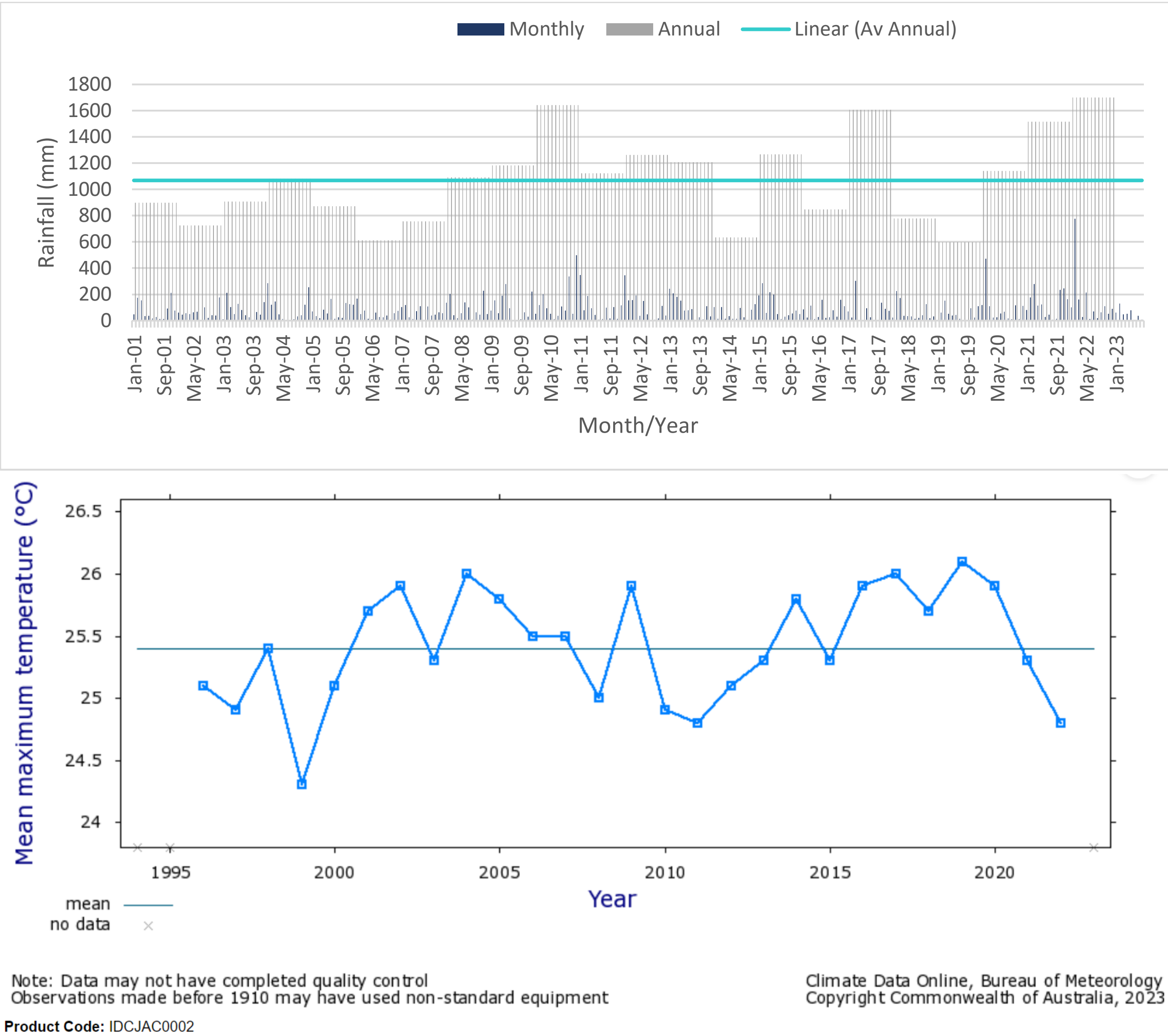


Figure 2.2 Monthly and annual rainfall from 2001 to 2023 (top) and annual mean maximum air temperature (bottom) at Brisbane Airport (Source: BoM station: 040842)

2.2 Survey Vessel and Positioning

All sampling was carried out using the BMT research vessel ‘Resolution II.’ Location and navigation to sites was undertaken using a Garmin GPS.

2.3 Monitoring Locations, Sites and Approach

Monitoring locations for this survey were:

- Test and control locations as defined when the SMP was developed in 2002 (WBM Oceanics Australia 2002), namely Fisherman Islands (putative impact/test), Manly (control), Cleveland (control); and
- An addition control location was included in 2020, 2021, 2022 and 2023 (Deception Bay) to better define ‘background’ conditions in western Moreton Bay, north of the Brisbane River.

Since its development in 2002 the SMP 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.

The term ‘sites’ refers to individual transects at each location.

Ground-truthing

Field sampling was conducted using a systematic grid style sampling approach. 500 m survey grids were developed at each study area and are shown in in Figure 2.3 (Fisherman Islands), Figure 2.4 (Manly), Figure 2.5 (Cleveland) and Figure 2.6 (Deception Bay).

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.

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 2.3).

It should be noted that two intertidal sites in the Cleveland study area were unable to be sampled in 2023 due to tidal conditions being too low for the research vessel. These two sites were C_G2 and C_F2. Notes have been included on the relevant maps (Figure 2.2 and Figure 3.3).

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, 2018, 2019, 2020, 2021 and 2022.

Two depth profile transects occur at each survey location and run approximately perpendicular to the shoreline (Figure 2.3 to Figure 2.6). 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

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 2.1). Assemblages correspond with percent composition that each seagrass contributes to the meadow. Seagrass meadow landscape category (Table 2.2) is a method established by James Cook University (see Carter et al. 2015) for long-term monitoring of seagrass meadows over a large area. Nomenclature from Carter et. al. (2015) has been adopted, however in many instances’ seagrass patches have been mapped at a scale of metres based on the field validation and high-resolution aerial imagery. Therefore, for the present survey some areas of “patchy” cover have been mapped as smaller isolated or aggregated patches with dense or continuous cover, as opposed to broader meadows with aggregated or isolated patches within the meadow boundaries. A chi-square test of independence will be performed to examine the relation between seagrass detections at each location.

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%

Table 2.2 Seagrass meadow categories (Carter *et. al.* 2015)

Meadow landscape category	Description
Isolated seagrass patches	The majority of area within the meadows consisted of unvegetated sediment interspersed with isolated patches of seagrass
Aggregated seagrass patches	Meadows are comprised of numerous seagrass patches but still feature substantial gaps of unvegetated sediment within the meadow boundaries
Continuous seagrass cover	The majority of area within the meadows comprised of continuous seagrass cover interspersed with few gaps of unvegetated sediment

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 3.4. In addition, groupings of overall seagrass cover were used to provide context to the broad community categories described in Table 2.3.

Table 2.3 Broad seagrass density categories

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

Algae

Algae relative abundance was estimated for the following groups: (i) filamentous algae including epiphytic and turfing algae; and (ii) other macroalgae (non-filamentous). Abundant macroalgae species were documented.

2.5 Seagrass Meadow Extent Mapping

Mapping The extent of seagrass meadows was mapped adjacent to Fisherman Islands using a combination of remote sensing (aerial imagery) and field observations.

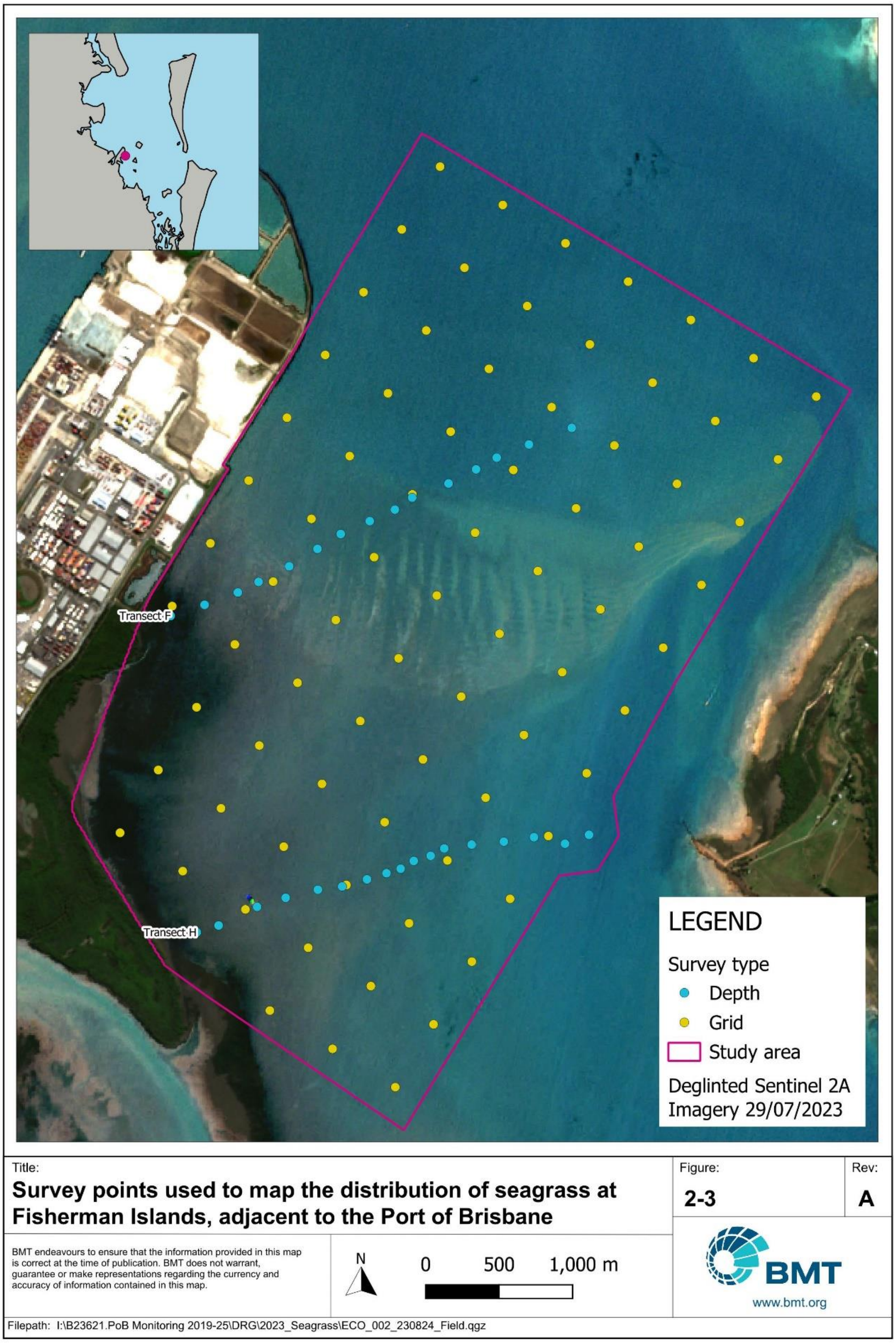


Figure 2.3 Survey points used to map the distribution of seagrass at Fisherman Islands; adjacent to the Port of Brisbane

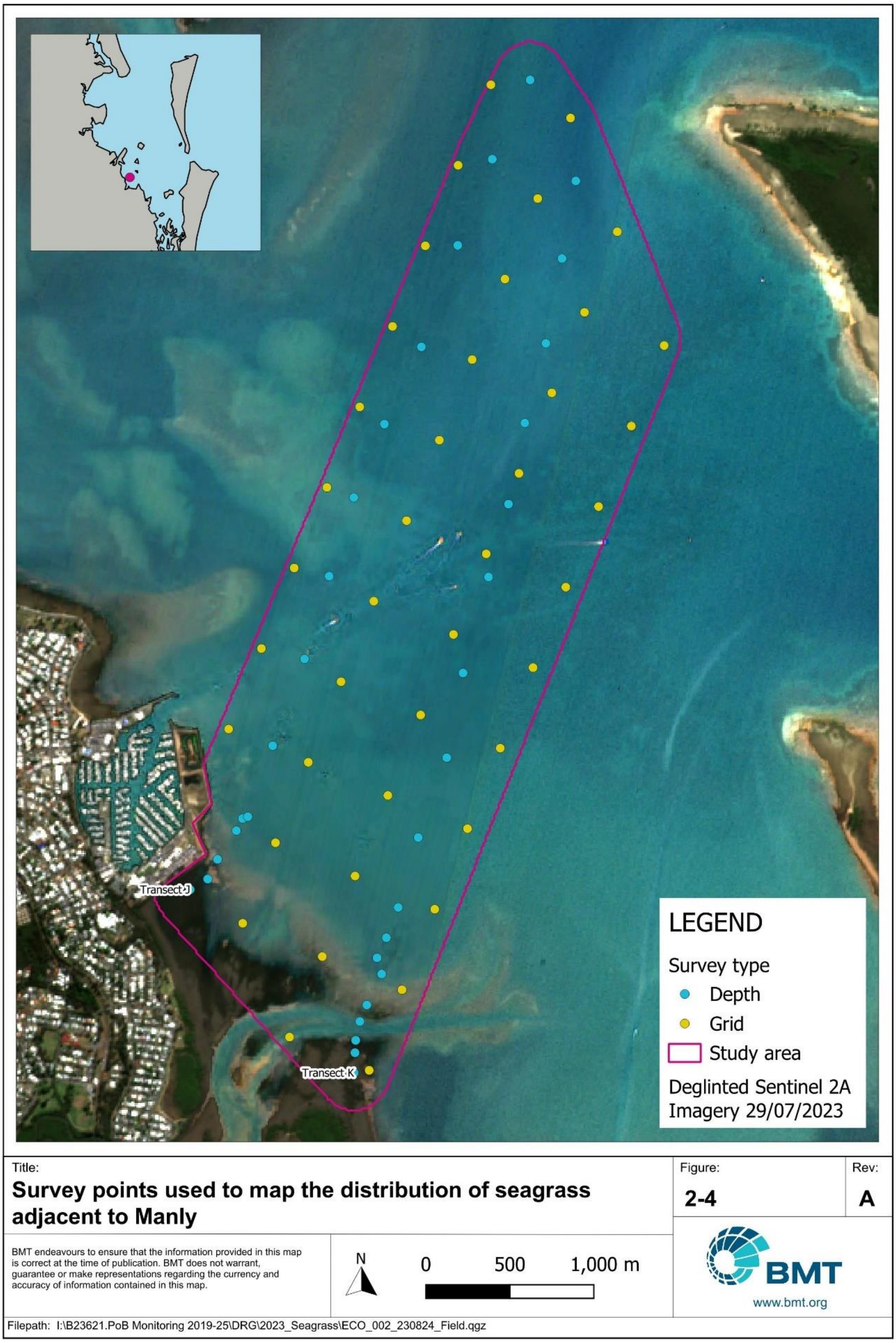


Figure 2.4 Survey points used to map the distribution of seagrass adjacent to Manly (control sites)

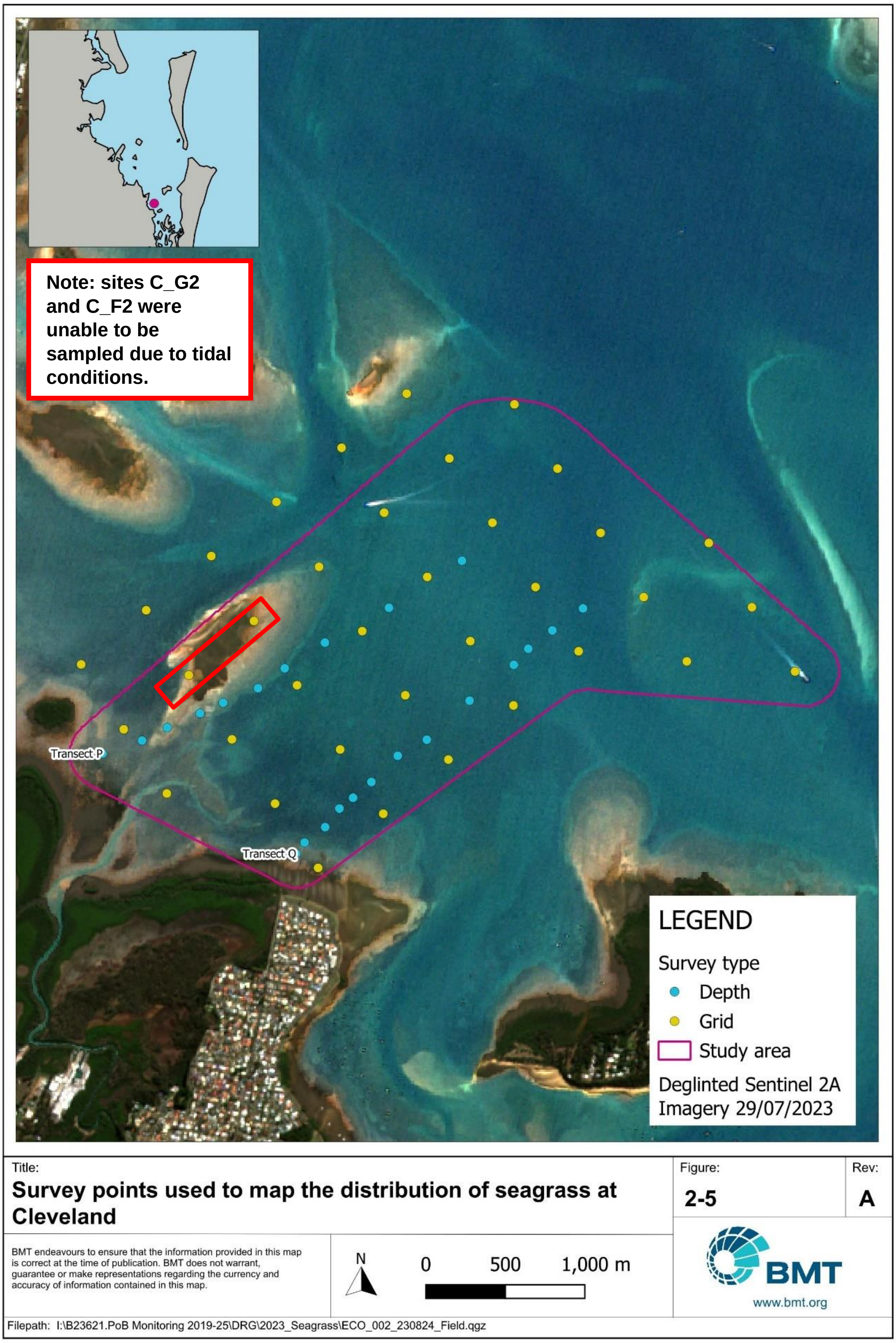


Figure 2.5 Survey points used to map the distribution of seagrass at Cleveland (control sites)

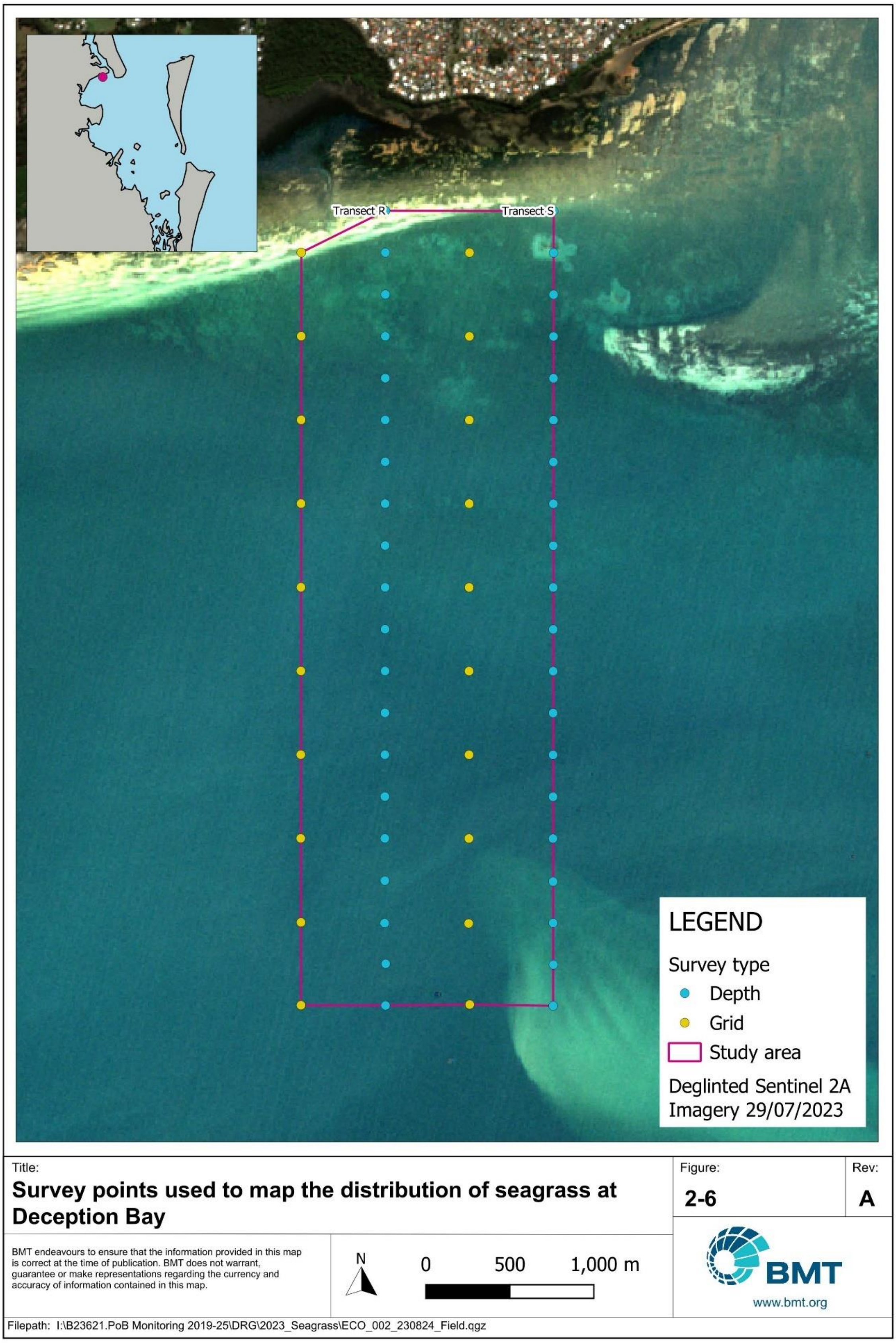


Figure 2.6 Survey points used to map the distribution of seagrass at Deception Bay (control sites).

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 2023 survey: *Zostera muelleri (subsp. capricorni), Halophila ovalis, Halophila spinulosa, Halophila decipiens and Halodule uninervis. Cymodocea serrulata* was recorded in the 2021 survey but not observed in 2023.

Maps showing the spatial distribution of each seagrass species in 2023 survey are shown in Figure 3.1 to Figure 3.4 The general pattern of assemblage structure across the depth zones at Fisherman Islands was as follows (Figure 3.5):

- *Zostera muelleri* numerically dominated intertidal and subtidal waters*;*
- *Halophila spinulosa* was numerically dominant or co-dominant in the intertidal - subtidal transitional zone, with small patches of *H. ovalis* and *H. decipiens* also present in this transitional zone;
- Subtidal areas were numerically co-dominated by sparse *H. ovalis*/*H. decipiens* and *Zostera muelleri*;
- Increased species mixing occurred in the subtidal areas in 2023.

The following describes trends in species distribution and cover.

Species Distribution

The findings from the 2023 survey showed an increase in seagrass at all sites in comparison to the 2022 survey, as follows:

- Seagrass was recorded at 62% of the Fisherman Island sites (*n* = 109), 84% of Manly sites (*n* = 75), 79% of Cleveland sites (*n* = 57) and 54% of Deception Bay sites (*n* = 60). The frequency of seagrass detections in 2022 was 58%, 60%, 51% and 43% of the sites at Fisherman Islands, Manly, Cleveland and Deception Bay respectively. A chi-square test of independence was performed to examine the relation between seagrass detections at each location (Fisherman Islands, Manly, Cleveland, Deception Bay) and year (2022, 2023). There was no significant association between time and locations ($_{X}{}^{2}$ (df = 3, N = 8) = 2.312, p = 0.510), indicating temporal trends were consistent over the survey area (i.e. between control sites and Fisherman Islands).
- *Zostera muelleri* dominated meadows were mainly located within the intertidal zone, extending from above LAT at the landward edge into shallow subtidal areas (-3.6 m LAT). Intertidal meadows were compromised of mixed meadows of all four present species. Mixed meadows of *Halophila* were more common in subtidal areas, however, *Zostera muelleri* meadows had extended further into the subtidal area in the Fisherman Island site.
- *Halodule spinulosa* was the most frequently recorded species in 2023 across all sites with the exception of Deception Bay, with the number of detects increasing amongst all sampled sites compared to 2022 (Table 3.1). *Zostera muelleri* was the most frequently recorded species at the Fisherman Island site.
- *Halodule uninervis* was the least frequently detected species at all sites except Fisherman Islands and was recorded to be lower in all 2023 sites compared the previous year.

- *Halophila* frequency has been variable between years with an increase in *H. decipiens* at Fisherman Island, Cleveland and Deception Bay, but relatively stable at Manly. The increase in *H. decipiens* in Deception Bay is significant compared with past recorded values since 2020. *H. ovalis* showed no consistent trends.
- Macroalgae detections generally increased at all sites. Macroalgae was detected at 205 sites in 2023, compared with 11 in 2022.

Table 3.1 Seagrass presence at study sites (%)

Site	Species	No. of sites (%) 2019	No. of sites (%) 2020	No. of sites (%) 2021	No. of sites (%) 2022	No. of sites (%) 2023	Trend 2022-23
Fisherman Islands	*H. decipiens*	24	13	6	6	15	↑
	H. ovalis	36	27	28	18	23	↑
	H. spinulosa	53	42	39	20	31	↑↑
	H. uninervis	20	0	7	18	3	↓↓
	Z. muelleri	40	46	38	38	47	↑
	C. serrulata	0	0	1	0	0	↔
Manly	*H. decipiens*	14	6	24	0	0	↔
	H. ovalis	34	11	23	11	11	↔
	H. spinulosa	51	49	56	39	61	↑↑
	Z. muelleri	17	16	20	18	21	↑
Cleveland	*H. decipiens*	21	21	17	3	37	↑↑
	H. ovalis	23	-	2	10	12	↑
	H. spinulosa	29	30	51	34	39	↑
	Z. muelleri	14	9	12	19	16	↓
	H. uninervis	-	-	-	-	4	
Deception Bay	*H. decipiens*	Not sampled	0	8	0	22	↑↑
	H. ovalis	Not sampled	32	18	18	27	↑
	H. spinulosa	Not sampled	3	18	2	5	↑
	Z. muelleri	Not sampled	25	18	29	40	↑↑
	H. uninervis	Not sampled	10	30	14	0	↓↓

single arrow = difference ≤10% cover; two arrows = difference >10% cover

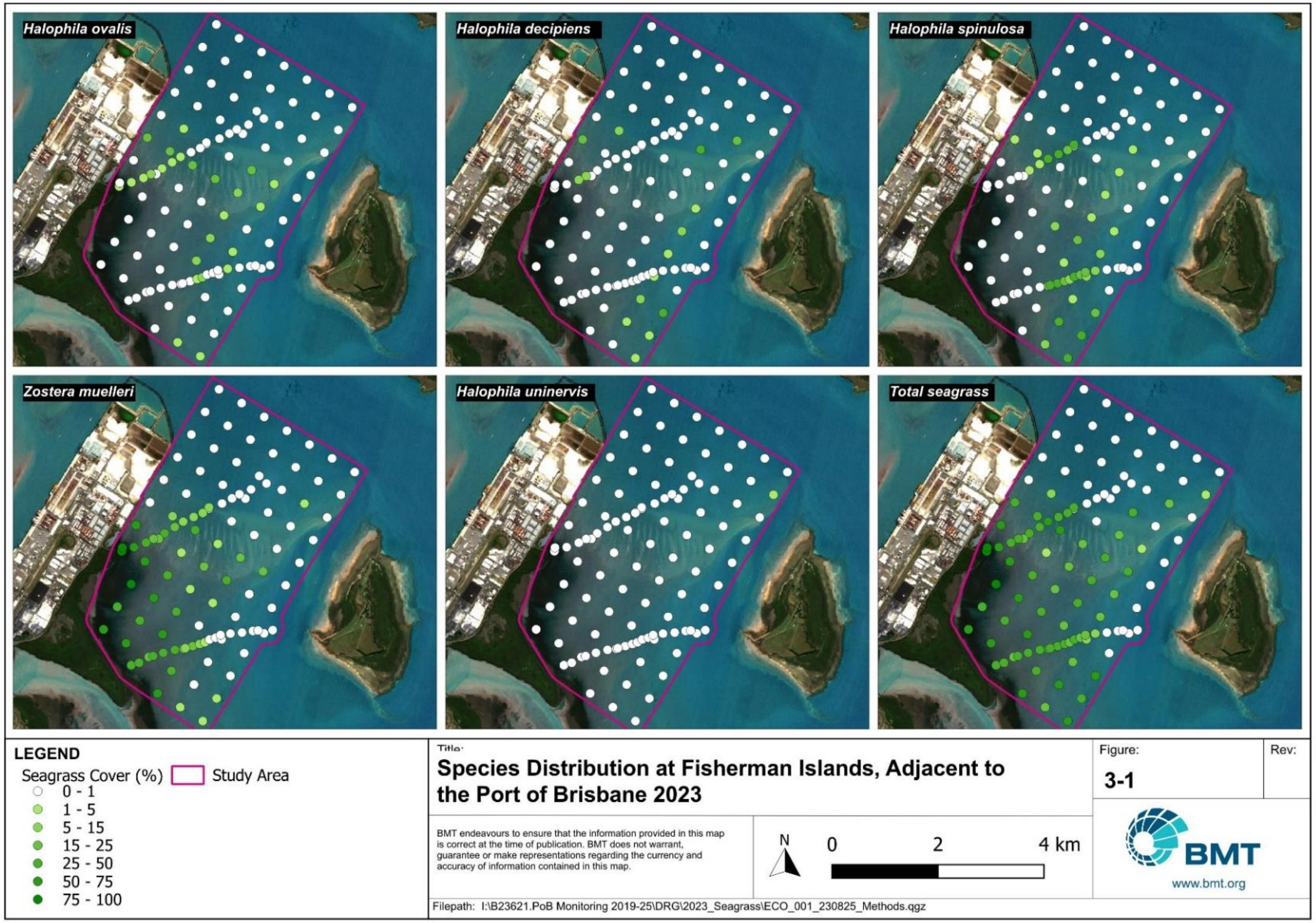


Figure 3.1 Species Distributions at Fisherman Islands, adjacent to the Port of Brisbane in 2023

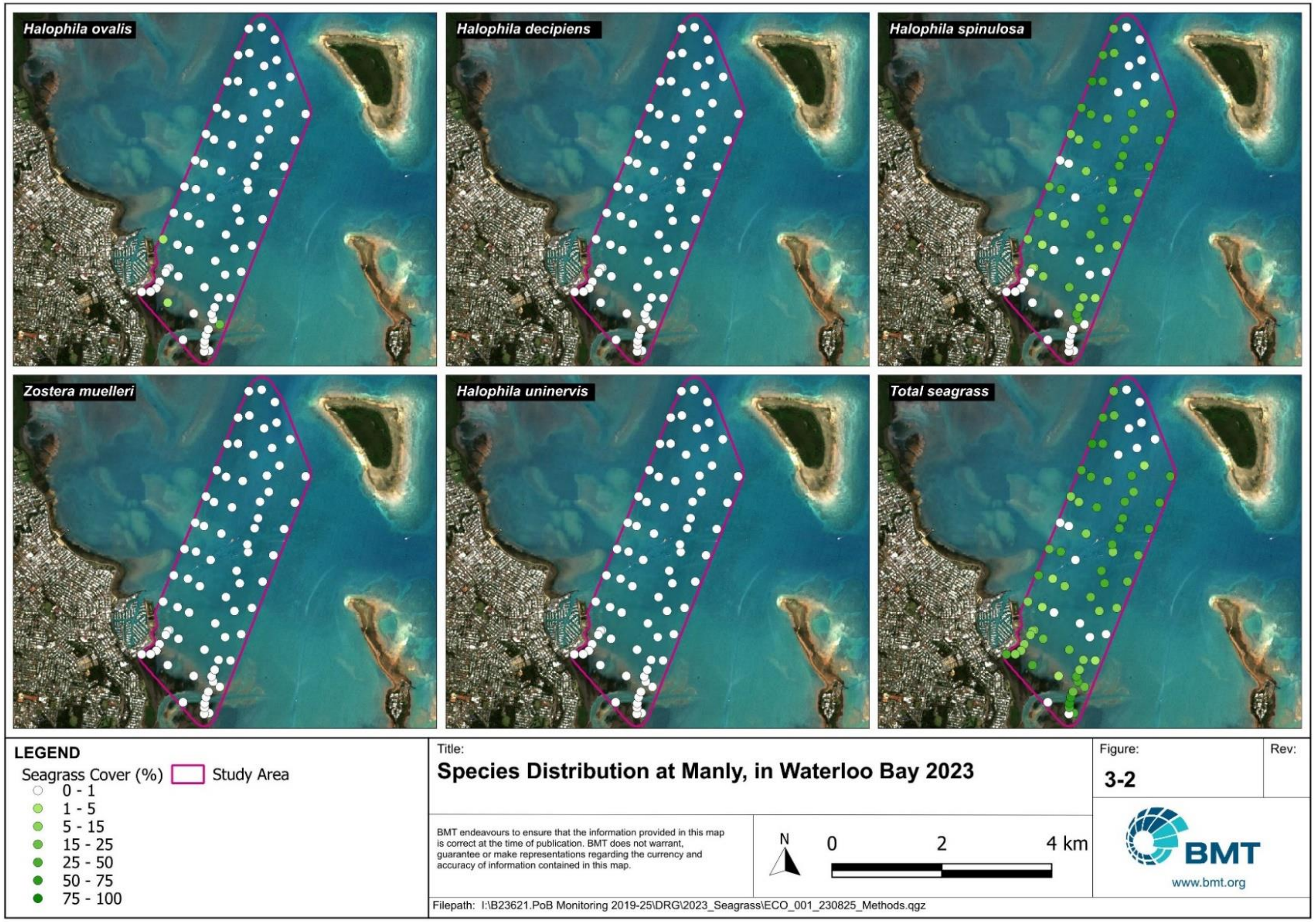


Figure 3.2 Species Distributions at Manly, in Waterloo Bay 2023

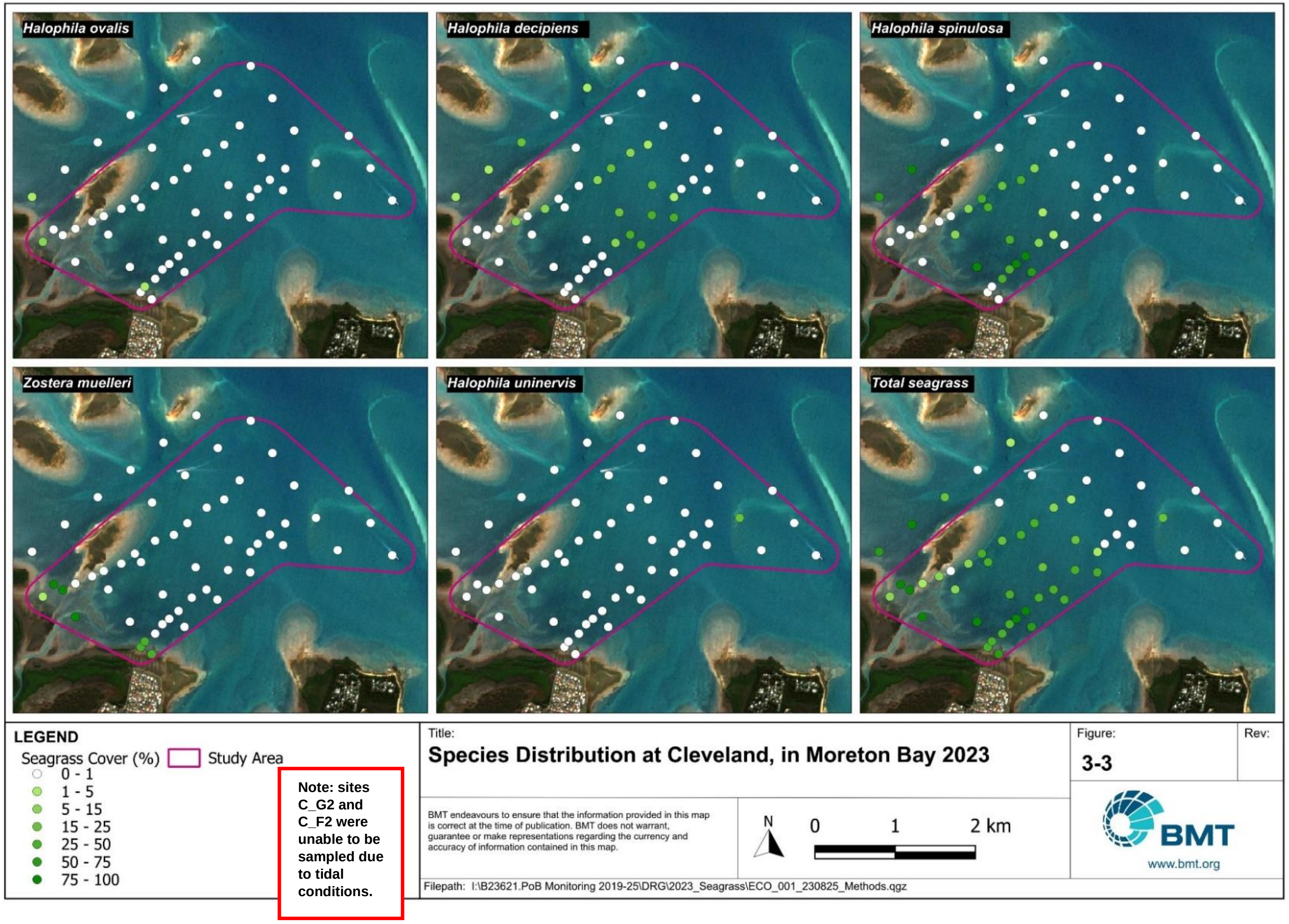


Figure 3.3 Species Distributions at Cleveland, in Moreton Bay 2023

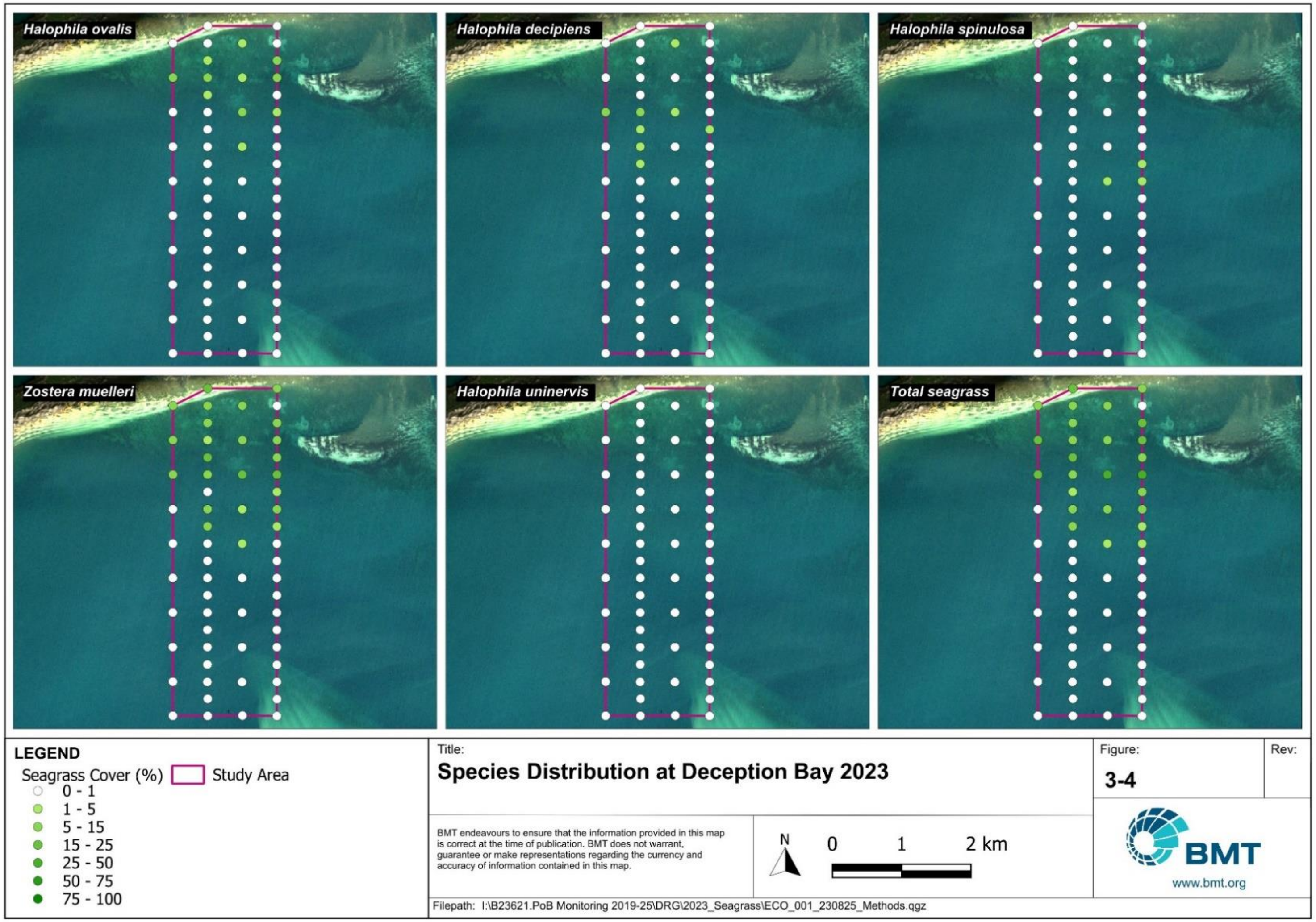


Figure 3.4 Species Distributions at Deception Bay 2023

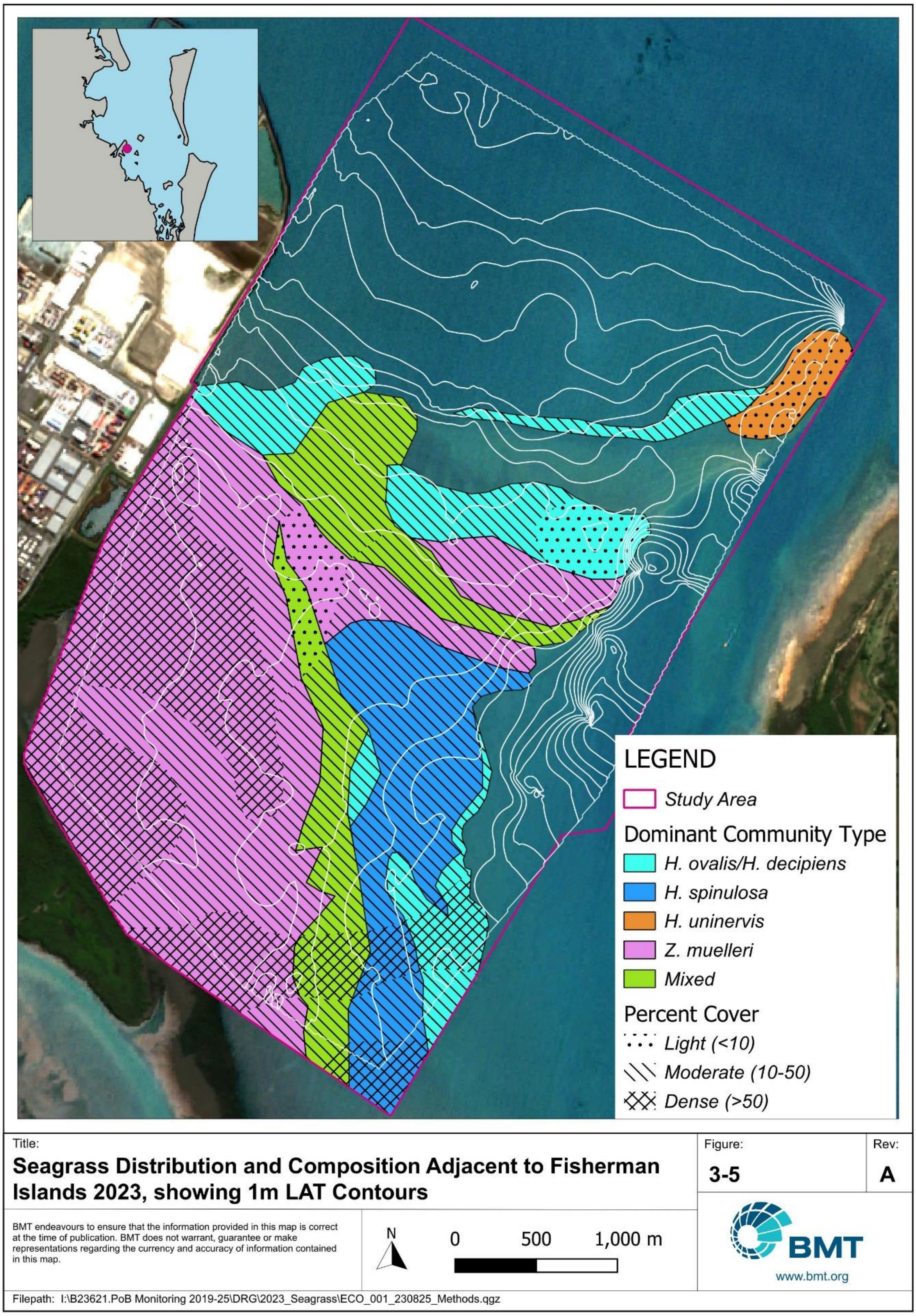


Figure 3.5 Seagrass distribution and community structure adjacent to Fisherman Island, 2023

Seagrass Cover

Figure 3.6 shows the change in total seagrass cover between 2022 and 2023 at Fisherman Islands. Most sites had an increase in seagrass cover, with the largest changes in seagrass cover occurring in areas supporting dense seagrass meadows. There were some substantial changes to the northeastern seaward extent of Fisherman Islands seagrass meadows. The magnitude of change in total seagrass cover was significant due to the sparse cover in 2022. There is an observable increase in the seaward extent of the *Zostera muelleri* species, as well as significant increases in seagrass density amongst all species.

3.2 Seagrass Depth Range (SDR) and Assemblage Structure

Table 3.2 presents the maximum recorded depths of seagrass species (seagrass depth range – SDR) on permanent 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 shown. 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.

Seagrass assemblage composition and percent cover for the depth transects is shown in Figure 3.7 for Fisherman Islands and Manly, and Figure 3.8 for Cleveland and Deception Bay. Most sites have a percent cover between the historical minimum and maximum.

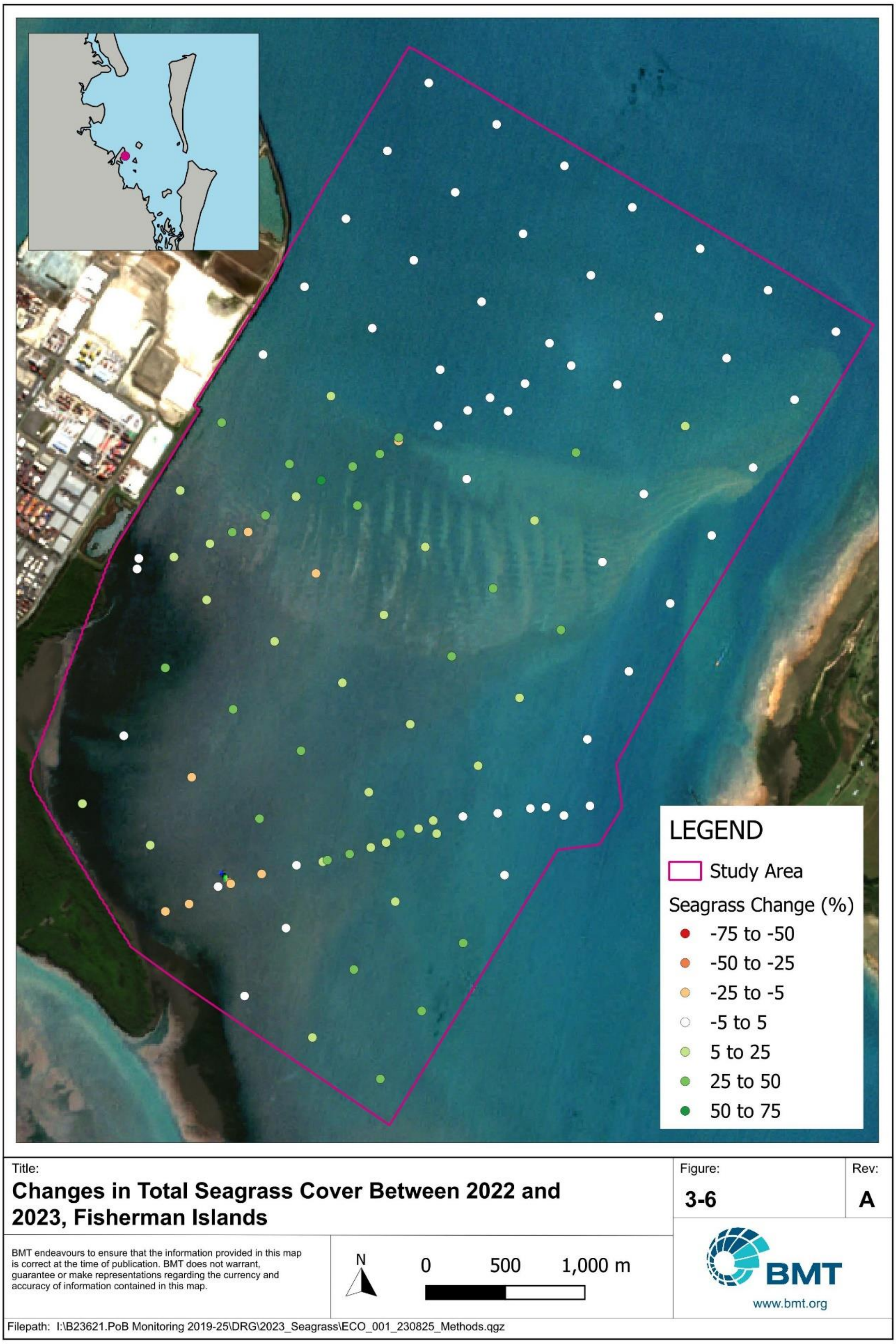


Figure 3.6 Changes in total seagrass cover between 2020 and 2021 Fisherman Islands

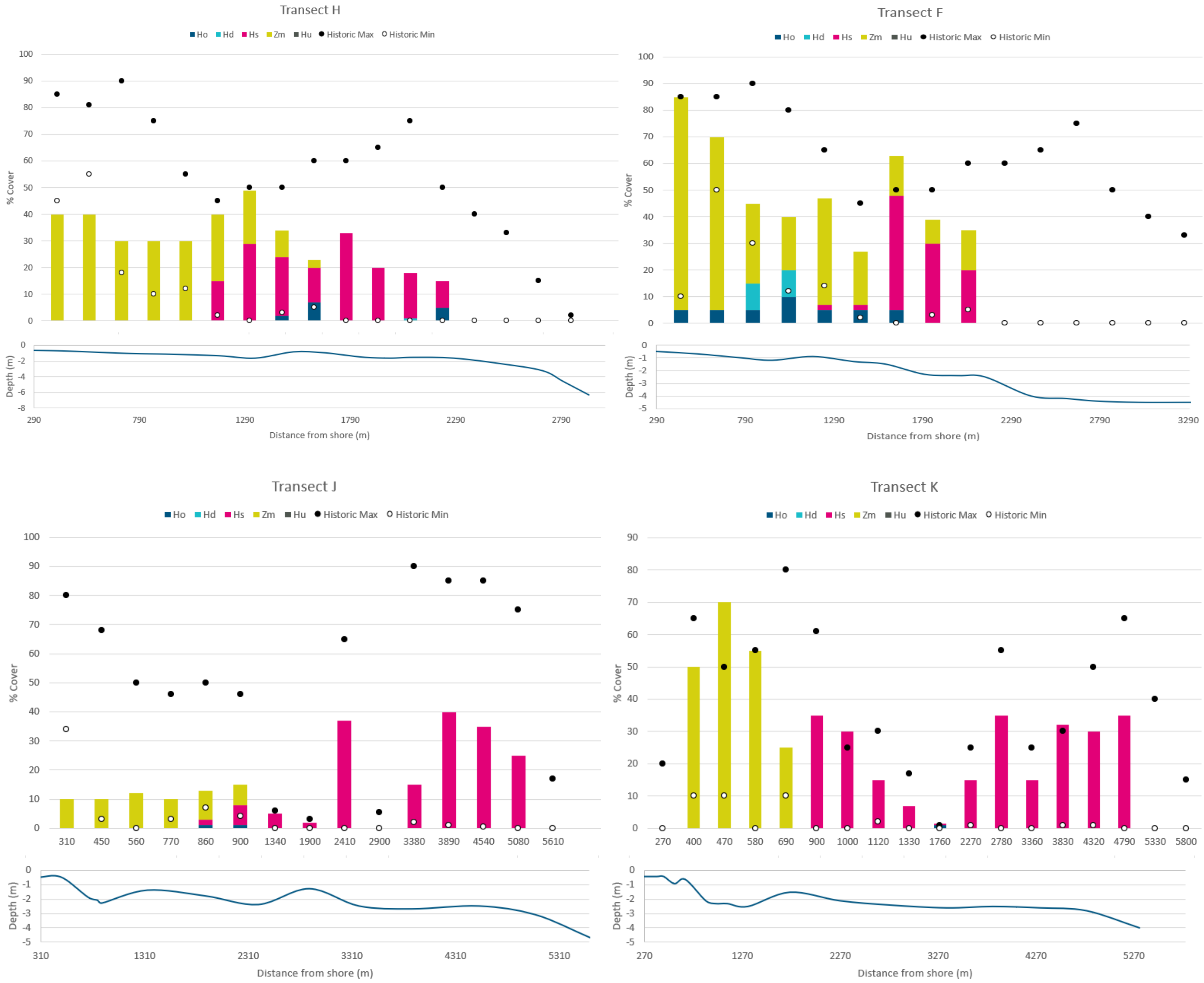


Figure 3.7 Percent cover of seagrass distribution across depth transects at Fisherman Islands (transects H & F) and Manly (transects J & K). Ho = *Halophila ovalis,* Hd = *Halophila decipiens,* Hs = *Halophila spinulosa*, Zm = *Zostera muelleri*, Hu = *Halodule uninervis*.

Figure 3.8 Percent cover distribution across depth transects at Cleveland (P & Q) and Deception Bay (R & S).). Ho = *Halophila ovalis,* Hd = *Halophila decipiens,* Hs = *Halophila spinulosa*, Zm = *Zostera muelleri*, Hu = *Halodule uninervis*.

Spatial Patterns in 2023

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

- *Zostera muelleri* was observed at all locations, with maximum depths at Fisherman Islands, Cleveland, Manly and Deception Bay of –2.9 m, -1.6 m, -2.3 m and -2.9 m (AHD) respectfully. At Fisherman Islands, Manly, Cleveland and Deception Bay, average cover was highest within intertidal meadows (above LAT) than subtidal meadows (below LAT). The greatest depth recorded for *Z. muelleri* was -2.9 m AHD at Fisherman Islands and Deception Bay. *Zostera muelleri* formed mono-specific meadows or mixed assemblages with *Halophila* species.

- *Halodule uninervis* was recorded at a small number of Fisherman Islands sites and at Deception Bay. Previously it has also been observed at both Cleveland and Fisherman Islands predominately between -1 m and -2.5 m LAT in mixed communities at low cover.

- *Halophila spinulosa* was observed at moderate-to-dense densities at all locations with a maximum depth of -3.6 m, -2.9 m, -3.6 m and -3.2 m AHD at Fisherman Islands, Cleveland, Manly and Deception Bay respectively. This species was present at a variety of depths and community compositions, found predominately between -1.5 m and -4 m AHD.

- *Halophila ovalis* was present at all sites in a range of depths and formed predominately mixed communities with *H. decipiens, Z. muelleri* and *H. spinulosa*. The depths that had *H. ovalis* present were: -0.5 m to -3.2 m, -0.6 m to -2.3 m, -0.2 m to -1.6 m, -1.1 m to -3.2 m AHD at Fisherman Islands, Manly, Cleveland and Deception Bay respectively. The highest densities were generally found between -0.5 m and -2.5 m AHD.

- *Halophila decipiens* was observed at all locations except for Manly, with the maximum depths at Fisherman Islands, Cleveland and Deception Bay being -3.6 m, -3.8 m and -4.5 m AHD respectively. *H. decipiens* generally occurred between -1 m and -4 m AHD. The coverage was predominately moderate to dense and was generally either in monospecific stands or mixed communities with *H. spinulosa* and *Z. muelleri*.

Temporal Patterns

Table 3.2 shows SDR values for each species over time on permanent transects. *Zostera muelleri* SDR, a key indicator of long-term patterns in water quality, showed complex spatial and temporal patterns. Table 3.2 shows that:

- *Zostera muelleri* – Deception Bay had the highest SDR values.

- *Halophila ovalis/decipiens* – Deception Bay had the highest SDR values. The other four sites had fairly consistent SDR values, however no *H. decipiens* were recorded along the Manly transects.

- *Halophila spinulosa* – Manly and Deception Bay tended to have the highest SDR values.

- *Halophila uninervis* – Deception Bay Transect S was the only transect which recorded SDR values for *H. uninervis*.

Figure 3.9 shows the *Zostera muelleri* SDR for Transects F and H at Fisherman Islands and the average (±) for control sites. Figure 3.9 shows that:

- The SDR on Transect H has been variable through time with 2010, 2014-2017 and 2021 having the highest values. Between 2021 to 2022 there was a decrease in SDR across all sites, however, between 2022 to 2023 there was an increase in SDR across all sites.

- The SDR on Transect F was variable between 2006 and 2013, remaining relatively stable until 2018. Higher SDR values were observed between 2019 and 2021 before decreasing in 2022. SDR increased significantly in 2023, reaching values similar to 2010 and 2021.

Pearson Product-Moment correlation analysis was undertaken to assess potential associations between antecedent 12-month rainfall and periods of potential low seagrass condition (SDR non-detects/lowest Zostera SDR). There was no significant correlation between the lowest *Zostera* SDR and antecedent rainfall ($r = 0.49$, $p > 0.05$) however, there was a significant correlation between the frequency of non-detects and antecedent rainfall ($r = 0.88$, $p < 0.001$).

SDR Index and Water Quality Objective

The *Z. muelleri* SDR water quality objective (WQO) for Waterloo Bay (Figure 3.9) 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:

- Fisherman Islands Transect H (2010, 2014, 2016-18, 2020 and 2021) and F (2006, 2010, 2019-21, 2023);

- Manly Transect J (2006, 2010, 2016, 2018, 2019-21, 2023) and K (2006, 2010, 2014, 2016, 2017, 2019, 2020);

- Cleveland Transect P (2019); and

- Deception Bay Transect R (2020-23) and Transect S (2020-23).

Transect H at Fisherman Islands failed to meet the WQO, however, it showed improvement from the previous year (2022). Transect F at Fisherman Islands met the WQO following significant improvement from 2022. Transect F has an equal number of years where the WQO has and has not been met.

[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 3.2 Comparison of SDRs (maximum recorded depth m AHD) of seagrass on permanent transects at each location from 2006 to 2021

Species*	Location	Transect	2006	2010	2013	2014	2016	2017	2018	2019	2020	2021	2022	**2023**	Mean	CoV
Zm	Fisherman Island	F	-2	-2.5	-1.8	-1.7	-1.6	-1.7	-1.4	-2.1	-2	-2.2	-1.2	-2.4	-1.9	-18
		H	-1.3	-2.3	-1.5	-2.4	-2.4	-2.5	-2.2	-1.7	-2.3	-2.7	-1.5	-1.6	-2.0	-26
	Manly	J	-2.2	-2.3	-1.6	-1.5	-2.1	-1.6	-2.1	-1.9	-2.1	-2.4	-1.7	-2.3	-2.0	-16
		K	-2.1	-2.2	-0.4	-2.1	-2.2	-2	-0.7	-3.3	-2.1	-0.7	-0.3	-0.9	-1.6	-60
	Cleveland	P	-1.3	-0.8	-0.6	-0.7	-0.7	-0.9	-1.7	-1.9	-0.5	-1.1	-0.7	-0.2	-0.9	-54
		Q	-0.6	-1.5	-1.8	-1.4	-1	-1.4	-1.2	-1.8	-1.2	-1.7	-1.2	-1.6	-1.4	-26
	Deception Bay	R	-	-	-	-	-	-	-	-	-3.8	-2.8	-2.5	-2.8	-3.0	-19
		S	-	-	-	-	-	-	-	-	-3.3	-3.3	-3.0	-2.8	-3.1	-8
Ho	Fisherman Island	F	-3.8	-5.7	-2.2	-2	-1.8	-4.7	-1.6	-5.1	-1.9	-4.2	-0.6	-1.5	-2.9	-58
		H	-2.6	-4.6	-2.5	-2.4	-2.4	-5.5	-2.2	-4.4	-1.2	-3.2	-1.4	-1.6	-2.8	-47
	Manly	J	-2.2	-4.9	-4.5	-2	-2.1	-2.9	-2.1	-3.3	-2.1	-2.8	-2.4	-2.3	-2.8	-35
		K	-0.4	-8.8	-5	-2.1	-2.2	-2.4	-1.8	-7.9	-2.5	-2.9	-2.0	-1.5	-3.3	-79
	Cleveland	P	-5.9	-6.4	-6.2	-4.8	-3.6	-3.3	-2.1	-3.6	Absent	Absent	-0.67	-1.5	-3.8	-53
		Q	-5.7	-6.2	-5.7	-2.7	-2.5	-5	-2.4	-2.8	-2.5	Absent	-1.2	-1.1	-3.4	-54
	Deception Bay	R	-	-	-	-	-	-	-	-	-4.2	-0.8	-0.4	-2.8	-2.0	-88
		S	-	-	-	-	-	-	-	-	-3.8	-4.0	-1.1	-2.9	-2.9	-45
Hd	Fisherman Island	F	-3.8	-5.7	Absent	-4	-4.1	-4.3	-4.1	-4.2	-4	-4.6	Absent	-1.2	-4.0	-28
		H	Absent	Absent	-2.9	-5.1	-5	Absent	-7.2	Absent	-5.4	-3.7	-3.2	-1.5	-4.3	-42
	Manly	J	-2.2	-4.9	-4.5	-4.4	-3.5	-4.8	-4.5	Absent	Absent	-3.6	Absent	Absent	-4.1	-22
		K	-0.4	-8.8	-5	-3.7	-4	-5.3	-7.7	-4.1	-5	-2.7	Absent	Absent	-4.7	-51
	Cleveland	P	-5.9	-6.4	-5.1	-6.4	Absent	Absent	-4.4	Absent	-3.4	-4.0	Absent	-2.7	-4.8	-29
		Q	-5.7	-6.2	-4.6	-4.6	-5.9	Absent	-5.6	-5.8	-5.7	-5.1	Absent	-2.9	-5.2	-19
	Deception Bay	R	-	-	-	-	-	-	-	-	Absent	Absent	Absent	-3.4	-3.4	-
		S	-	-	-	-	-	-	-	-	Absent	-4.6	Absent	-3.3	-4.0	-23
Hs	Fisherman Island	F	-3.8	-4.3	-2.2	-1.6	-1.8	-3.8	-2.0	-5.1	-2	-2.5	-1.8	-2.4	-2.8	-42
		H	-2.5	-2.3	-2.5	-2.4	-3	-2.5	-3.9	-4.7	-2.8	-3.2	-2.3	-1.6	-2.8	-29
	Manly	J	-2.6	-4	-3.4	-3.4	-4.1	-3.4	-4.5	-4.8	-2.1	-4.3	-3.5	-3.1	-3.6	-22
		K	Absent	-4.4	-4	-3.9	-2.2	-2.3	-3.9	-8	-3.8	-5.5	-3.7	-2.8	-4.0	-40
	Cleveland	P	Absent	-3.4	-3.5	-4.8	Absent	-0.9	Absent	-3.1	-3.4	-4.0	-2.8	-2.4	-3.2	-35

Species*	Location	Transect	2006	2010	2013	2014	2016	2017	2018	2019	2020	2021	2022	**2023**	Mean	CoV
		Q	-3.2	Absent	-3.7	-4	-2.9	-3.3	-2.6	-3.1	-3.5	-3.8	-2.7	-1.7	-3.1	-21
	Deception Bay	R	-	-	-	-	-	-	-	-	Absent	Absent	Absent	-3.2	-3.2	-
		S	-	-	-	-	-	-	-	-	Absent	-4.0	Absent	-2.9	-3.5	-23
Hu	Fisherman Island	F	Absent	Absent	Absent	Absent	Absent	Absent	-2.0	-1.6	Absent	-2.5	-2.0	Absent	-2.0	-19
		H	Absent	Absent	Absent	Absent	Absent	Absent	Absent	-2.8	Absent	Absent	-2.0	Absent	-2.4	-25
	Manly	J	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	-	-
		K	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	-	-
	Cleveland	P	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	-	-
		Q	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	-	-
	Deception Bay	R	-	-	-	-	-	-	-	-	-3.2	-4.5	-3.1	Absent	-3.6	-22
		S	-	-	-	-	-	-	-	-	-3.6	-4.0	-3.6	-1.1	-3.1	-43
Rainfall (12months before the survey)			824	865	1318	549	689.5	952.2	848.8	572.2	1053	1138.6	2009.2	744		

SDR relative to historical maximum:

Max	99-80% max	79-50% max	49-20% max	<20% max	Absent

Trend since 2019: ↑ improvement, ↔ stable (within 0.1 m of 2019), ↓ 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 species.*

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)

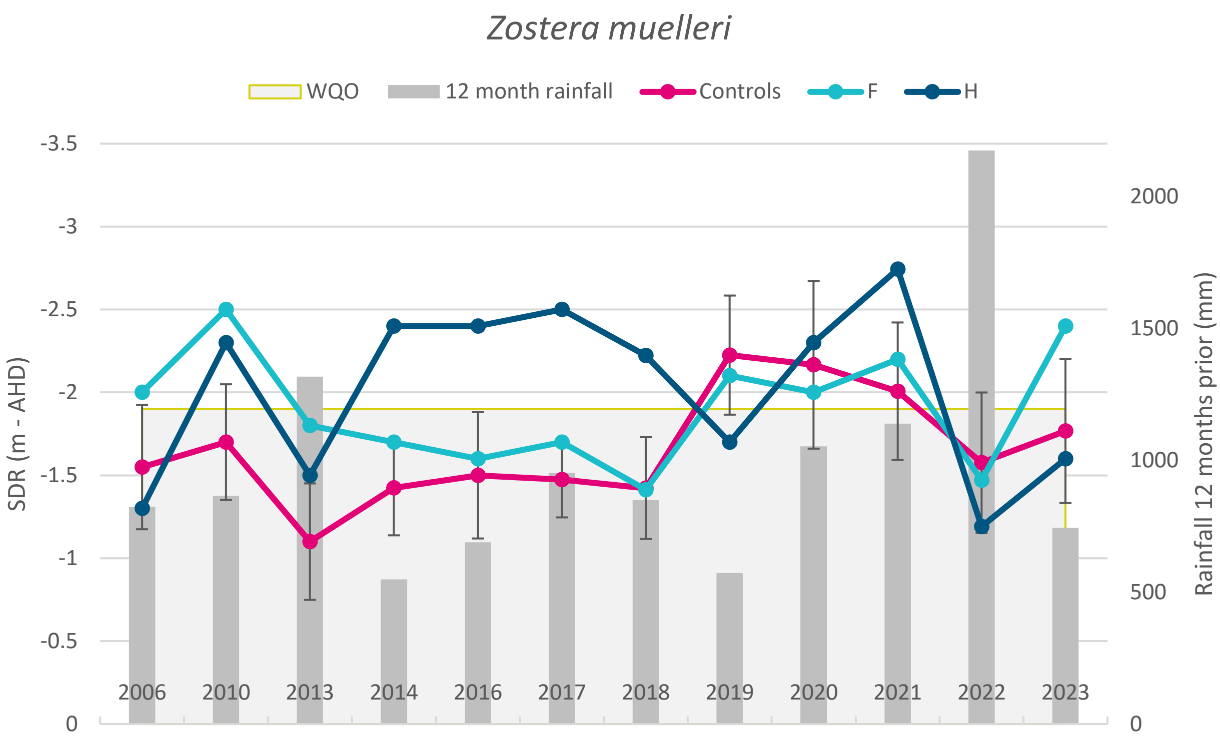


Figure 3.9 *Zostera muelleri* seagrass depth range (SDR) for Transect F and H at Fisherman Islands and the average (±SE) for control sites. Rainfall in the 12 months leading to the survey is also shown (BoM station number 040842 – Brisbane Aero)

4 Discussion

4.1 Overview

The SMP demonstrates that seagrass meadows at Fisherman Islands and western Moreton Bay had the following ecological characteristics:

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 (Kilminster *et al*. 2015). This is a necessary requirement for living in dynamic environments as occurs in Moreton Bay.

3. *Zostera muelleri* is typically restricted to shallow waters (<2 m below LAT), forming dense meadows that are comparatively stable over time in subtidal waters and areas.

4. Moderate density *Halophila* species meadows typically extend to depths down to -4 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.

6. The 2023 results indicate that seagrass meadows had commenced recolonisation (partial recovery) following the 2022 flood.

7. There has been a net long-term expansion in overall seagrass meadow extent at Fisherman Islands since the construction of the FPE (Figure 4.1).

These are described in the following section.

4.2 Species Composition

Eight seagrass species have been reported in 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*.

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. serrulata* and *H. minor* (Kirkman, 1997). *Halophila minor* was detected in the 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). *Cymodocea serrulata*, was recorded at Fisherman Island in the 2021 survey but was not observed in the 2022 or 2023 survey.

4.3 Spatial and Temporal Patterns in Assemblages

Overall, seagrass meadows at Fisherman Islands increased in extent between 2022 and 2023 by 0.6 km^2, from 9.9km^2 to 10.5 km^2 in 2023. This increase was seen predominately in the expansion of the northeasterly seaward edge of the meadow (Figure 4.1).

Figure 4.1 Seagrass meadow extent between 2013-2023

Halophila species

The distribution and cover of *Halophila* species generally increased across all sites in 2023 including the control sites. In most cases, these increases were significant compared to sparse populations observed in 2022. Variability in species distribution and cover is characteristic of *Halophila* species. In 2023, *H. ovalis* extent and percentage cover increased across all sites. These extent increases typically took the form of seaward expansions, with Fisherman Island experiencing a contraction in the landward extent and Cleveland experiencing an expansion along the coastline. *H. decipiens* expanded and increased their percentage cover (predominantly within the subtidal zone) across all sites except Manly, which experienced very little changes in extent or percentage cover from 2022. *H. spinulosa* expanded and increased their percentage cover across all sites in 2023, with the largest increases occurring at Manly and the smaller increases occurring at Deception Bay.

Halophila species are considered colonising species, capable of rapid recovery following disturbance but low physiological resistance, especially to low light conditions (Kilminster *et al*. 2015). The results of the SMP demonstrate that these species are highly dynamic in time and space, colonising deep waters during sustained periods of high-water clarity, and declining following floods and other disturbance events (as demonstrated in 2022) (Longstaff *et al.*1999).

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) (Hearne et al. 2018). Differences in suspended solid concentrations (and associated light availability) can also occur among transects, varying in response to proximity to channels and sand banks.

Halodule uninervis

Changes in distribution of *H. uninervis w*ere very variable across the sites, with Fisherman Islands and the Deception Bay control sites, observing reductions in total extent and percentage cover. While the Cleveland control sits observed an increase in extent and percentage cover since it was not present in 2022. The Manly control sites observed very little change in *H. uninervis* distribution from 2022.

Halodule uninervis, like *H. ovalis*, is an ephemeral, pioneer species that grows rapidly and survives well in unstable or depositional environments (Carruthers *et al.* 2002). This species has adaptations that enable it to grow in the intertidal zone (Waycott *et al.* 2004) and unstable subtidal shoals, as occurs in the study area. As *Halodule* has a similar growth form to *Z. muelleri*, it is possible that this species may be undetected due to misidentified when viewed *in situ* via underwater camera (a sample is generally needed to confirm identification).

Several drivers control *H. uninervis* growth and recruitment, including:

- Seasonality - In tropical environments *H. uninervis* exhibits strong seasonality, with a minimum occurring in August to September (Lanyon *et al.* 2004). Seasonal patterns in *H. uninervis* abundance in Moreton Bay are undefined. Assuming seasonal patterns in the local population are similar to those in tropical environments, the SMP (July-August) would occur around the time of the *H. uninervis* seasonal minima.
- Temperature, light and exposure - *H. uninervis* abundance is sensitive to a range of stressors, such as high temperatures, too much or too little light, variations in rainfall and high wind (Lanyon *et al.* 1994; Collier *et al.* 2016). *Halodule uninervis* was recorded exclusively in subtidal environments in 2019, and therefore not subject to atmospheric exposure and associated stressors (desiccation, high temperatures). *Halodule uninervis* has a higher light requirement than *Halophila* species

(Longstaff and Dennison 1999), and may therefore be sensitive to periods of low light in deeper waters.

Zostera muelleri

Zostera muelleri predominately occurred in intertidal and shallow waters of the study area (waters shallower than 2.5 m AHD). *Zostera 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 was the numerically dominant species. In 2023, an increase in the total extent and percentage cover of *Z. muelleri* was observed at Fisherman Islands and Deception Bay, however Manly experienced a reduction in both the extent and percentage cover. Cleveland observed an increase in percentage cover along the coastal regions but a slight reduction in overall extent.

SDR varied among locations, ranging from -0.4 m to -2.9 m AHD at Fisherman Islands, -0.2 m to -1.6 m AHD at Cleveland, -0.3 m to -2.3 m at Manly and -0.8 m to -2.9 m at Deception Bay. Differences in SDR among locations are likely to reflect differences in the availability of suitable (and stable) habitat and differences in water quality conditions among (and possibly within) locations (see BMT 2021).

SDR along the depth transects varied between years at both Fisherman Islands and the control sites. Maximum *Zostera* depth increased at the following transects between 2022-23: Fisherman Island (H and F), Cleveland (Q only) and Manly (J and K). Both transects at Deception Bay, as well as Transect P at Cleveland observed decreases in *Zostera* SDR from 2022. Increases in *Zostera* SDR were observed for Manly (J and K), Fisherman Island (F only) and Cleveland (Q only). This is contrary to 2021 survey results which noted a decrease in SDR across both transects.

Zostera muelleri depth range is more stable at Fisherman Islands (CoV -18 to -26), Cleveland (CoV -26 to -54) and Deception Bay (CoV –8 to -19) than Manly (CoV -16 to -60). This suggests that Manly is more prone to disturbance and/or habitat heterogeneity compared to the other sites, which is consistent with the 2021 and 2022 surveys.

Significant variability and differenced 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 four sampling locations are influenced to different degrees by river flows and wave-generated sediment resuspension.

Nearshore *Zostera muelleri*

The SMP focusses on quantifying the maximum seagrass depth range as an indicator of long-term water quality changes. The SMP has been incidentally noted that the landward margin of *Z. muelleri* meadows were variable over time. BMT (2020; 2021) observed a retraction in the landward margin of the Fisherman Islands meadow between 2019-21, which was hypothesised to be related to exposure during hot days, and possibly other environmental drivers such as rainfall. However, in 2022, BMT observed a landward expansion of *Z. muelleri* at Fisherman Islands between July 2021 and July 2022.

Inspections of aerial photography suggest that between July 2022 and July 2023, the landward boundary of the Fisherman Islands seagrass meadows were largely consistent (see example images in Figure 4.2). The 2022-23 mean maximum temperate remained cooler than average (similar to the 2021-22 period) (see Figure 2.3), potentially providing better growing conditions and sustaining the landward expansion observed in 2022. Further assessments would be required to test for potential links between long term patterns in seagrass meadow, temperature and solar radiation.

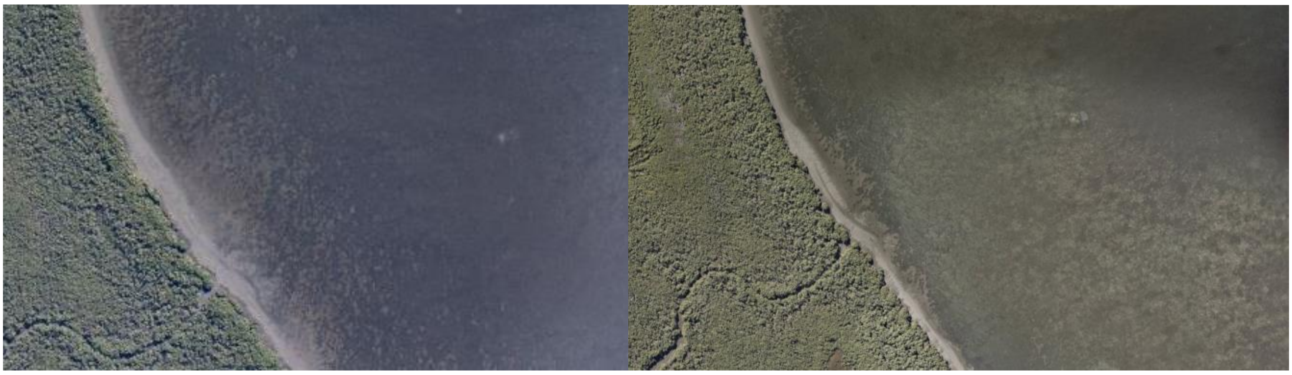


Figure 4.2 Change in Nearshore *Zostera* between July 2022 (left) and July 2023 (right).

Cymodocea serrulata

A small inshore patch of *Cymodocea serrulata* was recorded at Fisherman Islands in 2021 but not in the 2022 or 2023 survey. This is the first record of this species in the SMP. This species typically lives in intertidal and shallow subtidal areas with either sandy or muddy substrates and is often found in mixed communities. This species can rapidly out-compete *Halophila* species as part of a natural succession (Young and Kirkman 1975) and is considered an opportunistic species (Kilminster *et al*. 2015).

This species has been recorded elsewhere in Moreton Bay. Young and Kirkman (1975) recorded a monospecific *C. serrulata* meadow in eastern Moreton Bay in similar habitat conditions to the Fisherman Islands meadow (sandy substrate, approximately 3 m deep). The Atlas of Living Australia has less than 15 records of this species in Moreton Bay with the most recent being at the tip of North Stradbroke Island in 2020.

Drought-Flood Cycles in Seagrass Meadow Extent

A reduction in seagrass meadow extent below 0 m LAT was observed across all locations between 2021 and 2022 (BMT 2022). However, seagrass meadows appear to have started recovering in 2023, with increases in both extent and percentage cover of most seagrass types observed across all sites.

The results of the SMP indicate that seagrass meadows of western Moreton Bay show cyclic changes in extent in response to flood-drought cycles. Reductions in seagrass meadow extent were observed at Fisherman Islands and control sites following major flood events in 2010, 2013 and 2022. The magnitude of change in seagrass meadow extent and seagrass depth range in 2022 was similar to that observed in 2013. Seagrass losses were reported elsewhere in the region between 2021-22, including Hervey Bay (TropWATER 2022).

Flooding is a key driver of seagrass meadow changes. Flooding reduces seagrass through limiting light, increase in silt, organic matter and nutrients. The duration, frequency and intensity of disturbance influences the amount of loss and also the recovery time (Campbell and McKenzie 2001). With small disturbances recovering in weeks to months whereas larger disturbances can take more than two years to recover (Bulthuis 1981; Birch and Birch 1984; Preen *et al*., 1995; Onuf 2000; Blake and Ball 2001).

Lower antecedent rainfall in 2023 and subsequent lack of major disturbance events since the 2022 survey have likely contributed to the increase in seagrass meadows observed across the project sites. If no major disturbance events occur in the next few years seagrass meadow extent are expected to continue to recover within the next several years.

Filamentous Algae and Other Macroalgae

Filamentous algae was the dominant algae group across the survey locations, other macroalgae observed included *Hydroclathrus, Sargassum, Padina, Caulerpa taxifolia, Zonaria* and *Sporochnus*. Filamentous algae can proliferate under nutrient enriched conditions, leading to reductions in available light and loss of seagrass (Han and Liu 2014). Nutrient inputs into Moreton Bay originate from a range of sources including urban land, aquaculture, wastewater treatment and general catchment runoff which are likely to promote filamentous algae productivity.

Epiphytes that grow on seagrass leaves include a range of small algae species. Like seagrass, these epiphytes are primary producers and therefore contribute to the productivity of seagrass meadows. However, if epiphyte cover becomes too high then this can restrict the light available to the seagrass, therefore limiting growth. Epiphyte cover was observed at 7% of Fisherman Island sites, indicating an increase in 4% from the 2022 survey. Like seagrass, different macroalgae species show great variation in distribution and cover over time and space.

The most abundant macroalgae 'seaweed' genera was *Padina.* The average macroalgae cover was highest at Deception Bay (3.5%), followed by Cleveland (3%), Manly (2.7%) and Fisherman Islands (1.7%). There was an overall increase in macroalgae presence and cover between 2022-23. At all sites except for Cleveland, the macroalgae increase was accompanied by increased monthly rainfall in either one or both of the sampling months (July and August). However, the monthly rainfall in Cleveland was lower in both July and August of 2023 (BOM 2023). Macroalgae was present at a variety of depths at across all sites.

Lyngbya is a species of cyanobacteria that occurs in Moreton Bay attached to seagrass beds. Some strains of *Lyngbya* are capable of making toxins and cause skin irritation. A small patch of *Lyngbya* was observed in the 2022 survey, however none was observed in 2023.The most notable temporal change observed over time has been cyclic changes in the green alga *Caulerpa taxifolia. Caulerpa 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. *Caulerpa taxifolia* can replace seagrass during extended dry periods (West and West, 2007). The distribution and density of *C. taxifolia* declined across the study area post-2010 and was only observed in three sites in 2023 (two sites in Cleveland and one in Fisherman Islands).

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.

The transects that met the SDR (WQO) of -1.9 m AHD were Fisherman Island Transect F, Manly Transect J and both Deception Bay transects. Deception Bay has been surveyed four times to date and met the WQO on all occasions, while the other sites remain more variable. Of the other sites, Manly transects most frequently met the SDR WQO, followed by Fisherman Islands and Cleveland. The Fisherman Island transects are very variable in their ability to meet the WQO, most likely due to frequent changes in local hydrodynamic conditions (e.g. mobile sandy bed). The SDR WQO was met more frequently in 2023 than 2022 potentially due to lower antecedent rainfall in 2023. There was no correlation found between long term SDR and antecedent rainfall, however further analysis is required.

4.5 Impacts of the FPE Seawall

The results of the SMP 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) up until 2022 where flood conditions resulted in a major contraction of seagrass extent. Seagrass extents have recovered in 2023, with increases in extent and percentage cover of most seagrass types observed across all sites. This is consistent with the predictions of the FPE IAS (WBM 2000), with the results of the Port of Brisbane SMP suggesting 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 south and east of Fisherman Islands (BMT WBM 2010; 2015; 2016; 2017, 2018, 2019, 2020). 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.

5 Conclusion

The key findings of the 2023 are:

- Overall, the meadow extent of seagrass at Fisherman Islands remained consistent and had slight increases to the previous year in the upper north study area but experienced slight declines along the eastern belt of the study area.
- Seagrass community composition remains relatively consistent with previous surveys, with *Z. muelleri* dominating intertidal habitat and *Halophila* dominating subtidal areas. However, *Z. muelleri* had an increase in seaward extent in Fisherman Islands and occupied some of the subtidal area.
- SDR changes from 2022-23 were variable on all transects. This suggests that the driver/s leading to changes between 2022 and 2023 were operating over broad scales throughout western Moreton Bay and were therefore unrelated to Port activities.
- *Z. muelleri* SDR WQO for Waterloo Bay was used as a benchmark to assess seagrass condition. Four transects met the WQO: Fisherman Island Transect F, Manly Transect J and both Deception Bay transects.
- The results of the Port of Brisbane SMP suggest that there was a long-term expansion in seagrass meadows at Fisherman Islands which has stabilised in recent years, contracted in 2022 due to flooding and then began to recover in 2023 due to lack of major disturbances. 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.

6 References

Abal EG, Dennison WC (1996). Seagrass Depth Range and Water Quality in Southern Moreton Bay, Queensland, Australia. Marine and Freshwater Research. 47, 763-771

Al-bader DA, Shuail DA, Al-hasan R, Suleman P (2014). Intertidal seagrass Halodule univervis: factors controlling its density, biomass and shoot length. Kuwait Journal of Science 41: 171-192.

ANZECC/ARMCANZ (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council/Agriculture and resource Management Council of Australia and New Zealand

Birch WR & Birch M (1984). Succession and pattern of tropical intertidal seagrasses in Cockle Bay, Queensland, Australia, a decade of observations. Aquatic Botany 19, 343e367.

Blake S & Ball D (2001). Victorian marine habitat database seagrass mapping of Westernport. Marine and Freshwater Resources Institute, Report No. 29, 36 pp.

BMT WBM (2006) Port of Brisbane Seagrass Monitoring – July (2006). Report prepared for the Port of Brisbane Corporation.

BMT WBM (2008). Ecological character description for the Moreton Bay Ramsar Site. Report prepared for the Environmental Protection Agency

BMT WBM (2010a). Assessments of marine sediments adjacent to Fisherman Island. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2010b). Port of Brisbane Seagrass Monitoring 2010 Final Report. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2013). Port of Brisbane - Seagrass Monitoring Report 2013. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2014). Port of Brisbane - Seagrass Monitoring Report 2014. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2015). Assessments of marine sediments adjacent to Fisherman Islands - 2015. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2016). Port of Brisbane - Seagrass Monitoring Report 2016. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2017). Port of Brisbane - Seagrass Monitoring Report 2017. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2018). Port of Brisbane - Seagrass Monitoring Report 2018. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2019). Port of Brisbane - Seagrass Monitoring Report 2019. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2020). Port of Brisbane - Seagrass Monitoring Report 2020. Report Prepared for the Port of Brisbane Pty Ltd.

BMT WBM (2021). Port of Brisbane - Seagrass Monitoring Report 2020. Report Prepared for the Port of Brisbane Pty Ltd.

Bulthuis DA (1981). Distribution and summer standing crop of seagrasses and macroalgae in Westernport, Victoria. Proceedings of the Royal Society of Victoria 92, 107e112.

Bureau of Meteorology (2019). Available at: http://www.bom.gov.au/climate/influences/timeline/. Accessed 22/08/2019.

Bureau of Meteorology (2023). Monthly rainfall/BOM weather station 04082 Brisbane Aero. Available at: http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=040842. Accessed 21/09/2023.

Bureau of Meteorology (2023). Monthly rainfall/BOM weather station 040231 Manly Railway Station. Available at: http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=040231. Accessed 9/11/2023.

Bureau of Meteorology (2023). Monthly rainfall/BOM weather station 040770 Ormiston College. Available at: http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=040770. Accessed 9/11/2023.

Bureau of Meteorology (2023). Monthly rainfall/BOM weather station 040980 Deception Bay Alert. Available at http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=040980. Accessed 9/11/2023.

Burfeind D (2009). Caulerpa taxifolia growth dynamics and habitat value of native and invasive populations PhD Thesis, School of Engineering, The University of Queensland.

Burfeind D (2012). Assessing the seagrass depth range data to determine historical changes in Caulerpa taxifolia distribution in Moreton Bay: Healthy Waterways, Brisbane Australia. 11 pp

Campbell SJ & McKenzie LJ (2001). Community-based monitoring of intertidal seagrass meadows in Hervey Bay and Whitsunday, 1998e2001. Queensland Department of Primary Industries Information Series No. QI01090 (QDPI, Brisbane), 30 pp.

Carter AB, Jarvis JC, Bryant CV & Rasheed MA (2015). Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 15/29, James Cook University, Cairns, 71 pp.

Carter, AB. and Rasheed, M A. (2016) Assessment of Key Dugong and Turtle Seagrass Resources in North-west Torres Strait. Report to the National Environmental Science Programme and Torres Strait Regional Authority. Reef and Rainforest Research Centre Limited, Cairns (41pp.).

Carruthers TJB, Dennison WC, Longstaff BJ, Waycott M, Abal EG, McKenzie LJ, Lee Long WJ (2002) Seagrass habitats of northeast Australia: models of key processes and controls. Bulletin of Marine Science of the Gulf and Caribbean 71, 1153-1169.

Chartrand KM, Ralph PJ, Petrou K, Rasheed MA (2012). Development of a light-based seagrass management approach for the Gladstone Western Basin Dredging Program. DAFF Publication. Fisheries Queensland, Cairns 126 pp.

Collier CJ, Waycott M (2009). Drivers of change to seagrass distributions and communities on the Great Barrier Reef: Literature review and gaps analysis. Reef and Rainforest Research Centre Limited, Cairns.

Collier CJ, Waycott M, McKenzie LJ, (2012). Light thresholds derived from seagrass loss in the coastal zone of the northern Great Barrier Reef, Australia. Ecological Indicators, 23 (2012): 211-219

Collier CJ, Adams MP, Langlois L, Waycott M, O'Brien KR, Maxwell PS, McKenzie L (2016). Thresholds for morphological response to light reduction for four tropical seagrass species. Ecological Indicators 67: 358-366.

Davie, P. (2011). Wild Guide to Moreton Bay and Adjacent Coasts. 2nd Edition. Queensland Museum.

Davie, PJF. and Phillips, JA (2009). Proceedings of the 13th International Marine Biological Workshop: The Marine Fauna and Flora of Moreton Bay, Queensland. Memoirs of the Queensland Museum, Nature 51(1).

Dennison WC, Abal EG (1999). Moreton Bay Study: A Scientific Basis for the Healthy Waterways Campaign. South-East Queensland Water Quality Management Strategy. Brisbane.

EHMP (2006). EHMP 2005-2006 Annual Technical Report. South East Queensland Healthy Waterways Partnership, Brisbane.

Gumusay MU, Bakirman T, Kizilkaya IT, Aykut NO (2019). A review of seagrass detection, mapping and monitoring applications using acoustic systems. European Journal of Remote Sensing, 52, 1-29.

Han Q, Liu D (2014). Macroalgae blooms and their effects on seagrass ecosystems. Journal of Ocean University of China 13, 791-798.

Hearne EL, Johnson, RA, Gulick AG (2018). Effects of green turtle grazing on seagrass and macroalgae diversity ery spatially among seagrass meadows. Aquatic Botany, 152.

Hyland SJ, Courtney AJ, Butler CT (1989). Distribution of Seagrass in the Moreton Region from Coolangatta to Noosa. Queensland Department of Primary Industries Information Series Q189010.

Kilminster K, McMahon K, Waycott M, Kendrick GA, Scanes P, McKenzie L, O'Brien KR, Lyons M, Ferguson A, Maxwell P, Glasby T et al. (2015). Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of the Total Environment 535, 97-109.

Kirkman H (1995). The Seagrass communities of Moreton Bay, Queensland. Aquatic Botany 1: 191-202.

Komatsu T, Igarashi C, Tatsukawa K, Sultana S, Matsuoka Y, Harada S. (2003). Use of multi-beam sonar to map seagrass meadows in Otsuchi Bay on the Sanriku Coast of Japan. Aquatic Living Resource 16: 223-230

Kiggins RS, Knott NA, Davis AR (2018). Miniature baited remote underwater video (mini-BRUV) reveals the response of cryptic fishes to seagrass cover. Environment Biology of Fishes, 101.

Lanyon JM, Marsh H (1994). Temporal changes in the abundance of some tropical intertidal seagrasses in North Queensland. Aquatic Botany 49, 217-237.

Lee Long WJ, Mellors JE, Coles RG (1993). Seagrasses Between Cape York and Hervey Bay, Queensland, Australia. Aust. J. Mar. Freshwater Res. 44, 19-31.

Longstaff BJ, Dennison WC (1999). Seagrass survival during pulsed turbidity events: the effects of light deprivation on the seagrasses Halodule pinifolia and Halophila ovalis. Aquatic Biology 65, 105-121.

Longstaff BJ, Loneragan NR, O'Donohue M, Dennison WC (1999). The effects of light deprivation on the survival and recovery of the seagrass Halophila ovalis. Journal of Experimental Marine Biology and Ecology. 234: 1-27

Lyons, MB, Phinn SR, Roelfsema CM, (2012). Long term land cover and seagrass mapping using Landsat and object-based image analysis from 1972 to 2010 in the coastal environment of Southeast Queensland, Australia. ISPRS Journal of Photogrammetry and Remote Sensing, 71: 34-46

McKenzie LJ (1994). Seasonal Changes in Biomass and Shoot Characteristics of Zostera muelleri Aschers Dominant Meadow in Cairns Harbour, Northern Queensland. Australian Journal of Marine and Freshwater Research. 45: 1337-1352

Mellors, JE, Marsh H, Coles RG (1993). Intra-annual Changes in Seagrass Standing Crop, Green Island Northern Queensland. Australian Journal of Marine and Freshwater Research, 44: 33-41

Moore KA, Wetzel RL, Orth RJ (1997). Seasonal pulses of turbidity and their relations to eelgrass (Zostera marina L.) survival in an estuary. Journal of Experimental and Marine Biology and Ecology. 215: 115-134.

Onuf CP (2000). Seagrass responses to and recovery from seven years of brown tide. Pacific Conservation Biology 5, 306- 313.

OzCoasts (2004) Changes in seagrass communities. Available online at: https://ozcoasts.org.au/indicators/biophysical-indicators/changes_seagrass_area/#footnote_8_2868

Preen A.R, Lee Long WJ & Coles RG (1995). Flood and cyclone related loss, and partial recovery, of more than 1000 km2 of seagrasses in Hervey Bay, Queensland, Australia. Aquatic Botany 52, 3e17.

Ralph P (1998). Photosynthetic responses of Halophila ovalis (R. Br.) Hook. f. to osmotic stress, Journal of Experimental Marine Biology and Ecology. 227: 203-220

Rolfsema C, Phinn SR, Dennison WC, Dekker AG, Brando VE (2006). Monitoring toxic cyanobacteria *Lyngbya majuscula* (Gomont) in Moreton Bay, Australia by integrating satellite image data and field mapping. Harmful Algae, 5: 45-56

Rolfsema C, Phinn SR, Udy N, Maxwell P (2009). An Integrated Field and Remote Sensing Approach for Mapping Seagrass Cover, Moreton Bay, Australia. Spatial Science, 54, 45-62.

Rolfsema C, Lyons M, Kovacs EM, Maxwell P, Sauners MI, Samper-Villarreal J, Phinn SR (2014). Multi-temporal mapping of seagrass cover, species and biomass. A semi-automated object-based image analysis approach. Remote Sensing Environment 150 (2014): 172-187

O'Brien K, Tuazon D, Grinham A, Callaghan D, (2012). Impact of mud deposited by 2011 floods on marine and estuarine habitats in Moreton Bay. Healthy Waterways, Brisbane Austraia 61pp.

Preen A. (1995). Impacts of dugong foraging on seagrass habitats: observational and experimental evidence for cultivation grazing. Marine Ecology Progress Series, 124: 201-213.

"© The State of Queensland (Department of Transport and Main Roads) 2014, Tidal Data".

Sagawa T, Boisnier E, Komatsu T, Mustapha KB, Hattour A, Kosaka N, Miyazaki S (2010). Using bottom surface reflectance to map coastal marine areas: a new application method for Lyzenga's model. International Journal of Remote Sensing, 31: 12, 3051 — 3064

Shields EC, Parrish D, Moore K (2019). Short-term temperature stress results in seagrass community shift in a temperate estuary. Estuaries and Coasts 42, 755-764.

Sozou AM, Rasheed MA (2018). Port of Weipa long-term seagrass monitoring program, 200 - 2017. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 18/02, JCU Cairns, 45pp.

Thomas J. (2003). Caulerpa taxifolia in Moreton Bay – distribution and seagrass interactions. Honours Thesis, Department of Botany. University of Queensland.

TropWATER (2022). Turtles, dugongs in danger from seagrass loss. Available online at: https://www.jcu.edu.au/news/releases/2022/may/turtles-dugongs-in-danger-from-seagrass-loss

University of Queensland (2011) Habitat map of seagrass cover in Moreton Bay, 2011.

Uy, WH (2001). Functioning of Phillipines seagrass species under deteriorating light conditions. CRC Press.

Waycott M, McMahon K, Mellors J, Calladine A, Kleine D (2004). A guide to tropical seagrasses of the Indo-West Pacific. James Cook University, Townsville.

WBM Oceanics Australia (2000). Port of Brisbane – Port Expansion Impact Assessment Study. Report prepared for the Port of Brisbane Corporation.

WBM Oceanics Australia (2002). Port of Brisbane Seagrass Monitoring Pilot Study. Report prepared for the Port of Brisbane Corporation.

WBM Oceanics Australia (2003a). Port of Brisbane Seagrass Monitoring – Stages One and Two. Report prepared for the Port of Brisbane Corporation.

WBM Oceanics Australia (2003b). Port of Brisbane FPE Seagrass Monitoring Report May 2003. Report prepared for the Port of Brisbane Corporation.

WBM Oceanics Australia (2004). Port of Brisbane Seagrass Monitoring – March 2004. Report prepared for the Port of Brisbane Corporation.

WBM Oceanics Australia (2005). Port of Brisbane Seagrass Monitoring – April 2005. Report prepared for the Port of Brisbane Corporation.

West EJ, West RJ (2007). Growth and survival of the invasive alga, *Caulerpa taxifolia*, in different salinities and temperatures: implications for coastal lake management. Hydrobiologia, 577, 87-94.

Young PC, Kirkman H (1975). The seagrass communities of Moreton Bay, Queensland. Aquatic Botany 1, 191-202.

Annex A Photo Plates

Figure A.1 Deception Bay: Mixed community of *Halophila ovalis* and *Haoldule uninervis* (A), *Haoldule uninervis* (B), Manly: *Zostera Muelleri* (C and D), *Halophila spinulosa* (E), Fisherman Islands: *Halophila ovalis* (F).

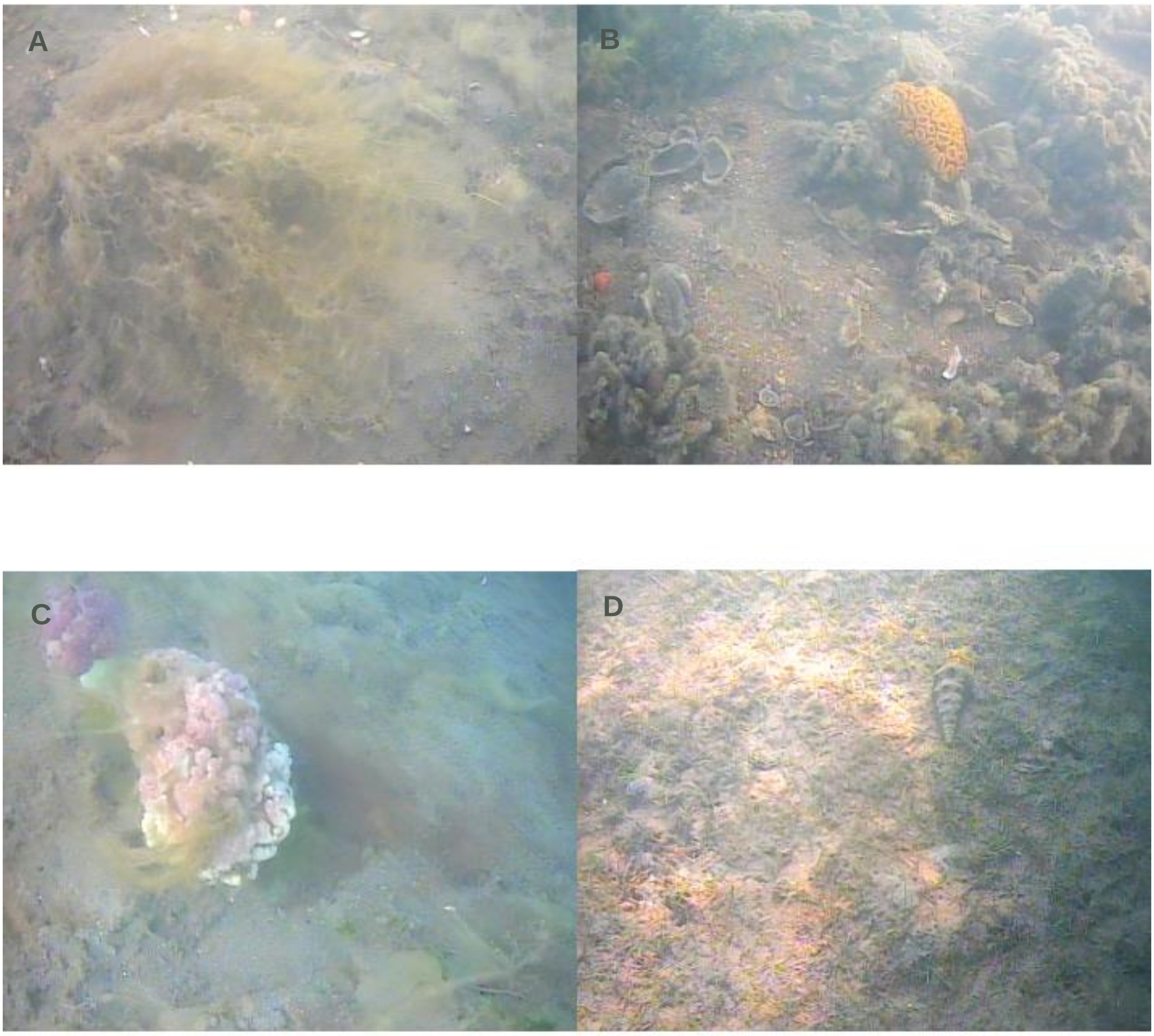


Figure A.2 Manly: Macroalgae Assemblages (A), Scleractinia Coral (B), Soft Coral (C), Mixed Seagrass community with Gastropod (D).

Annex B Broad scale patterns in seagrass species distribution at the Port of Brisbane 2010, 2013-2020

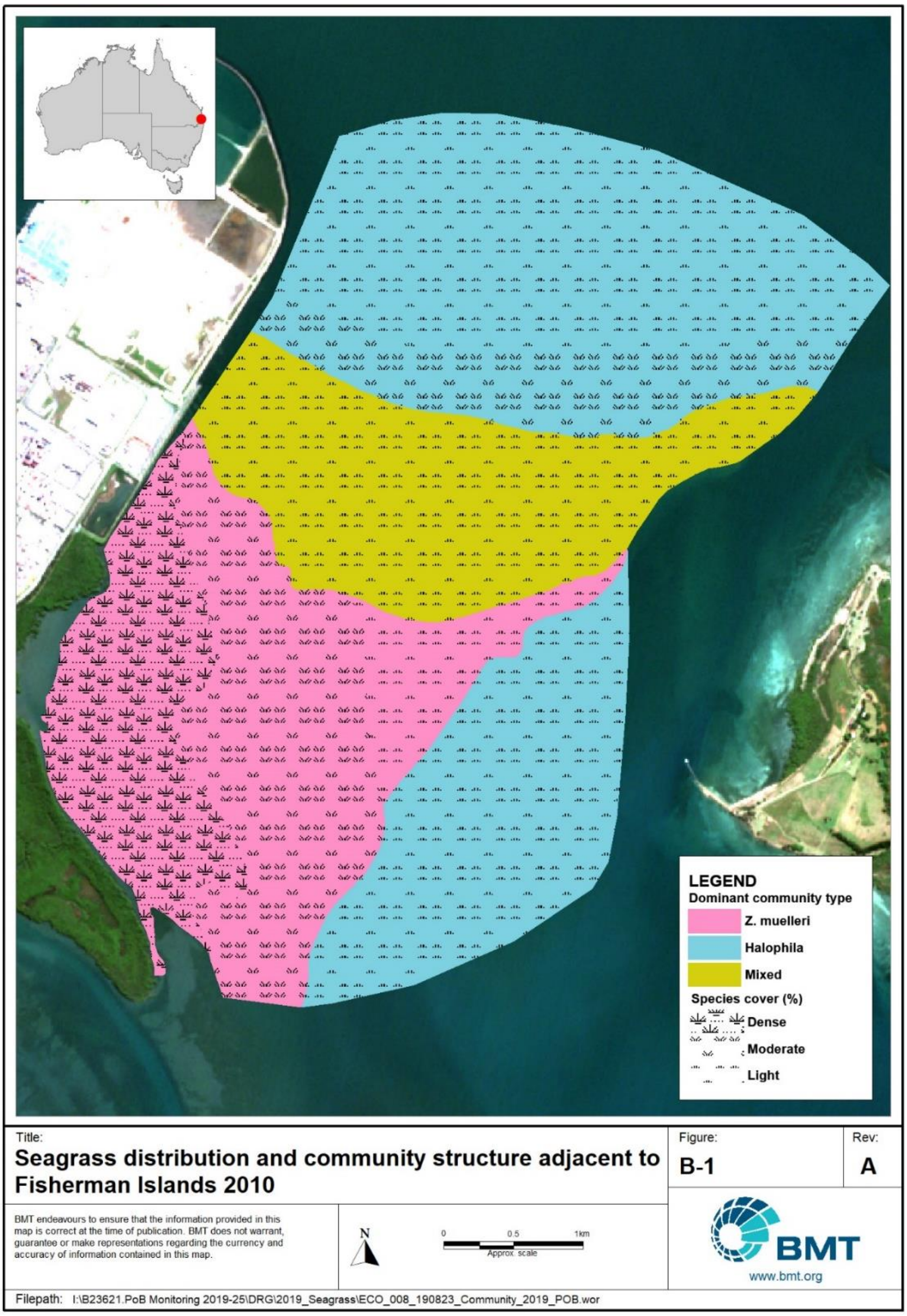


Figure B.1 Broadscale Patterns in Seagrass Distribution and Community Structure Adjacent to Fisherman Islands in 2010

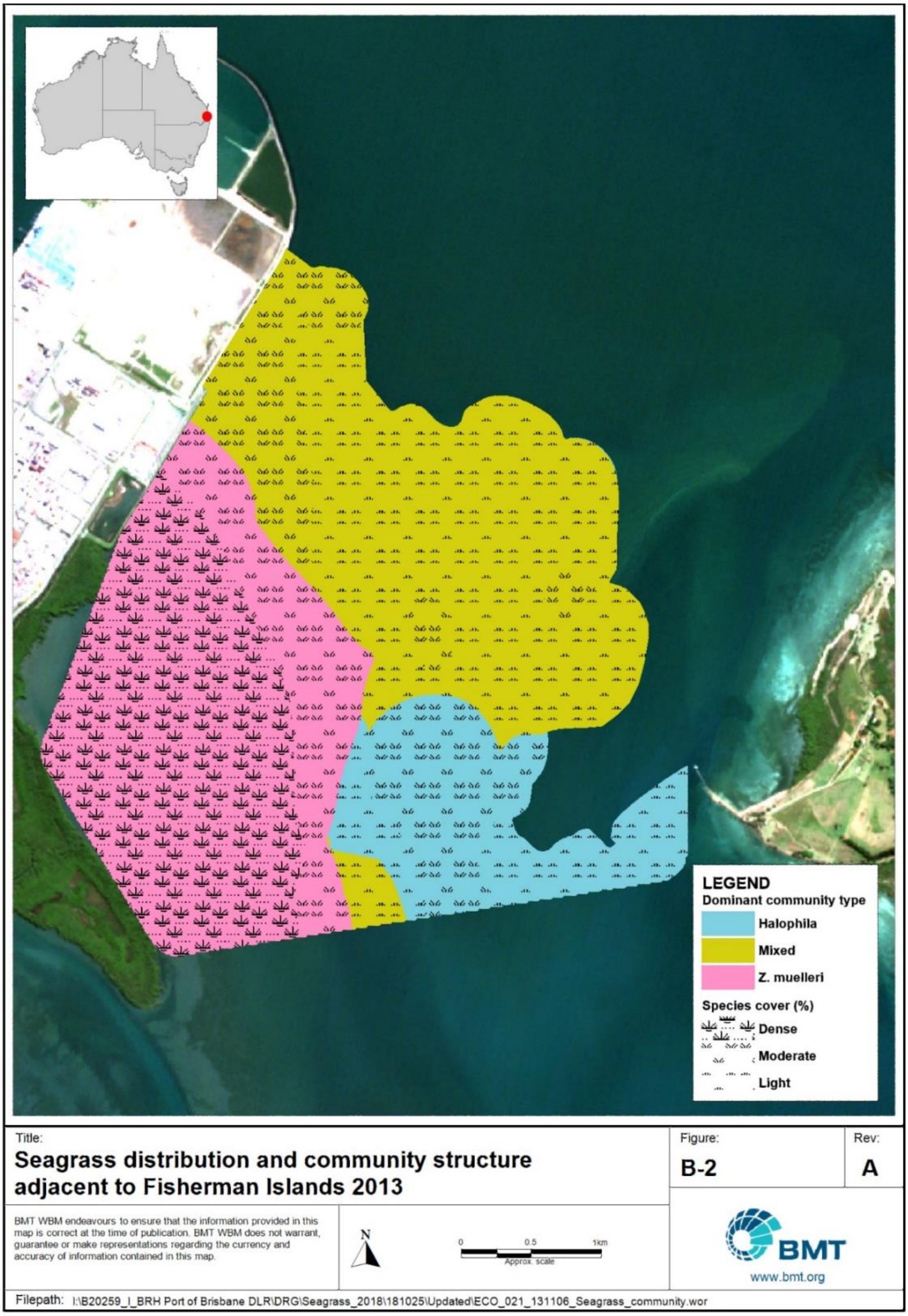


Figure B.2 Broadscale Patterns in Seagrass Distribution and Community Structure Adjacent to Fisherman Islands in 2010

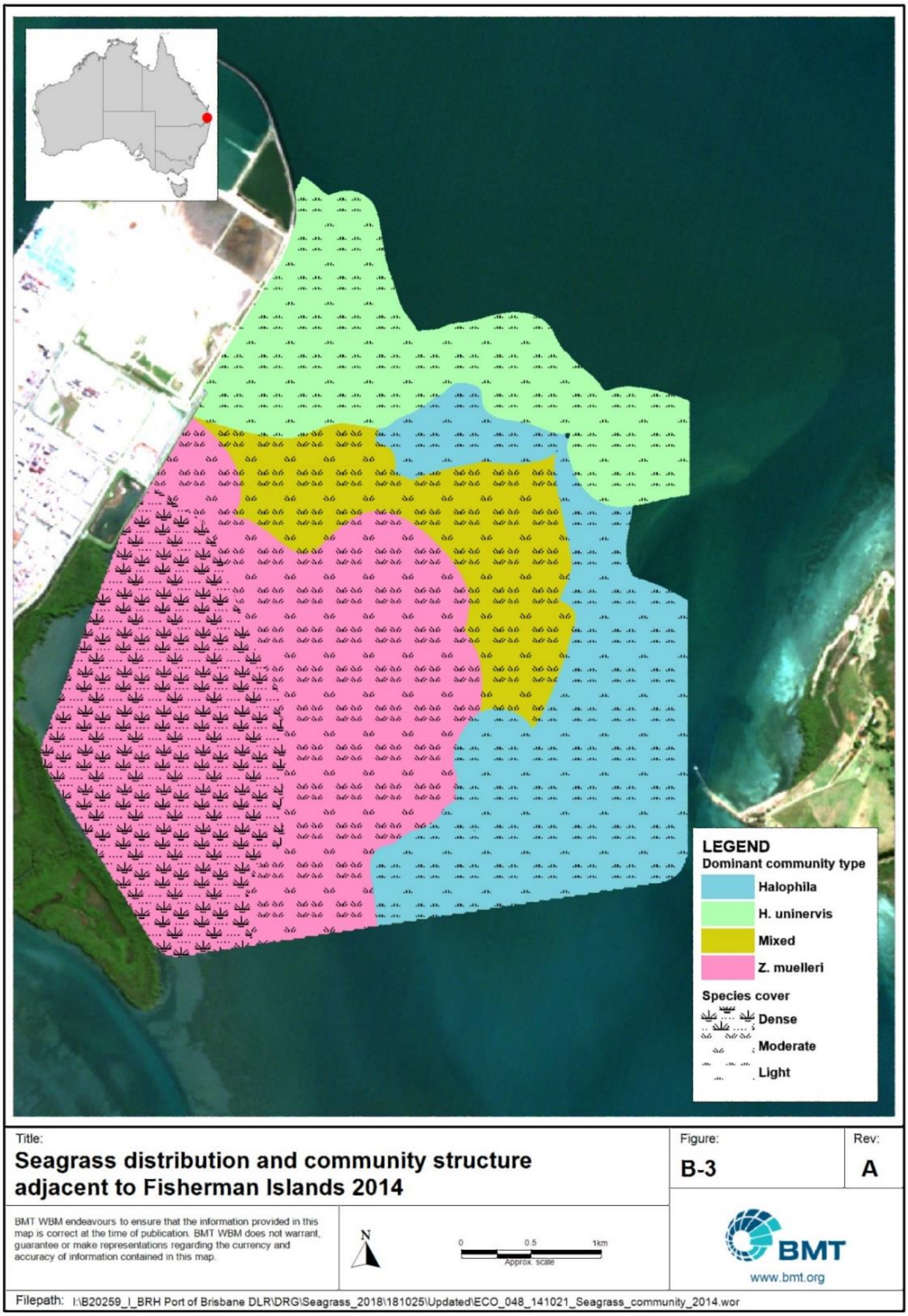


Figure B.3 Broadscale Patterns in Seagrass Distribution and Community Structure Adjacent to Fisherman Islands in 2014

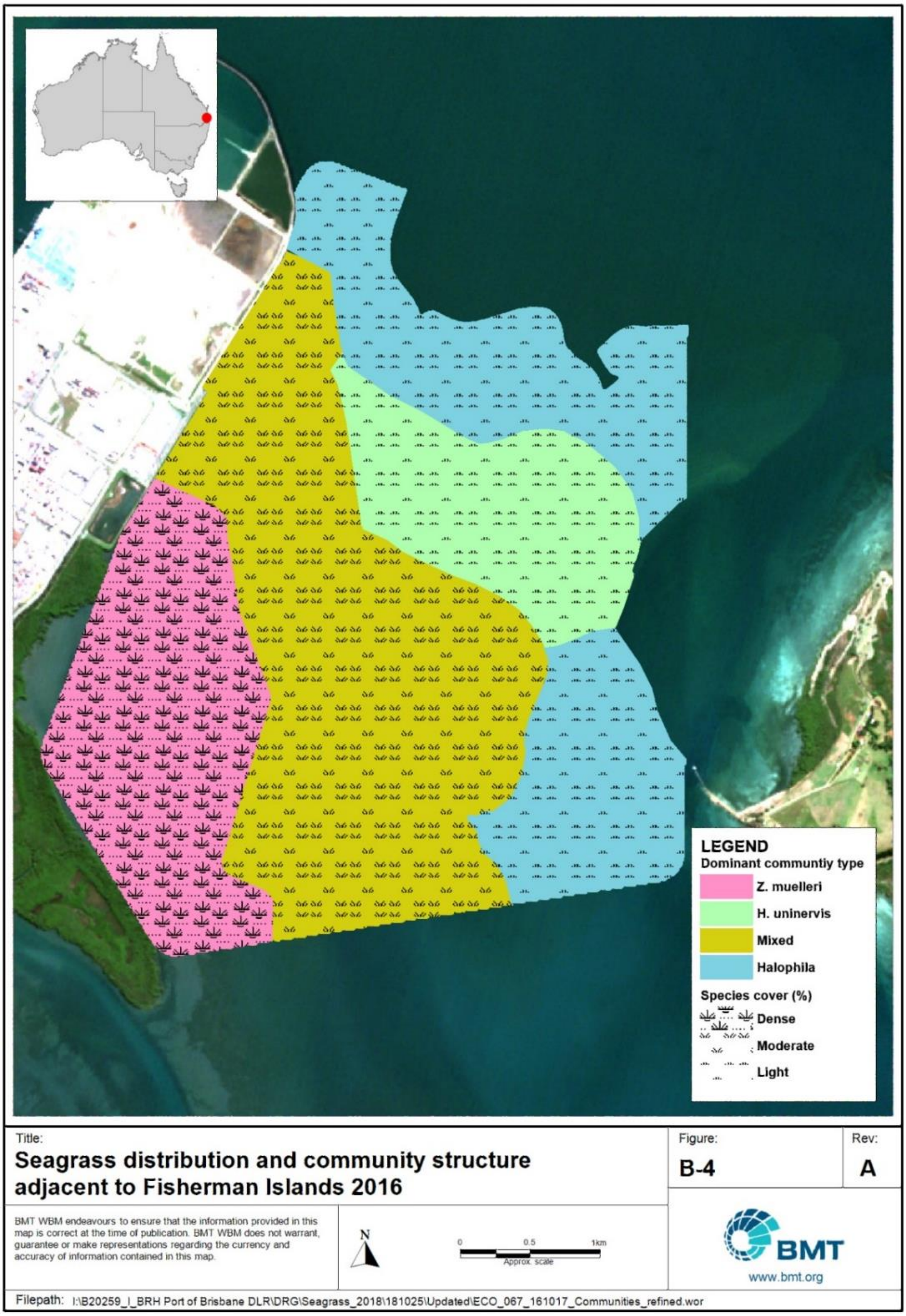


Figure B.4 Broadscale Patterns in Seagrass Distribution and Community Structure Adjacent to Fisherman Islands in 2016

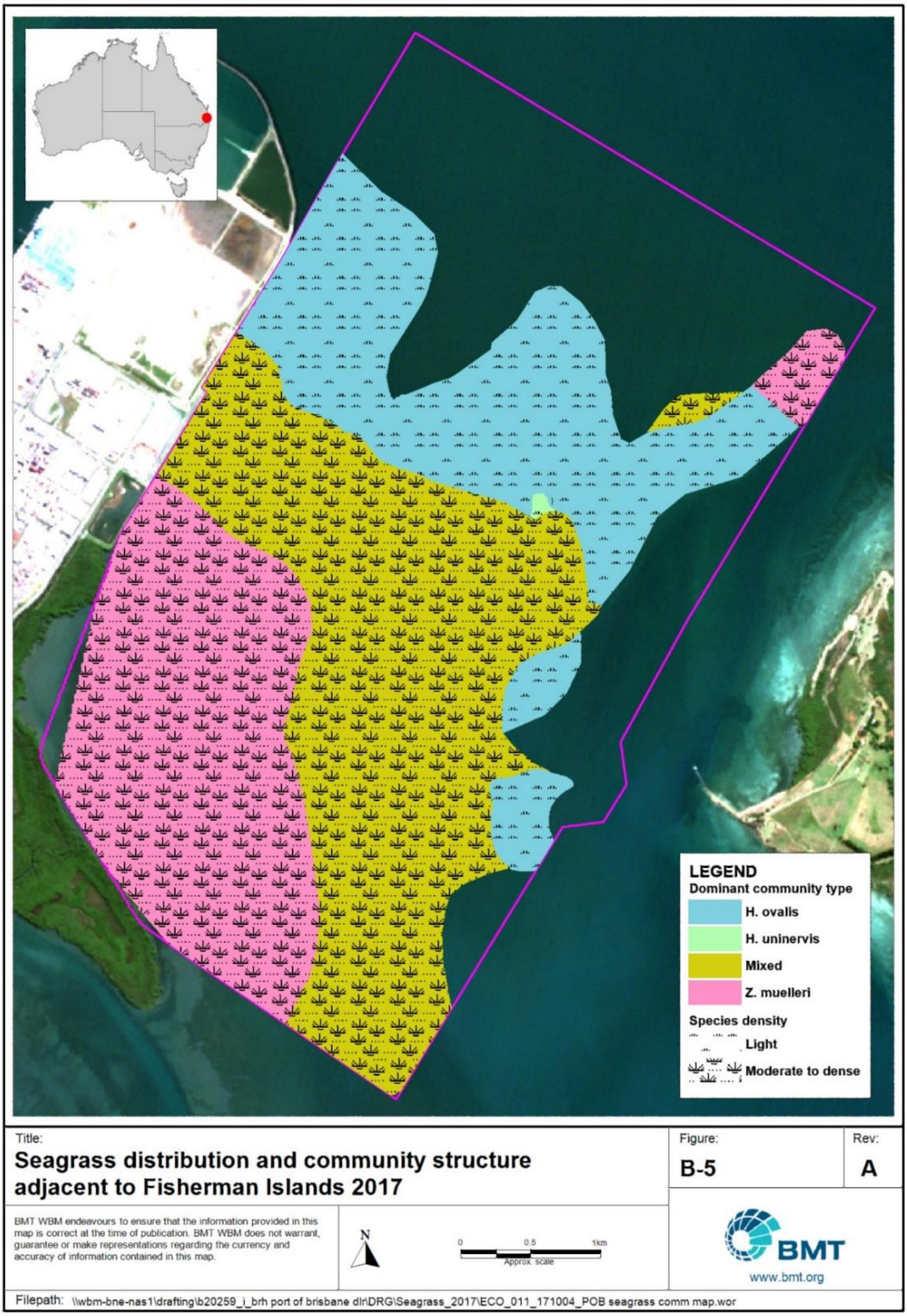


Figure B.5 Seagrass Distribution and Community Structure Adjacent to Fisherman Island, 2017

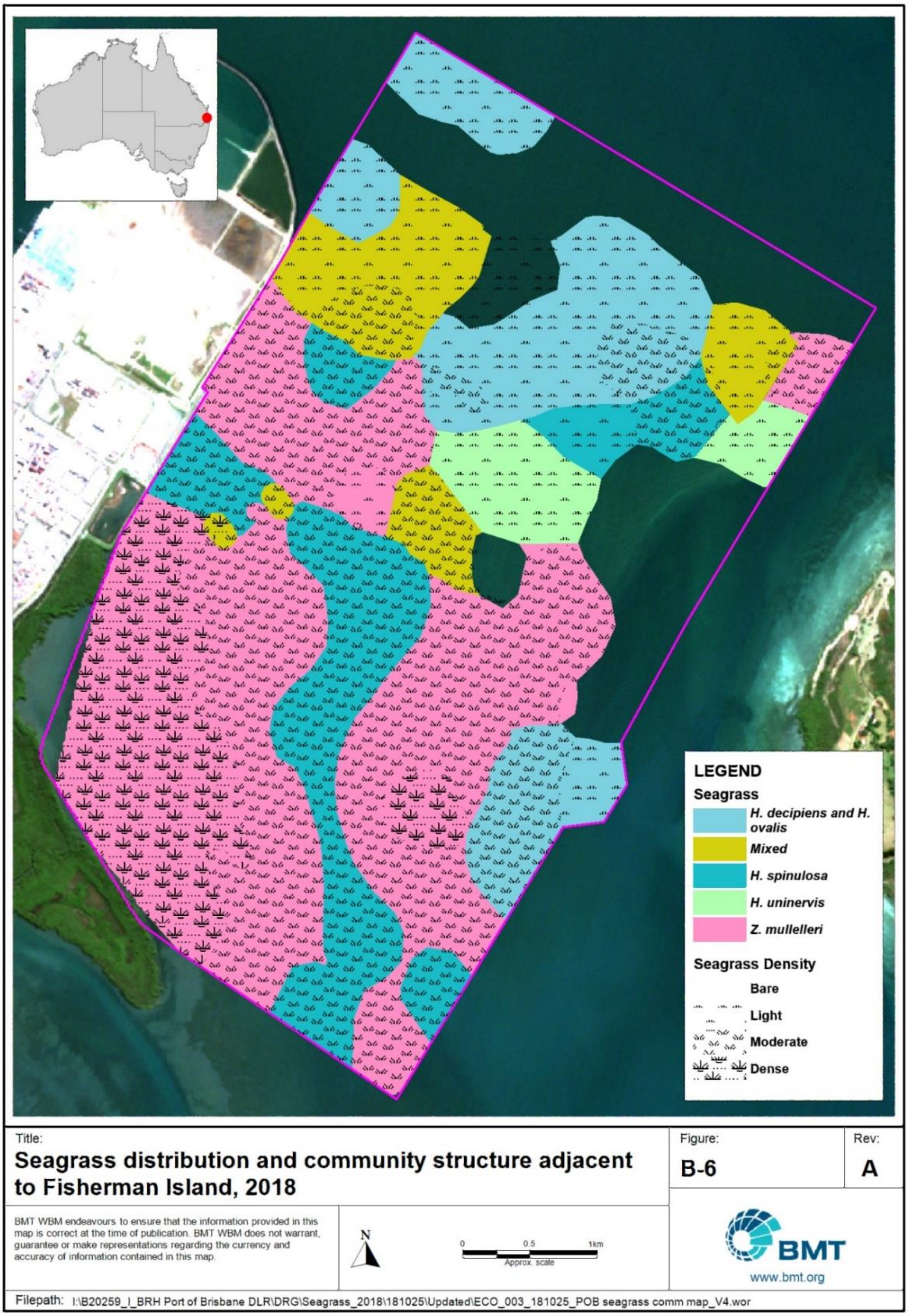


Figure B.6 Seagrass Distribution and Community Structure Adjacent to Fisherman Island, 2018

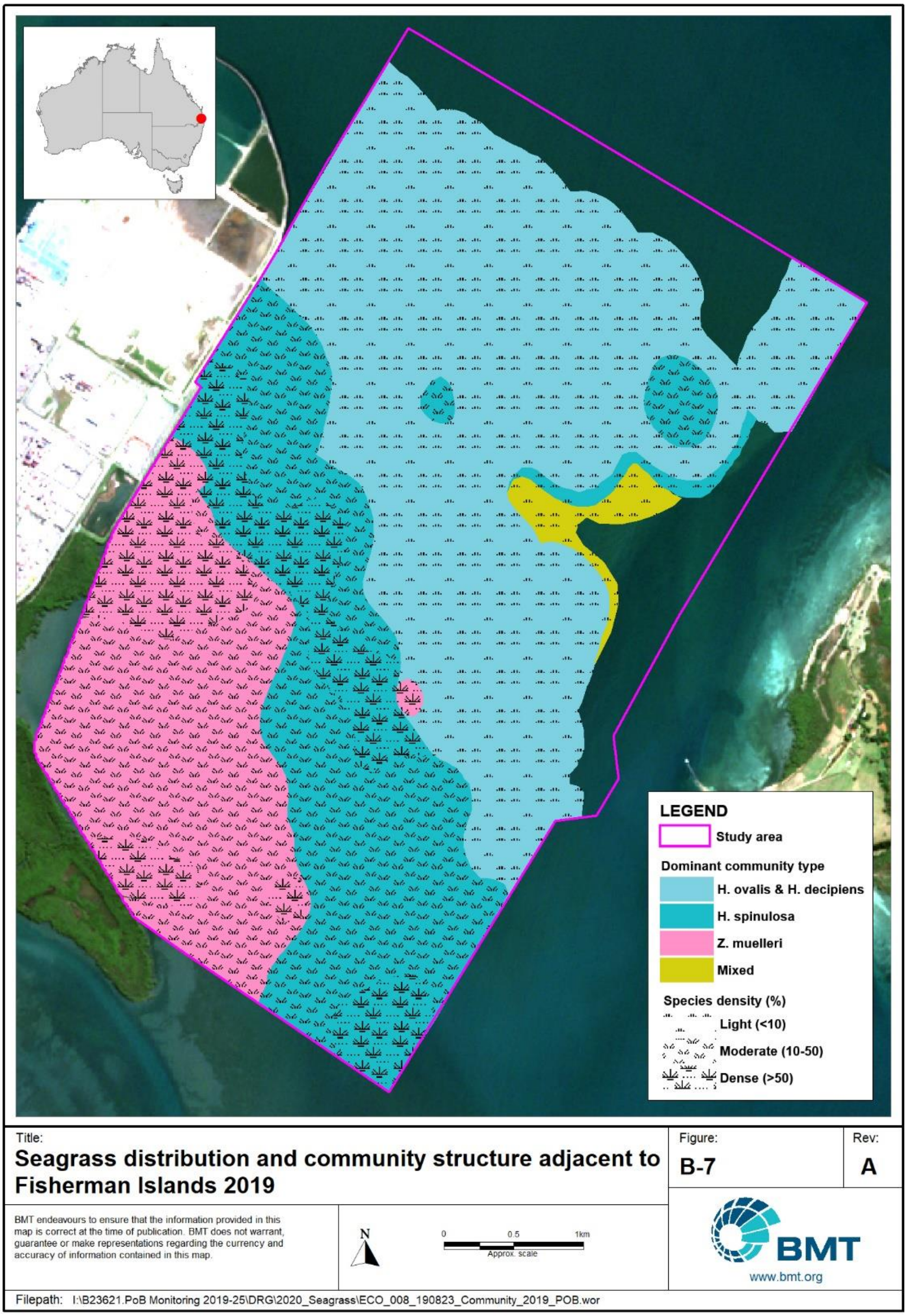


Figure B.7 Seagrass distribution and community structure adjacent to Fisherman Island 2019

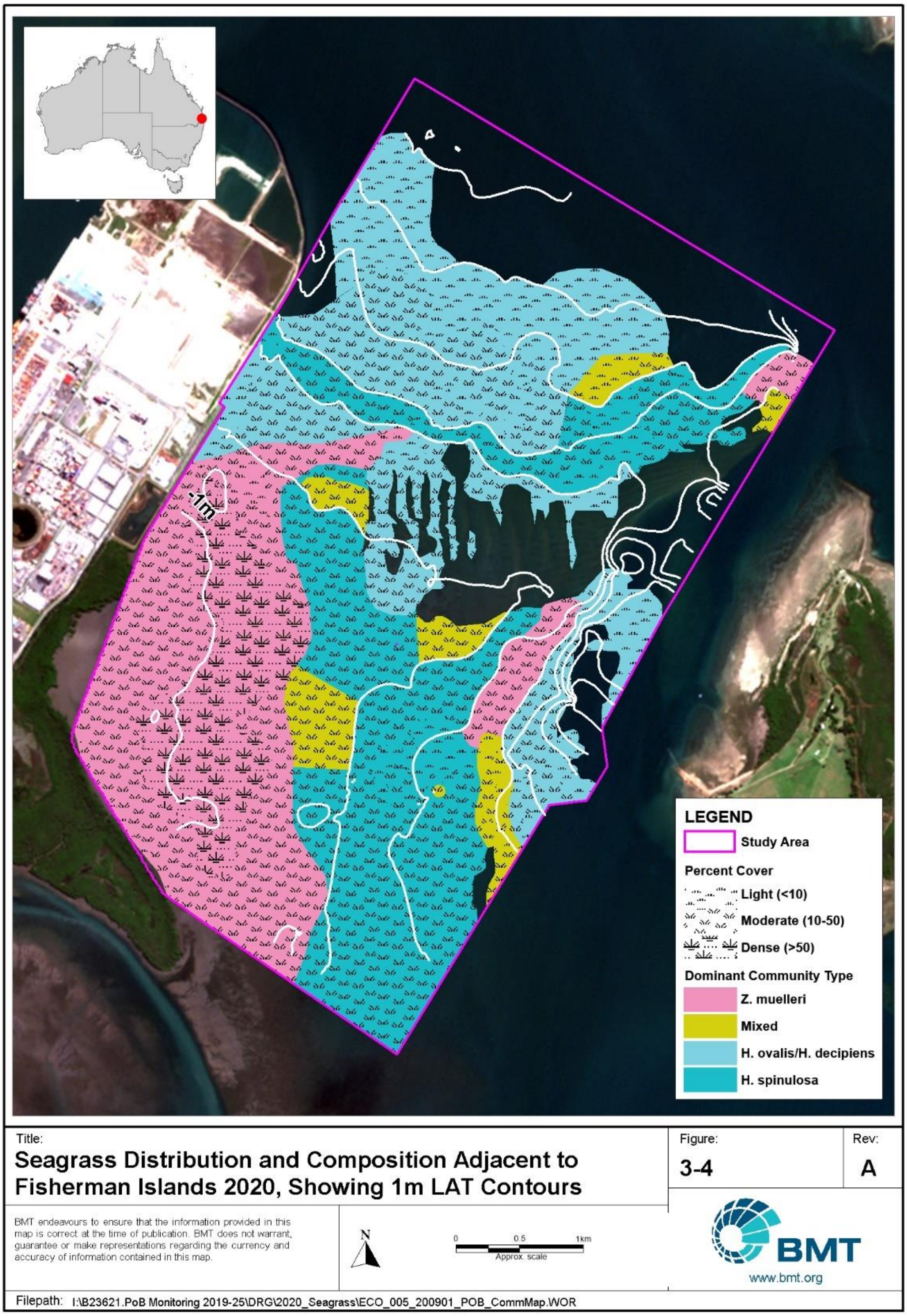


Figure B.8 Seagrass distribution and community structure adjacent to Fisherman Island 2020

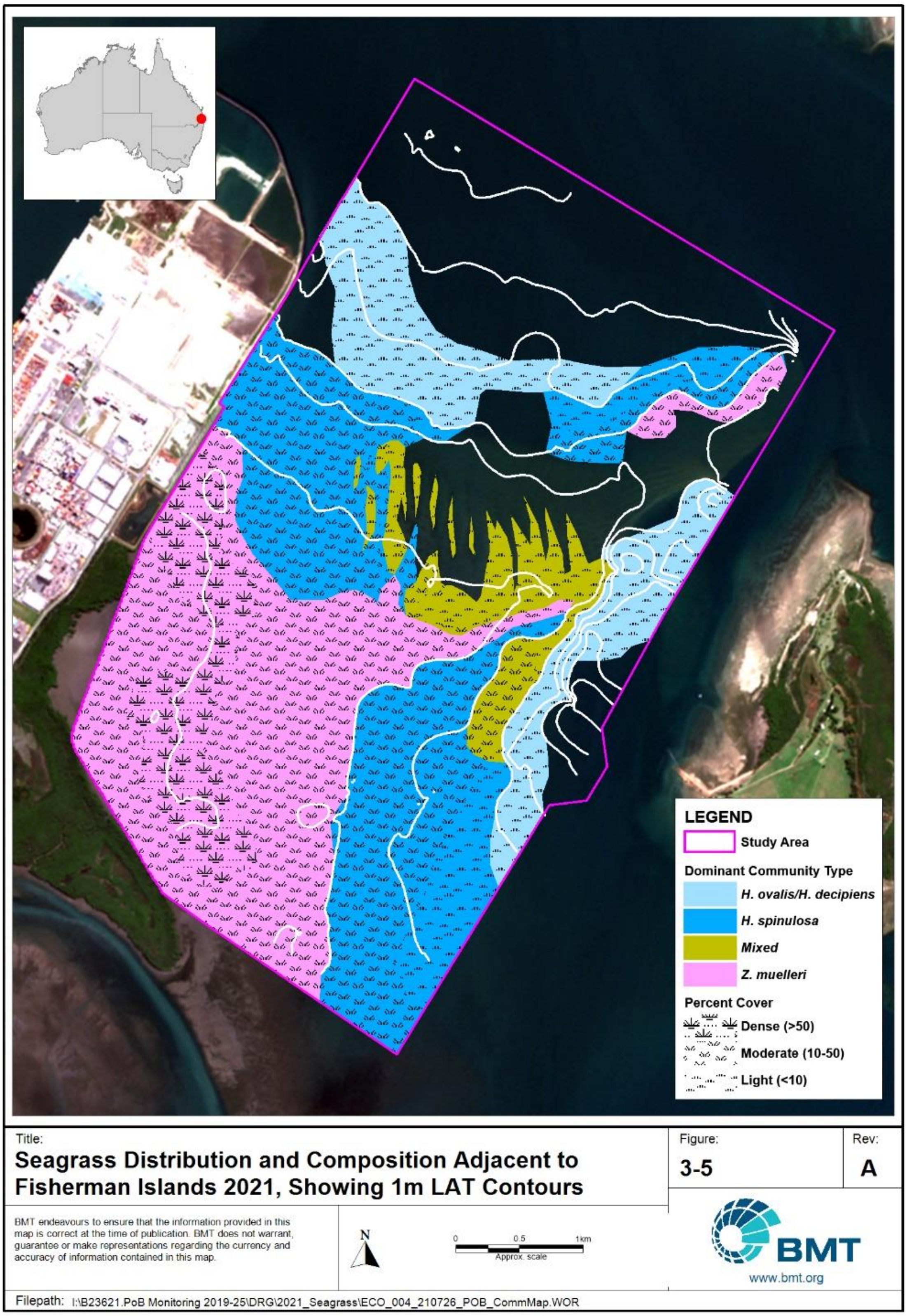


Figure B.9 Seagrass Distribution and Composition Adjacent to Fisherman Islands 2021, Showing 1m LAT Contours

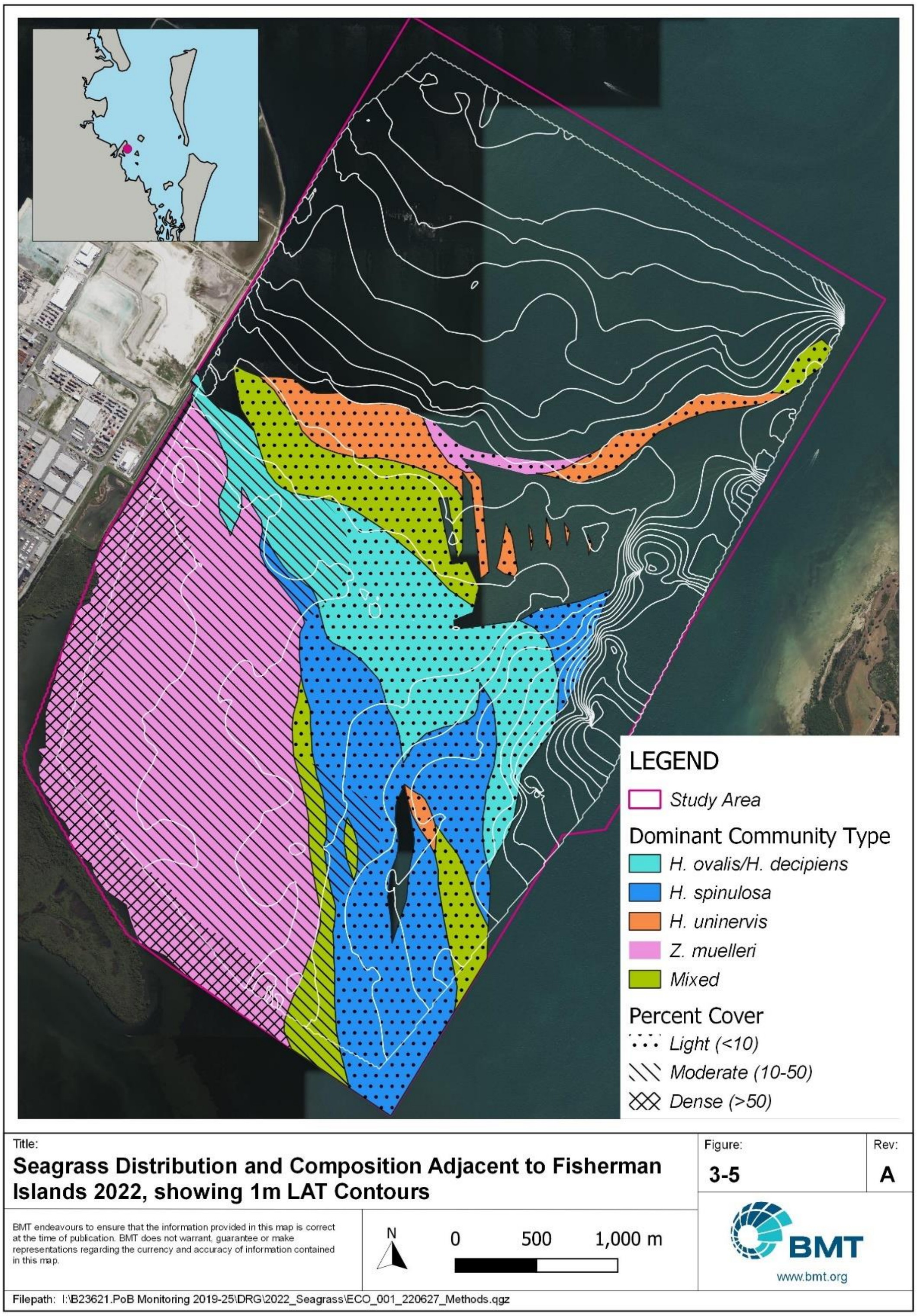
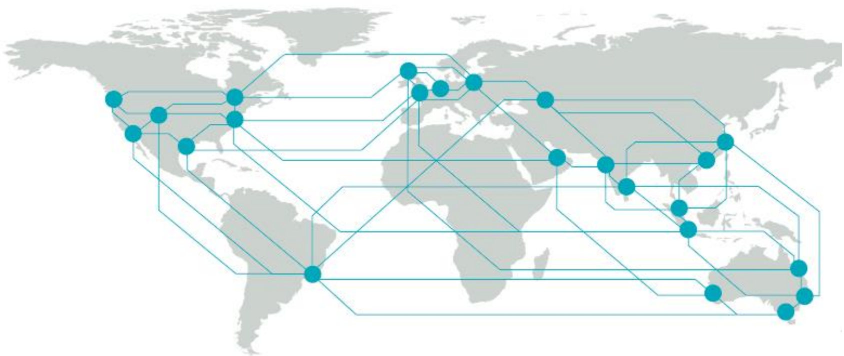


Figure B.10 Seagrass Distribution and Composition Adjacent to Fisherman Islands 2022, Showing 1m LAT Contours



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