Port of Brisbane Seagrass Monitoring Program - 2016

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Executive Summary

Background

The Fisherman Islands area supports seagrass meadows of high biodiversity value. Port of Brisbane Pty Ltd (PBPL) undertakes routine monitoring of seagrass meadows adjacent to the port at Fisherman Islands, as well as control locations at Manly and Cleveland. This monitoring is intended to provide port management with information on the condition and status of seagrass meadows, and to identify whether there is any evidence that port operations are affecting seagrass meadows.

The present study involved three components:

- A review of previous seagrass monitoring assessments to identify long-term changes in seagrass meadow extent
- Field surveys to describe patterns in seagrass meadow distribution and assemblage structure along depth gradients, and patterns of change in time and space
- Mapping of seagrass meadow distribution and extent based on field surveys and interpretation of satellite and aerial imagery.

Historical Changes in Seagrass Meadow Distribution Pre-FPE

Seagrass mapping studies have been conducted at Fisherman Islands since the late 1980's. While recognising limitations resulting from the use of different methodologies and sampling effort by different studies, there is a clear temporal trend of seagrass meadow expansion between the late 1980's and 1998. In this regard, there was: (i) a landward expansion in dense *Zostera* meadow in the embayment on the eastern side of Fisherman Islands, (ii) a seaward expansion in dense seagrass to the north of Fisherman Islands (directly abutting the newly reclaimed area); and (iii) a seaward expansion in seagrass to the east of Fisherman Islands. Seagrass depth range also increased during this period for *Zostera muelleri* and *Halophila ovalis*, whereas *Halophila spinulosa* declined over this time period. The loss of *Halophila spinulosa* post October 1995 was coincident with a period of high rainfall.

The Impact Assessment Study for the Future Port Expansion (FPE) Project suggested that reclamation works undertaken in the 1990's provided favourable conditions for the expansion of seagrass meadows by offering protection from Brisbane River flood flows. The Impact Assessment Study also predicted that the FPE reclamation would provide additional protection from flood flows and wind waves, providing conditions that were conducive to further seagrass expansion.

2016 Seagrass Monitoring Program (SMP) Findings

The Port of Brisbane Seagrass Monitoring Program (SMP) was developed in 2002 to monitor the effects of FPE construction and operation. The SMP was based on three components:

- Surveys of the maximum depth of seagrass meadows along permanent transects (seagrass depth range – SDR)
- Characterisation of spatial patterns in seagrass assemblages along a depth gradient
- Mapping of seagrass assemblages at Fisherman Islands.

The methods used were consistent with those adopted in previous surveys carried out for PBPL since 2002. In 2016, the use of satellite imagery was explored and provided a supplementary data source for seagrass mapping.

The key findings of the 2016 SMP survey were as follows:

- *Zostera muelleri* formed dense meadows in the intertidal and shallow subtidal waters. Intertidal meadows were comprised largely of dense mono-specific *Z. muelleri* meadows with occasional patches of *H. ovalis*. Shallow subtidal meadows were usually comprised of mixed assemblages of *Z. muelleri, H. ovalis, H. spinulosa* and *Halodule uninervis*.
- *Halophila ovalis*, *H. spinulosa, H. decipiens* and/or *Halodule uninervis* formed sparse mono-specific and mixed meadows in subtidal waters at all sites. This pattern in assemblage structure is consistent with previous surveys in the SMP, and is a typical pattern observed in Moreton Bay and other subtropical Queensland estuaries.
- Seagrass depth range (SDR) for *Z. muelleri* (a function of water quality and availability of suitable substrates) was higher at Fisherman Islands (-1.65 and -2.43 m) and Manly (-2.12 and -2.16 m) than Cleveland (-0.74 and -1.02 m). Since the 2013 survey there was a temporal trend of stable or slight declines in SDR at Cleveland and Fisherman Islands, and increasing SDR at Manly.
- Since the commencement of the SMP, seagrass meadows at Manly have displayed the largest losses and gains in extent, most likely in response to cyclic changes in water quality conditions.
- The distribution of *Halophila spinulosa* declined in 2016 at the Manly and Cleveland control sites, whereas the distribution of this species expanded over time at Fisherman Islands.

The SMP and historical mapping shows that there has been a long term trend of seagrass meadow expansion at Fisherman Islands, whereas seagrass meadows at control locations displayed great temporal variability and no consistent long term trend. The observed expansion in seagrass meadows at Fisherman Islands is consistent with the findings of the FPE Impact Assessment Study, which predicted that sheltering from wind waves and diversion of flood flows from the Brisbane River would enhance seagrass growing conditions (but also enhance sediment deposition) at this location. Seagrass meadows at the two control locations are highly variable (both spatially and temporally) than Fisherman Islands, reflecting more complex and variable environmental conditions at these control locations (i.e. hydrodynamic setting, exposure to floods, water quality conditions, and complex substrate types, bed slope etc.).

Program Review

A review of the monitoring program was undertaken taking into account the study objectives and in light of the results of the pilot satellite-based seagrass meadow mapping. While the existing monitoring techniques provide a sound basis for assessing variability in seagrass assemblage structure in space and time, and the detection of long term changes in water quality conditions, limitations in the existing seagrass mapping methodology were identified. Recommendations are provided to enable a more objective mapping approach while maintaining continuity with existing seagrass depth range and assemblage characterisation methods.

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1 Introduction

1.1 Background

The Fisherman Islands area contains one of the largest seagrass meadows in western Moreton Bay (Dennison and Abal 1999). These seagrass meadows have high biodiversity and fisheries habitat values, and are also located within an internationally significant wetland (Moreton Bay Ramsar site) and Moreton Bay Marine Park (Figure 1-1).

The Port of Brisbane is located directly adjacent to the Fisherman Island seagrass meadows. In recognition of the values of local seagrass meadows, the Port of Brisbane Pty Ltd (PBPL) undertakes routine monitoring of seagrass meadows adjacent to the port and more broadly at Manly and Cleveland. This Seagrass Monitoring Program (SMP) is intended to provide port management with information on the condition and status of seagrass meadows, and to identify whether there is any evidence that port operations are having an impact on these seagrass meadows.

Seagrass distribution and extent has been identified as a useful bio-indicator of water quality degradation because it can “integrate changes in aquatic light climate caused by various factors, and because seagrasses themselves are important and highly-valued elements of marine and estuarine environments.” (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:

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

- 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 metres) 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;
- On the basis of the above, identify possible broad-scale operational impacts of PBPL activities on the distribution and extent of seagrass meadows.

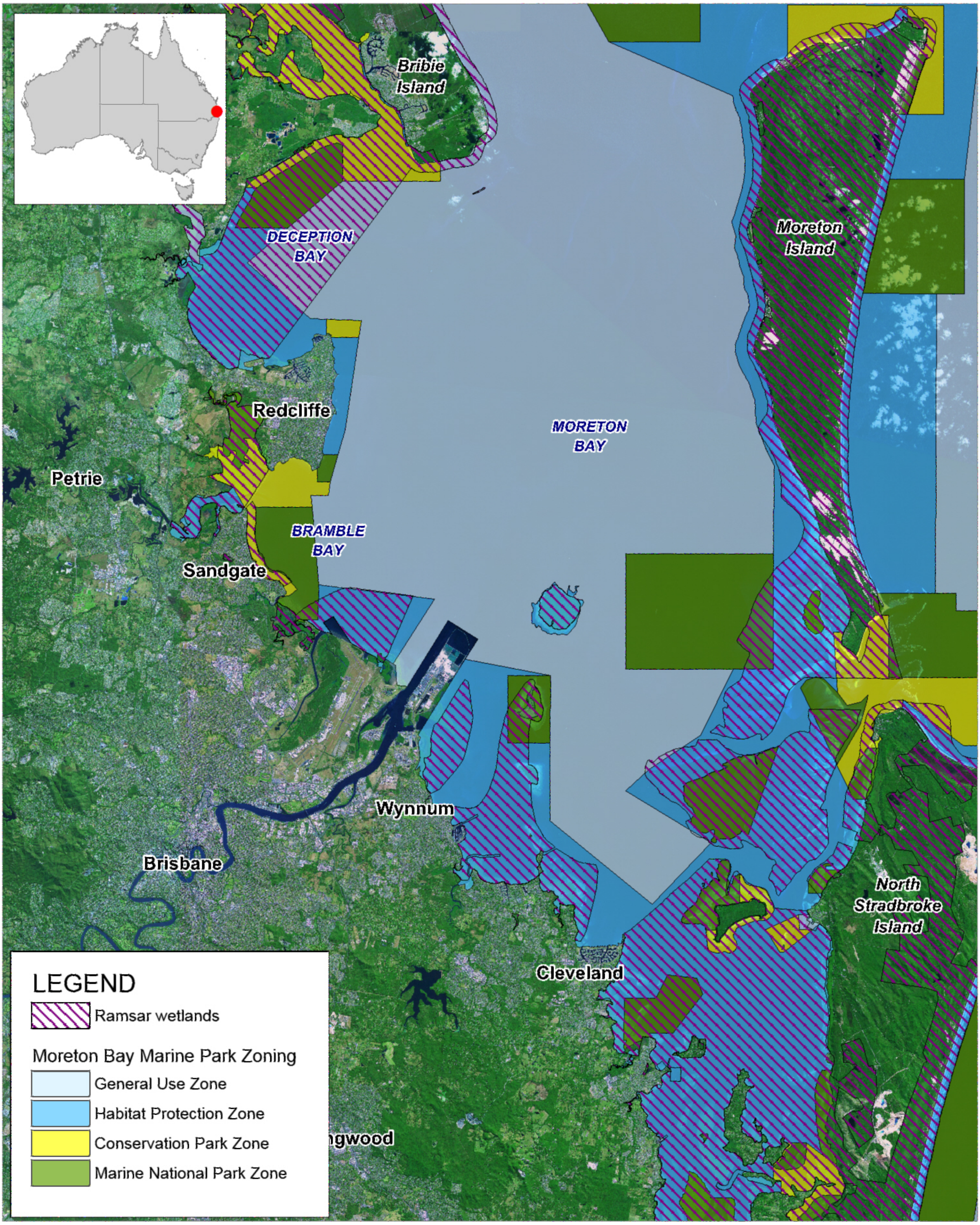
1.3 Study Area Context

The Port of Brisbane is located at Fisherman Islands (the study area), 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 1974. 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 site and in western Moreton Bay more generally.



Title:

Moreton Bay Ramsar Wetlands and Marine Park Zoning

Figure: 1-1

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2 Review of Previous Studies

2.1 Seagrass Mapping and Community Studies

Numerous studies have mapped seagrass meadow extent and seagrass assemblages within the study area (Table 2-1). This table shows that there was great variability among studies in mapping methodologies and the spatial accuracy/mapping error, similar to the situation for mangrove mapping studies (see BMT WBM 2016). It is therefore inappropriate to directly compare the mapped seagrass extents between the different mapping studies. The following provides an overview of the findings of previous seagrass mapping and health assessments in the study area.

Table 2-1 Previous seagrass mapping and monitoring studies

Source	Assessment Type	Assessment Methods	Years	Spatial coverage
Hyland *et al*. (1989)	Seagrass mapping	Aerial photograph (manual tracing) and diver transects and spot dives) Four cover types, species assigned to the polygons	Aug and Dec 1987	Moreton Bay < 10 m
WBM (1998)	Seagrass mapping	Aerial photograph (manual digitisation), benthic grabs and visual survey from surface	1991 (no ground truthing) July 1998	FI
	Seagrass depth range	Survey along a transect extending 350m perpendicular from shoreline	1993-98 (twice/year)	FI, Wynnum (shallow water)
Dennison *et al*. (1998)	Seagrass cover	% cover divided in 10 categories (vector) and species (point)	1998	Moreton Bay < 10 m
WBM (2000)	Seagrass mapping	Aerial photograph – manual digitisation Species assigned to the polygons	2000	FI
WBM 2002, 2003a; 2003b; 2004; 2005; BMT WBM 2006, 2010b, 2013, 2014	Seagrass depth range, profiles and mapping	Underwater video survey on fixed transects	Apr 2002, May 2003 (Wynnum), August 2003 (Wynnum and Cleveland), November 2003 (Wynnum and Cleveland), April 2004 (FI), August 2004 (FI), November 2004 (Cleveland), April 2005 (Cleveland and FI), July 2006 (Cleveland and FI), July 2010, August 2013, August 2014, August 2016	FI, Wynnum, Cleveland
	Seagrass mapping	Landsat multispectral data	Mar 2002	FI
Roelfsema *et al*. 2009, 2011	Seagrass mapping	Manual delineation/pixel based supervised classification based on Landsat data and field data (spot checks and video transects)	Jul-Sep 2004 Jun-Sep 2011	Moreton Bay < 10 m

FI – Fisherman Islands

2.1.1 Key Findings

Prior to Future Port Expansion Construction

Hyland *et al.* (1989) mapped seagrass meadows throughout Moreton Bay based on manual digitisation of meadows from aerial photography, and field surveys (transect surveys and spot check points). Data were collected between June and December 1987. Dense *Zostera* meadows were recorded in shallow water, whereas 'light' *Halophila ovalis* and *H. spinulosa* dominated meadows were mapped in deeper water adjacent to the *Zostera muelleri* dominated meadow. This community pattern has been consistently observed over the last 30 years, although the extent of the *Halophila ovalis* and *H. spinulosa* meadow (and to a lesser extent *Zostera)* has displayed marked temporal change (see below).

WBM (1998) mapped seagrass meadows at Fisherman Islands based on aerial photograph interpretation and grab surveys in 1992 and 1998 (Figure 2-2), and analysed seagrass depth range data collected by the Department of Environment in the period 1993 to 1998. These results indicate the following trends:

- 1987-1992. The mapped extent of seagrass meadows in 1992 was far greater than mapped by Hyland et al. (1989) in 1987 (see Figure 2-1). The extent of Zostera dominated meadows reportedly increased landward in the embayment on the eastern side of Fisherman Islands, as well as eastward. The northern margin of the seagrass meadow had not substantially changed between 1987 and 1992. Figure 2-3 shows that the period 1990-1995 was characterised by strong El Niño conditions and was a period of drought.
- 1992-1998. The mapped extent of seagrass meadows in 1998 was greater than 1992. There was an apparent further landward increase in dense *Zostera* in the embayment on the eastern side of Fisherman Islands, as well as increases in dense seagrass to the north (directly abutting the newly reclaimed area) and to the east of Fisherman Islands. Seagrass depth range also increased during this period for *Zostera muelleri* and *Halophila ovalis*, whereas *H. spinulosa* declined over this time period. The loss of *Halophila spinulosa* post October 1995 was coincident with a period of high rainfall (Figure 2-3).

WBM (2000) re-mapped seagrass meadows to inform the Port of Brisbane Future Port Expansion Impact Assessment Study. Seagrass meadows had further expanded to the north of the newly created reclaimed area at Fisherman Islands, as well as to the east. WBM (2000) postulated that the new reclamation area had provided favourable conditions for seagrass expansion by offering protection from Brisbane River flood flows. It is interesting to note that there was apparent increase in seagrass extent despite rainfall in 1999 being well above the annual average (Figure 2-3). WBM (2000) also noted that differences in mapping methods prevented direct, quantitative comparisons of mapped extent, but that repeat sampling at the same locations over time did suggest an actual increase in seagrass meadow extent northward (towards the Brisbane River mouth).

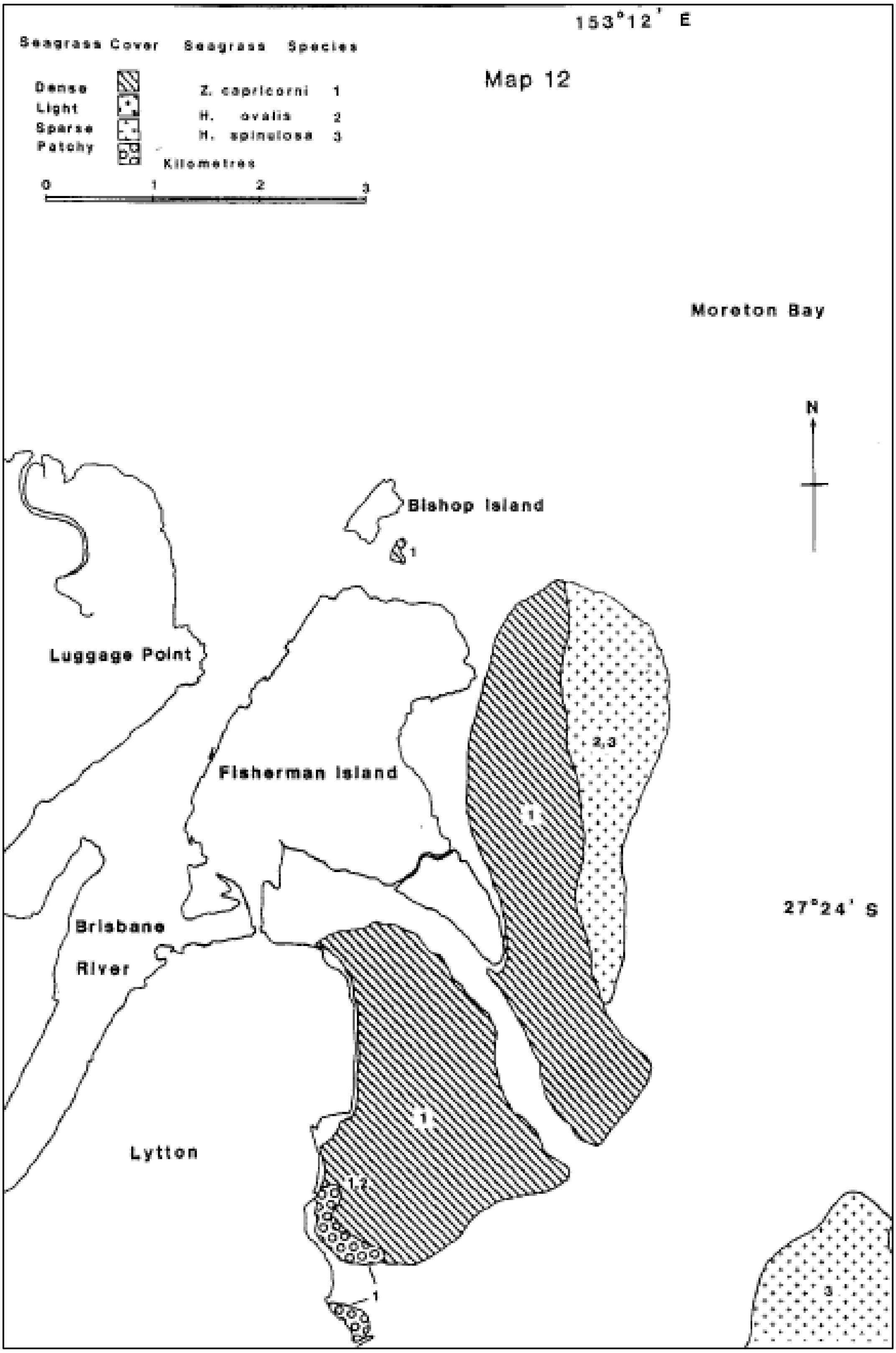
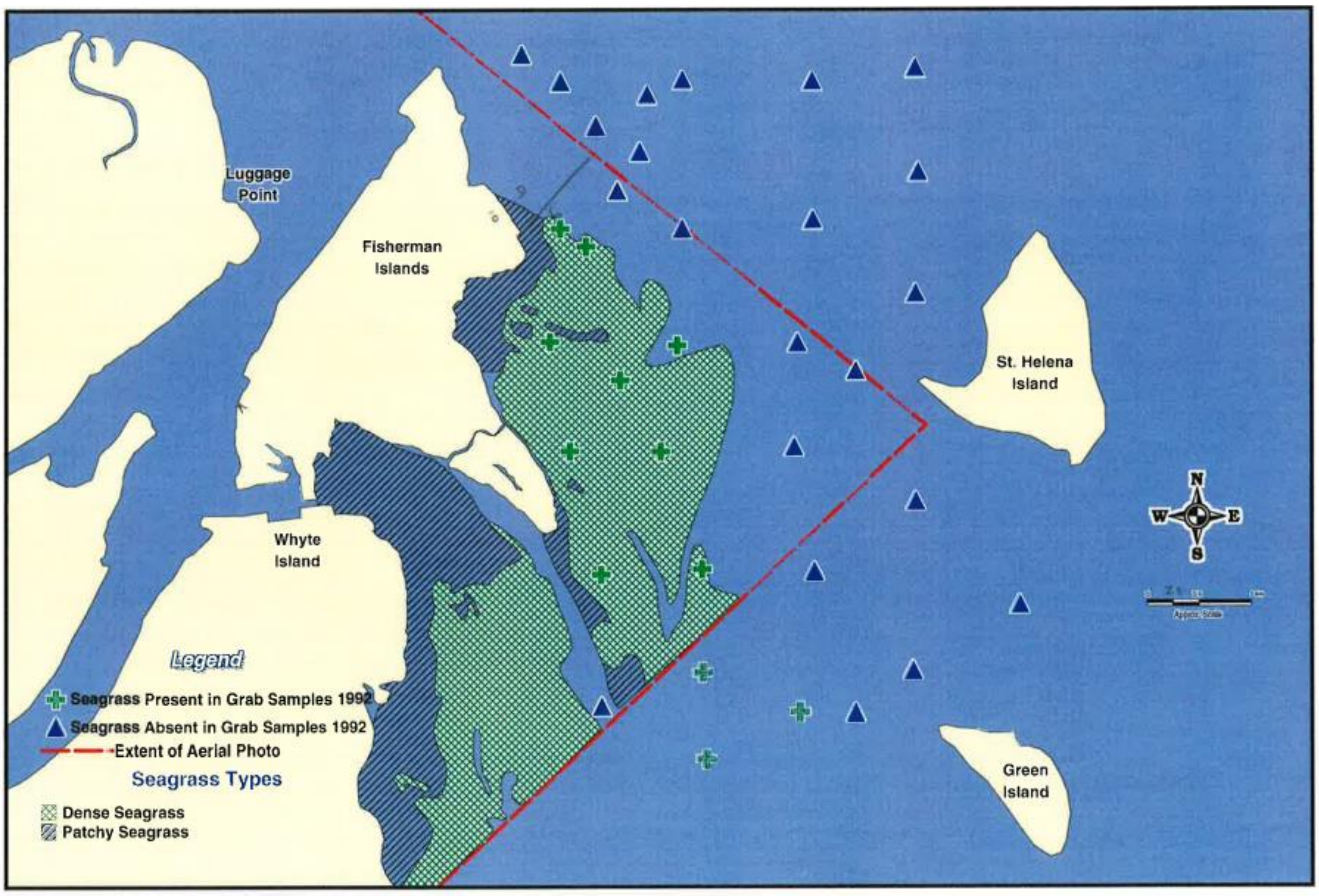


Figure 2-1 Fisherman Islands seagrass meadows mapped by Hyland et al. (1989)



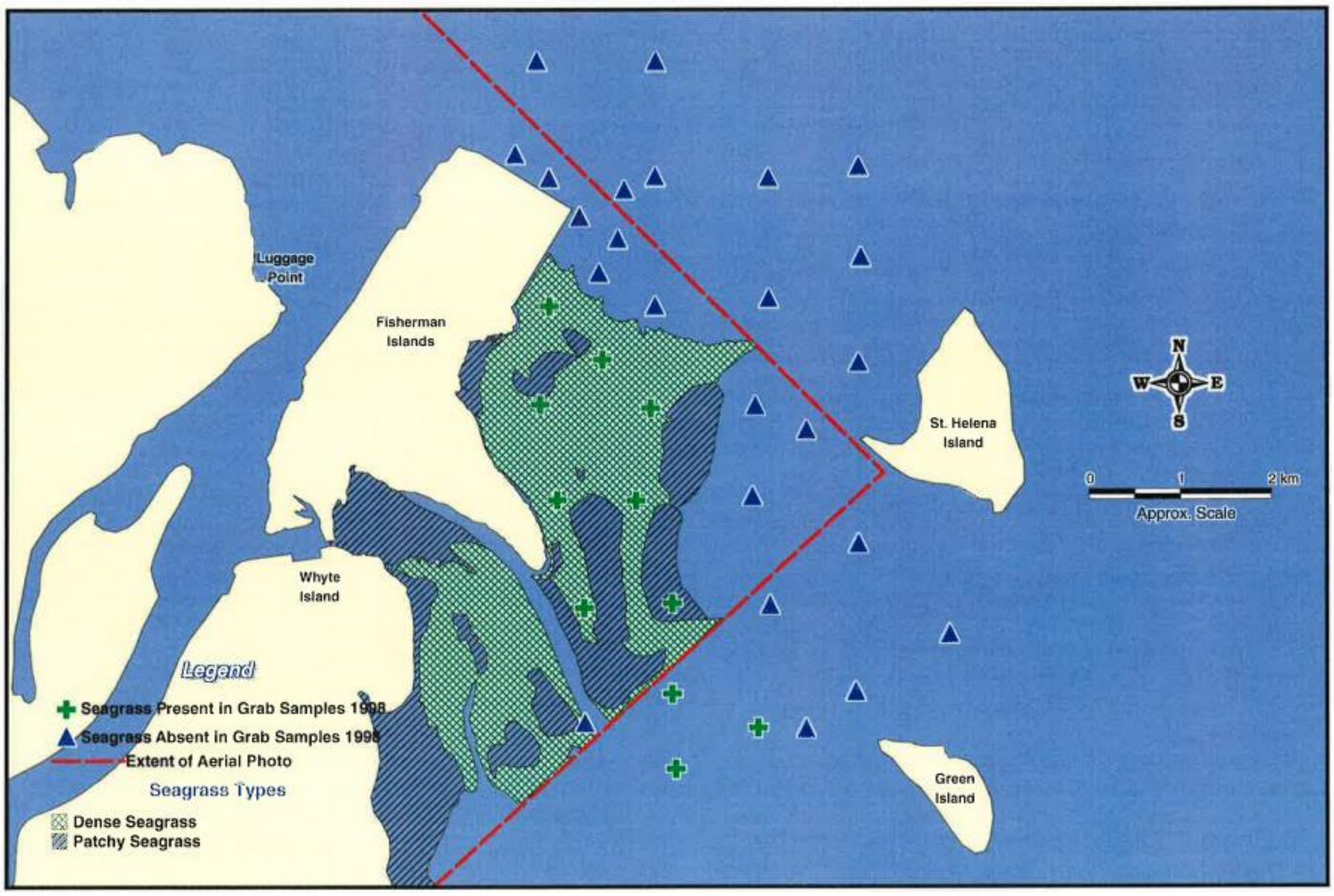


Figure 2-2 Seagrass meadows mapped by WBM (1998) for 1992 (upper) and 1998 (lower)

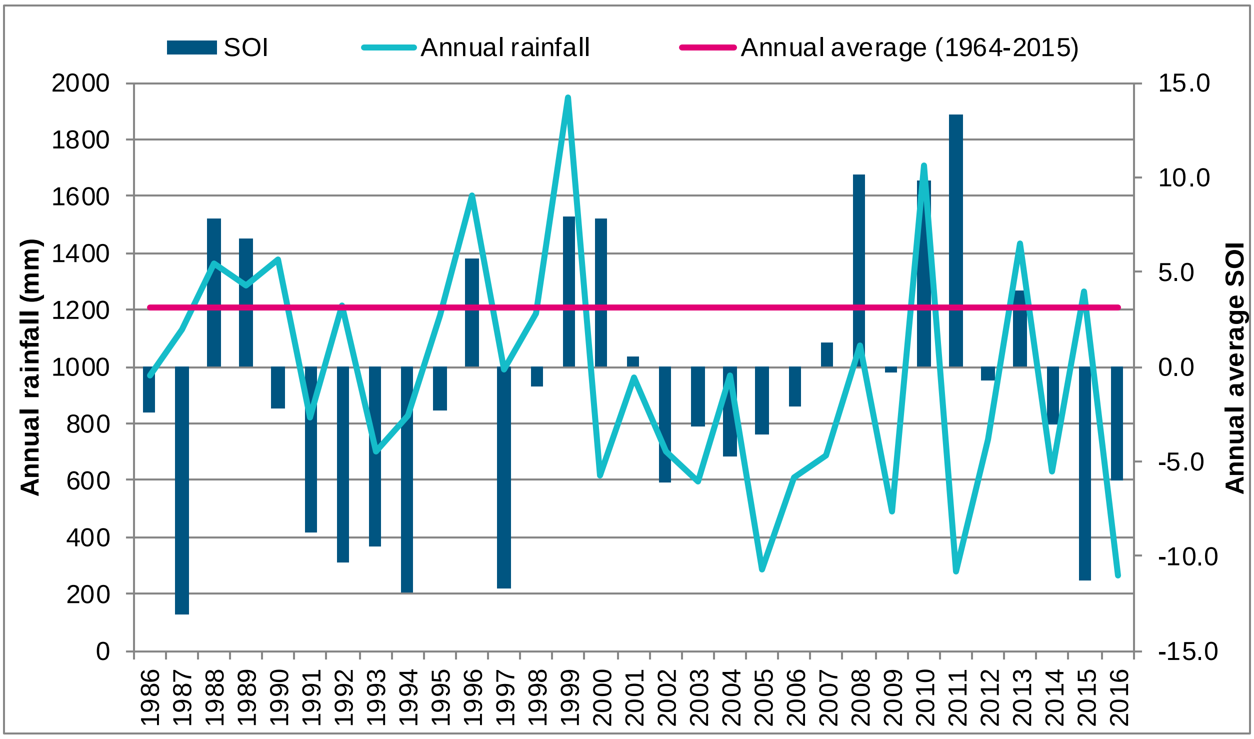


Figure 2-3 Annual rainfall at Fort Lytton and SOI

During and Post Construction of the FPE

The Port of Brisbane SMP commenced in 2002 (WBM 2002). The foundation report for the SMP (WBM 2002) was a detailed investigation that trialled a range of seagrass mapping and monitoring methods, including:

- Above and below ground seagrass biomass sampling (destructive techniques)
- Seagrass depth range (edge of meadow) using video camera
- Seagrass community profiling using video camera
- Mapping of seagrass meadows using Landsat satellite multispectral data and MODIS airborne hyperspectral data.

WBM (2002) sampled three locations:

- Test location - Fisherman Islands is adjacent to the major operational areas of the port and was therefore considered the most likely to be affected by port activities
- Control locations - Manly and Cleveland are located south of the port and outside the direct influence of port activities. It is acknowledged that changes to seagrass meadows at Fisherman Islands could potentially lead to indirect changes elsewhere, including Manly.

WBM (2002) recommended that future monitoring uses three indicators: seagrass depth range (edge of meadow), community profiling and meadow mapping (using aerial photography as a base). The sampling design recommended by WBM (2002) has been adopted in all subsequent seagrass monitoring episodes (see WBM 2003a; 2003b; 2004; 2005; BMT WBM 2006, 2010b, 2013, 2014). Multiple transect lines were established at each of these locations, although the position of some has changed to better capture long term changes in seagrass meadows.

Monitoring throughout the PBPL survey area between 2002 and 2006 found consistency in the size and composition of most meadows. This period included the completion of seawall construction for the Future Port Expansion (FPE) project in 2005. The 2010 monitoring event saw an expansion in the range of *Halophila ovalis* at all three survey locations.

In 2011 and 2013, major floods occurred in south east Queensland which affected the Brisbane River and other catchments which flow into southern Moreton Bay and influence the study area. The 2011 flood event resulted in the loss of approximately half of the seagrass area within parts of Moreton Bay. CSIRO estimated that seagrass cover had recovered within a year of the floods, but this estimate was based on Landsat imagery which has difficulty discerning deepwater seagrass distributions. The 2013 monitoring event undertaken by BMT WBM (2013) was the first assessment of the study locations since the flooding events in 2011 and 2013. Monitoring between 2006 and 2010 had seen large increases in seagrass cover at all locations, with a retraction back to pre-2010 levels observed in 2013. In 2014, the distribution of *Halophila ovalis* was more limited than recorded previously, whereas *Halophila decipiens* and *H. spinulosa* both increased their distribution at Manly and Cleveland. Despite these changes in meadow composition, overall meadow extent at all sites remained broadly consistent with 2014 patterns, with increased coverage compared to pre-2010 patterns.

2.1.2 Seasonality and Survey Timing

Seagrass meadows in Queensland naturally expand and contract over time in response to disturbance, seasonal growth patterns and water quality (particularly light) conditions (Mellors *et al*. 1993; McKenzie 1994). Within Moreton Bay, seasonal patterns in growth vary among species and in different locations. Preen (1992) sampled nine sites in eastern and western Moreton Bay over two years (eight episodes) and found the following general seasonal patterns:

- A distinct summer/autumn peak in shoot density was displayed for *Halophila spinulosa* and *H. ovalis*
- Shoot density of *Zostera capricornia* (= *muelleri*) peaked in spring (October) which is when shoot density of the other seagrass species tended to be lowest
- *Halodule uninervis* shoot densities had a slight peak in winter (July) although there was considerable overlap between seasons
- Large seasonal changes were displayed by *Halophila spinulosa* and *H. ovalis,* whereas *Zostera* and *Halodule uninervis* showed little seasonal change.

The Port of Brisbane SMP assessed seagrass meadows over winter and summer (WBM Oceanics Australia 2002, 2003a, 2003b, 2004) at Fisherman Islands, Manly and Cleveland. The SMP documented an expansion in total meadow extent (i.e. *Halophila* spp.) during winter months and contraction during summer. This contrasts with other workers (e.g. Preen 1992 in Moreton Bay, Sankey *et al*. 2011 in Gladstone) who found that *Halophila* species typically had lower biomass during winter than summer months.

It is important to note that temporal variability in other processes can affect seagrass and confound interpretations of seasonal patterns. For example, inter-annual changes in water quality (water temperature, turbidity, nutrients) as well as episodic disturbance (floods, dugong grazing), can lead to greater changes in seagrass meadow extent than seasonal cycles (e.g. Abal and Dennison 1996).

Monitoring events in 2004, 2006, 2010, 2013, 2014 and 2016 have been conducted in the winter months. Other seagrass workers in Moreton Bay (Roelfsema *et al.* 2009; 2011) have also targeted sampling during winter and early spring months. This timing takes advantage of the generally lower winds (and greater clearer waters) during winter, and removes the confounding influence of seasonality on detecting long term changes.

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Locality Plan

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3 Methodology

3.1 Timing

The field program for the 2016 seagrass monitoring event was undertaken between the 17th and 19th August, inclusive. Tidal data from the Tidal Unit, Maritime Safety Queensland was obtained for the Brisbane Bar throughout this study period (Figure 3-1) and was used to correct depth soundings to Australian Height Datum (AHD).

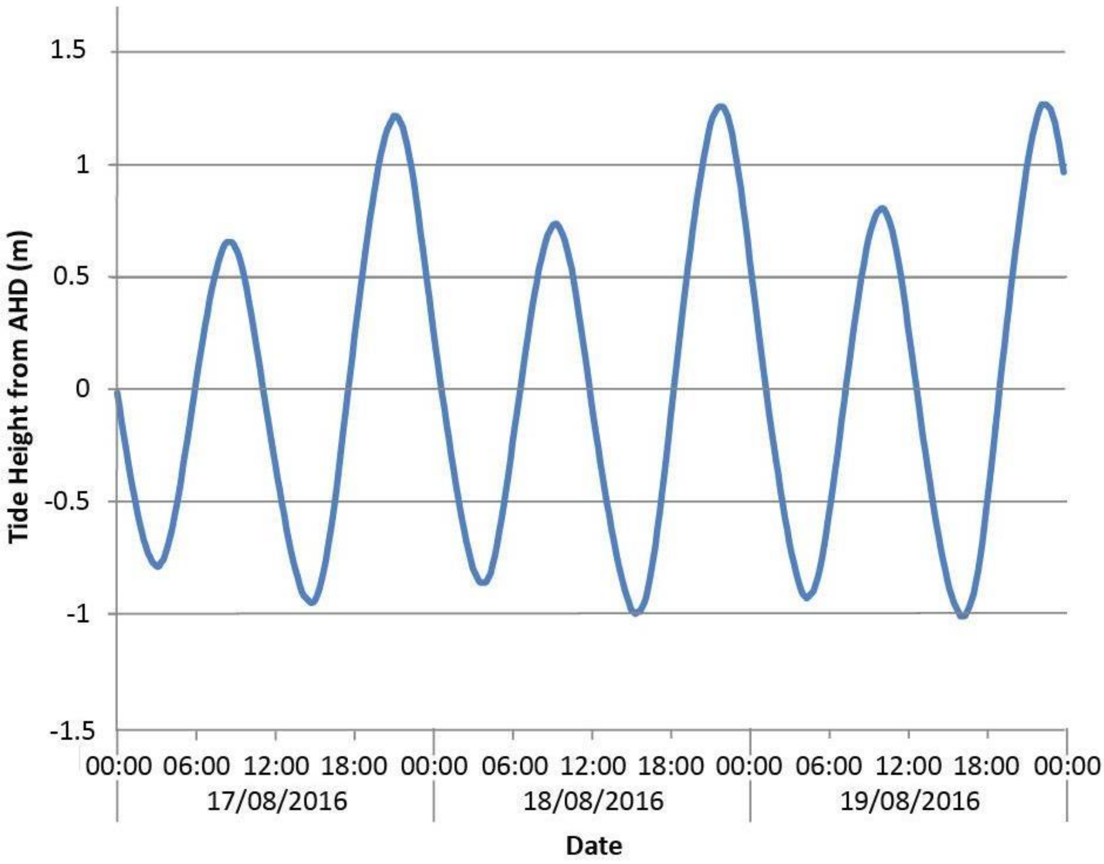


Figure 3-1 Tidal heights at Brisbane Bar during the study period

3.2 Survey Vessel and Positioning

All sampling was carried out using BMT WBM vessel '*Resolution II*'. Location and navigation to the sampling sites was undertaken using a real time differential Global Positioning System (dGPS) to provide position-fixing accuracy's of ±1m.

3.3 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). A pilot study for this monitoring program identified depth profiling and edge of meadow monitoring as the most suitable monitoring techniques. Sampling locations were Fisherman Islands (putative impact or test), Manly (control) and Cleveland (control) and monitoring sites for edge of meadow, depth profiling and general mapping were established at these locations (see Figure 3-3 to Figure 3-5).

3.3.1 Edge of Seagrass Meadow Monitoring

Sites were established at intervals along transects that traverse the known seasonal fluctuations in the deep-water edge of the seagrass meadow at each location. The approximate edge of each seagrass meadow was identified during the ground truthing of the mapping exercise undertaken during the pilot study (WBM Oceanics Australia 2002). The general distribution and extent of seagrass meadows was initially established by depth profiling (see WBM 2003a; b), which was used as guidance for positioning sites for this assessment method.

Along each transect, a number of permanent survey points were positioned at roughly 50-100m intervals (Figure 3-2), and recorded using a dGPS to ensure repeatability between surveys.

At each point along these transects, the seabed was surveyed using one (or both) of the following techniques. High-resolution cameras (capable of working under low-light conditions) with direct connection to a surface laptop were used to observe and record seabed features in real time. Video imagery was recorded and stored on an external hard drive by BMT WBM. At sites where poorer water quality or cryptic species were encountered, a van Veen grab sampler was used to collect samples of the seabed to confirm identifications made from the video imagery.

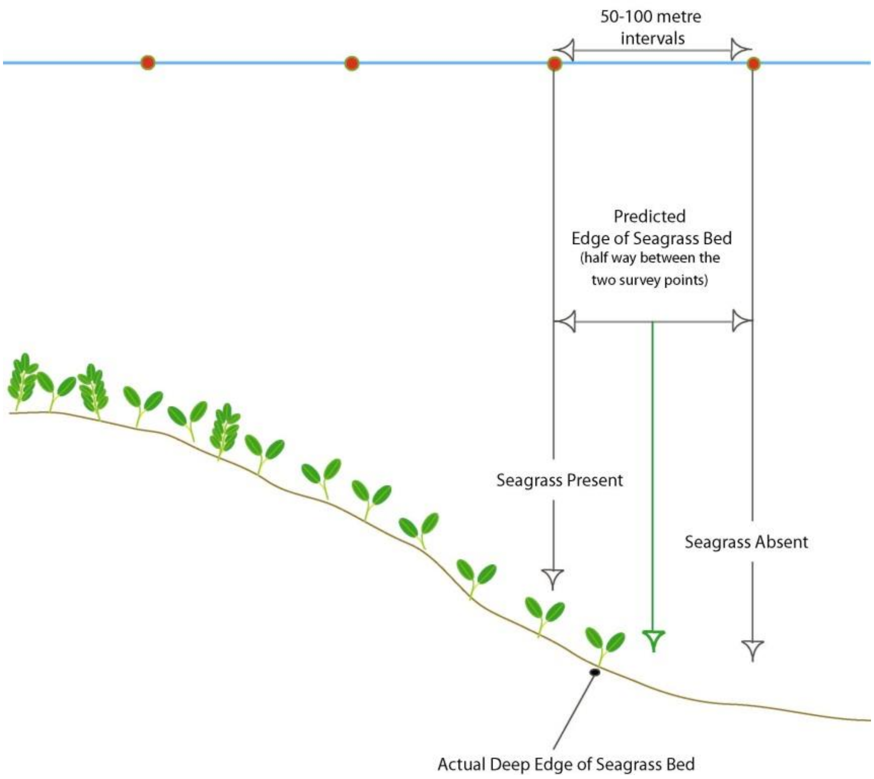


Figure 3-2 Permanent survey point method for identifying the edge of seagrass meadow

The surveys initially began at a shallow survey point where seagrass was thought to be present. The survey vessel then moved to the next point along the transect until seagrass could no longer be found on the seabed. The deep water edge of the seagrass meadow was assumed to be located mid-way between these two points. At each site, the depth of the seagrass and the time of survey were noted. Using this information and Brisbane Bar tidal data (Maritime Safety Queensland; 10 min interval), the depth of the seagrass meadow relative to the Australian Height Datum was calculated, enabling standardised depth comparisons between sites, locations and survey times.

3.3.2 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 and 2014.

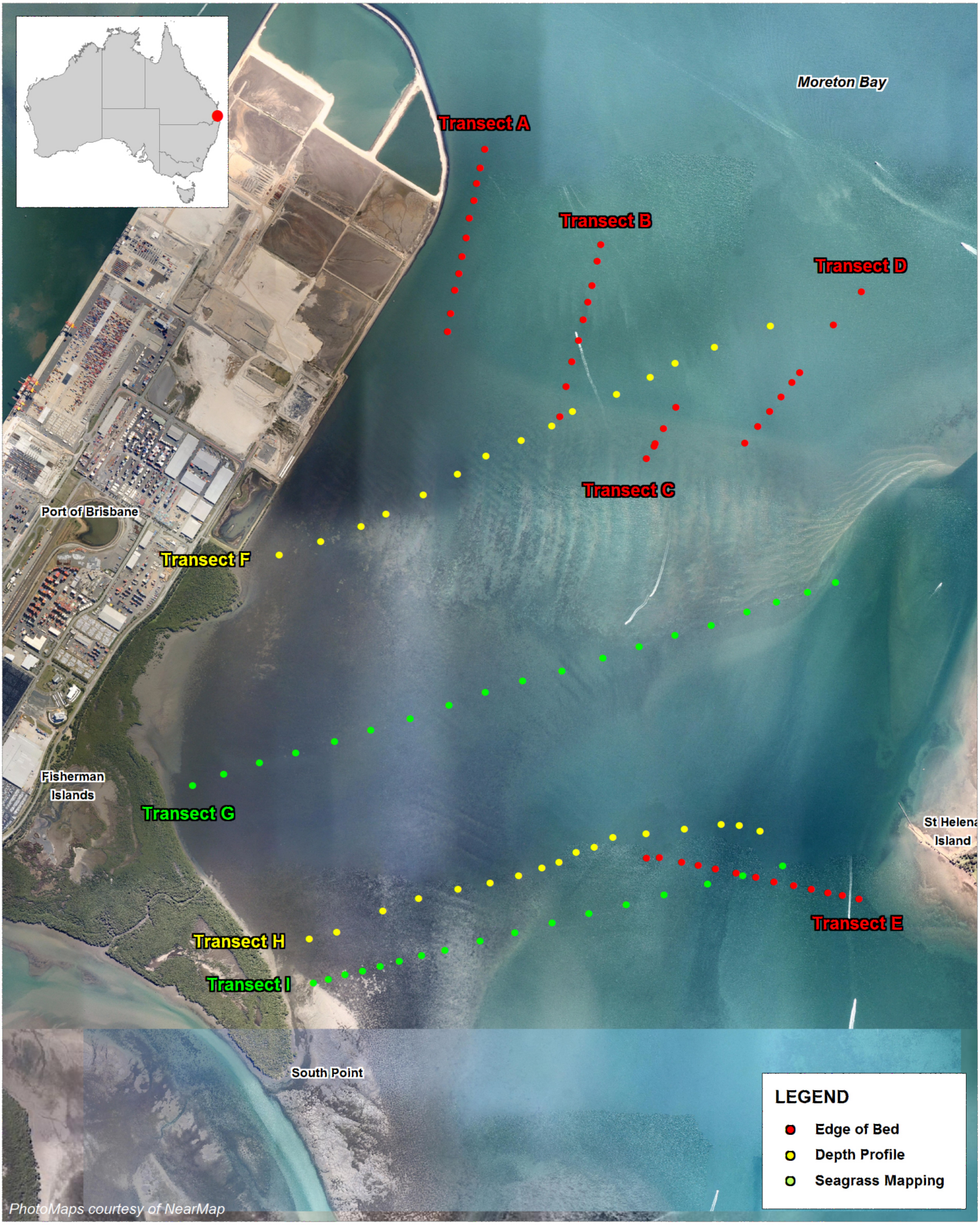
Two depth profile transects occur at each survey location, and run approximately perpendicular to the shoreline (Figure 3-3 to Figure 3-5). At each point along the profile transect, the following parameters were recorded: time, water depth (using the survey vessel's sounder), position (dGPS) and seagrass species (a video image was recorded at each point). The depth at each point was reduced 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.

3.3.3 Additional Seagrass Mapping Transects

Information from two seagrass mapping transects at the Port, in conjunction with depth profile transects and edge of meadow monitoring transects were also used to map the extent of seagrass meadows at Fisherman Islands, Manly and Cleveland (Figure 3-3 to Figure 3-5).

Consistent with depth profiling, at each point along the seagrass mapping transects the following parameters were recorded: time, water depth (using the survey vessel's sounder), position (dGPS) and seagrass species (a video image was also recorded at each point). The depth at each point was reduced to Australian Height Datum to enable comparisons between locations.



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Survey Points Used to Map the Distribution of Seagrass at Fisherman Islands, Adjacent to the Port of Brisbane

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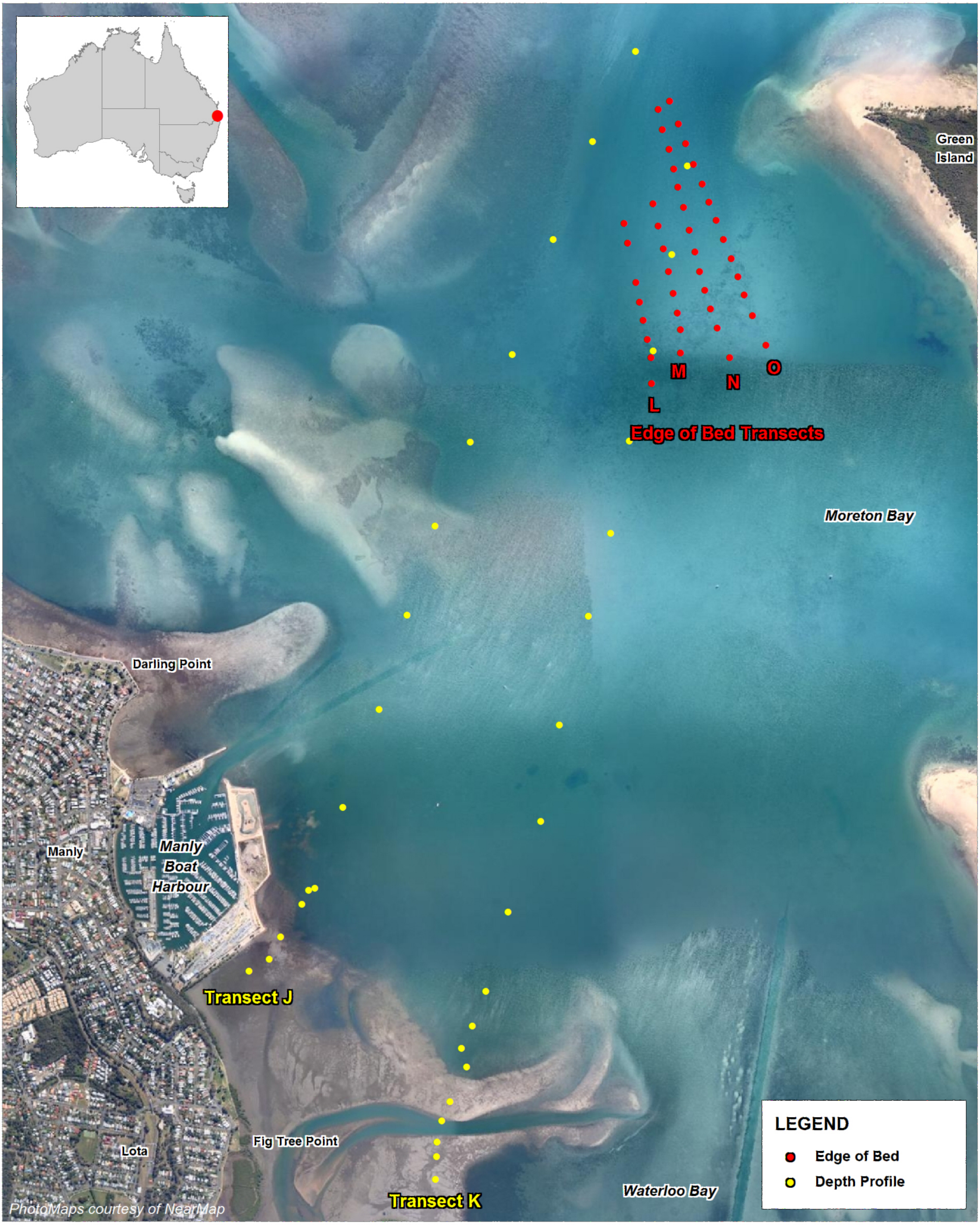

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Survey Points Used to Map the Distribution of Seagrass Adjacent to Manly

Figure: **3-4**

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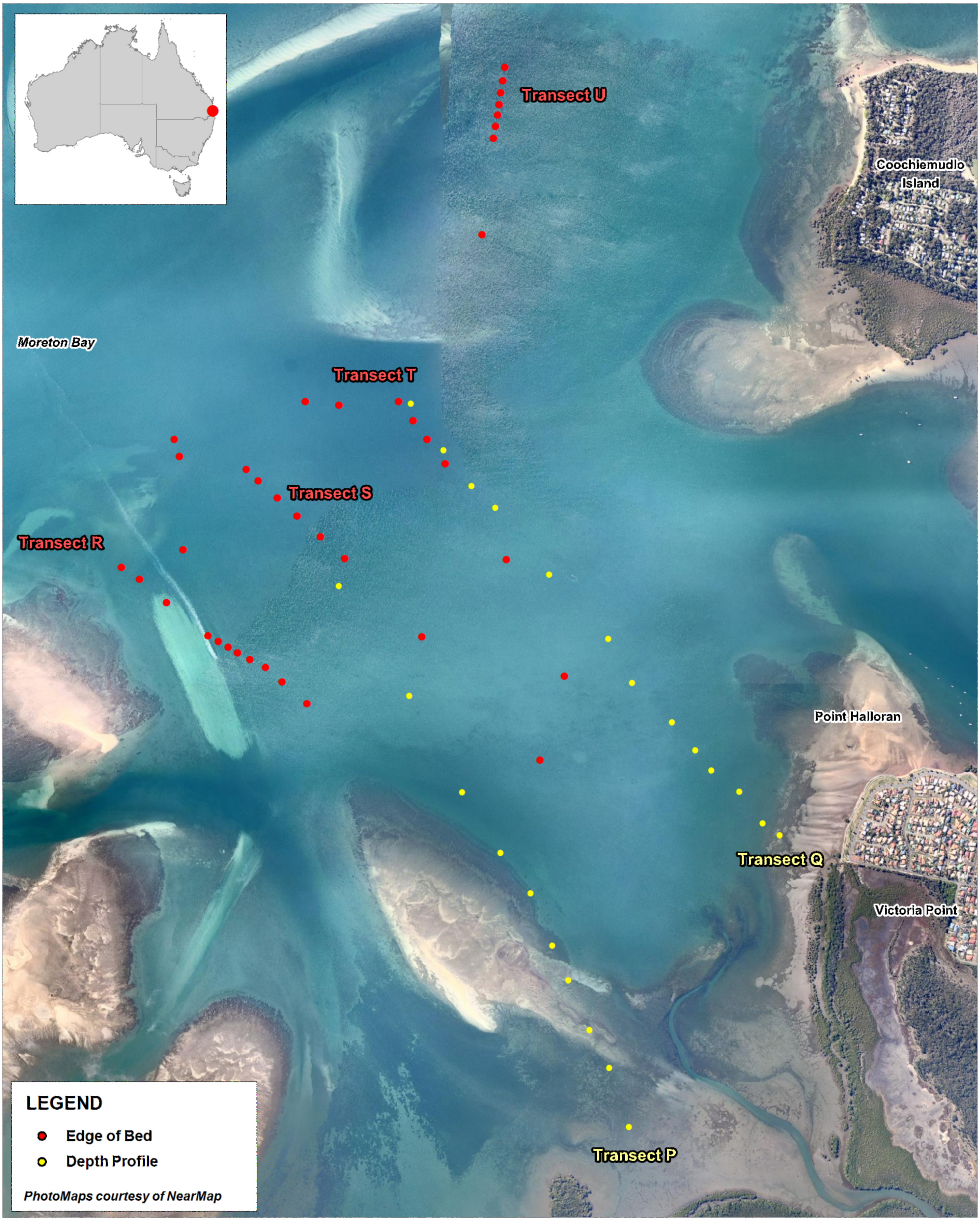

Title:

Survey Points Used to Map the Distribution of Seagrass Adjacent to Cleveland

Figure: **3-5**

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4 Results

4.1 Seagrass Species and their Distribution in 2016

Five seagrass species were recorded in the 2016 survey, consistent with previous years: *Zostera muelleri, Halodule uninervis, Halophila ovalis, Halophila spinulosa,* and *Halophila decipiens.*

Zostera muelleri

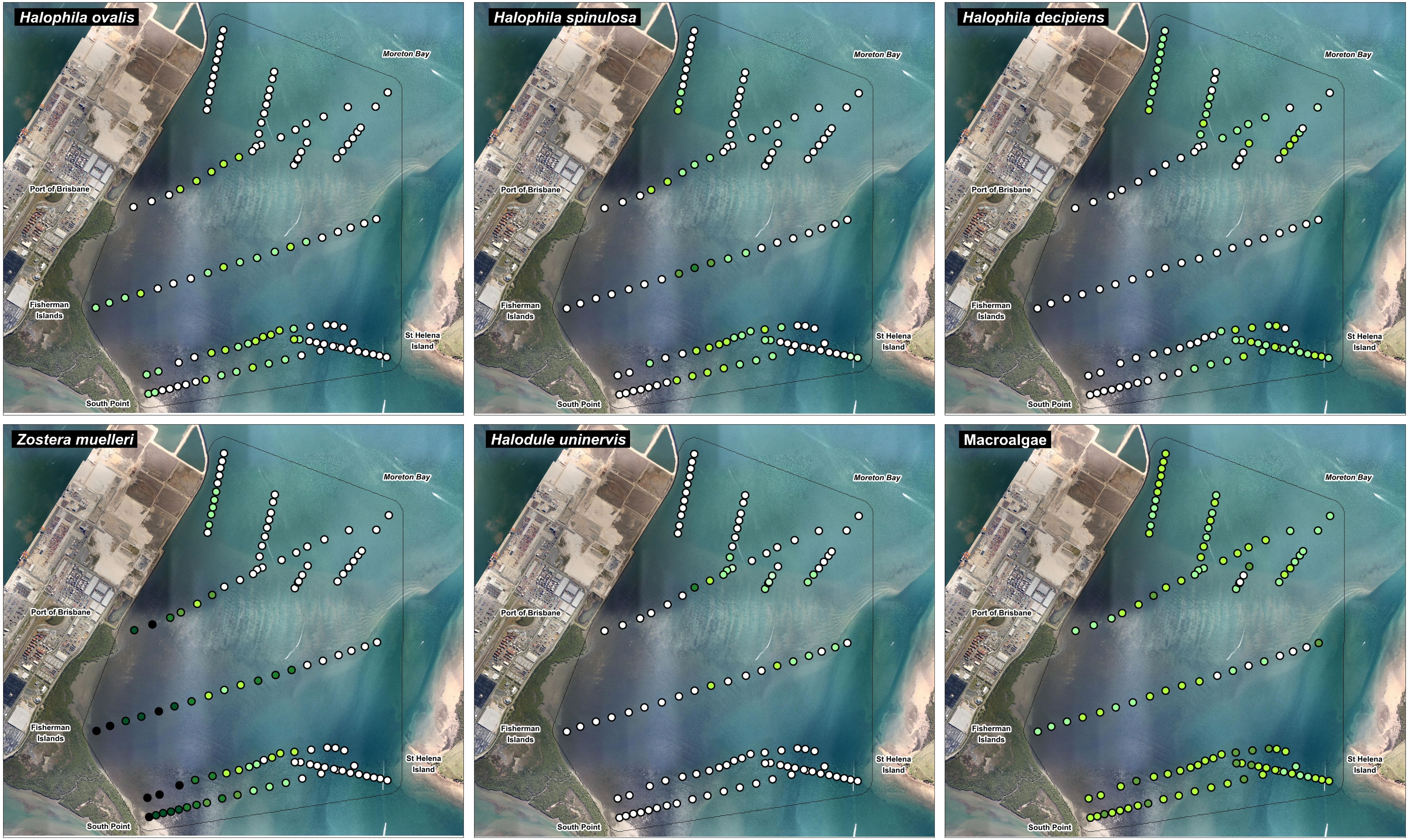
Halodule uninervis

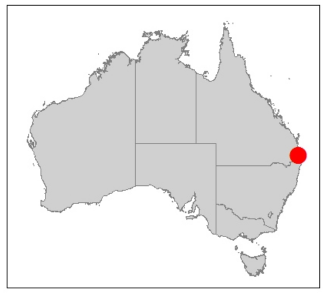
Halophila ovalis

Halophila spinulosa

Halophila decipiens

The spatial distribution of each seagrass species are shown in Figure 4-1 to Figure 4-3, and Figure 4-4 is a composite seagrass assemblage map for Fisherman Islands derived from survey data and interpretation of Landsat satellite data (see Section 1.1) and high resolution aerial photography (Nearmap – 1 July 2016). Spatial patterns of seagrass species are described in Section 4.2.1.





LEGEND

Coverage %

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

Survey Site

PhotoMaps courtesy of NearMap

Title:

Species Distributions at Fisherman Islands, adjacent to the Port of Brisbane in 2016

Figure: 4-1

Rev: A

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N

0 1 2km

Approx. Scale

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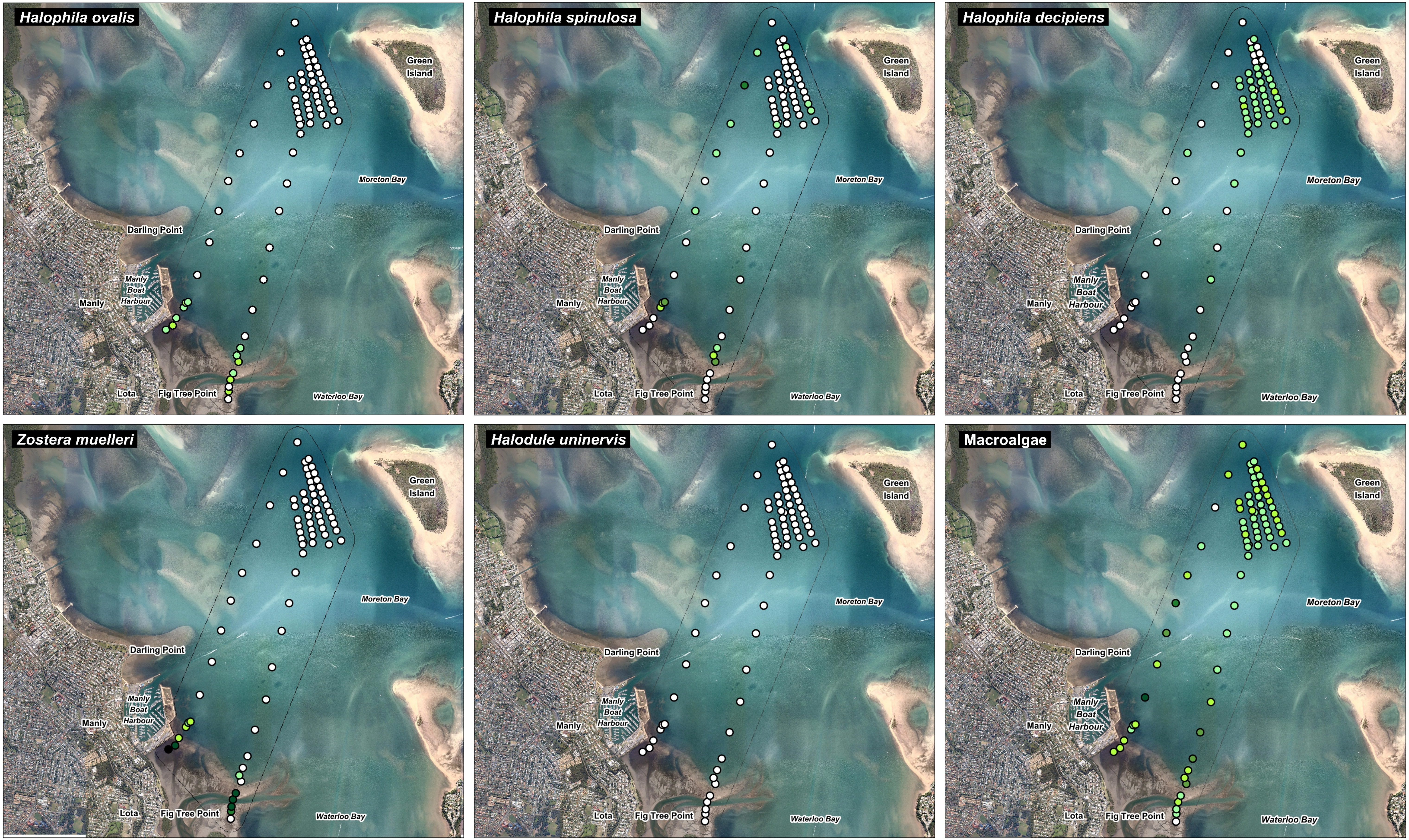

LEGEND

Coverage %

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

Survey Site

PhotoMaps courtesy of NearMap

Title:

Species Distributions at Manly in 2016

Figure 4-2

Rev: A

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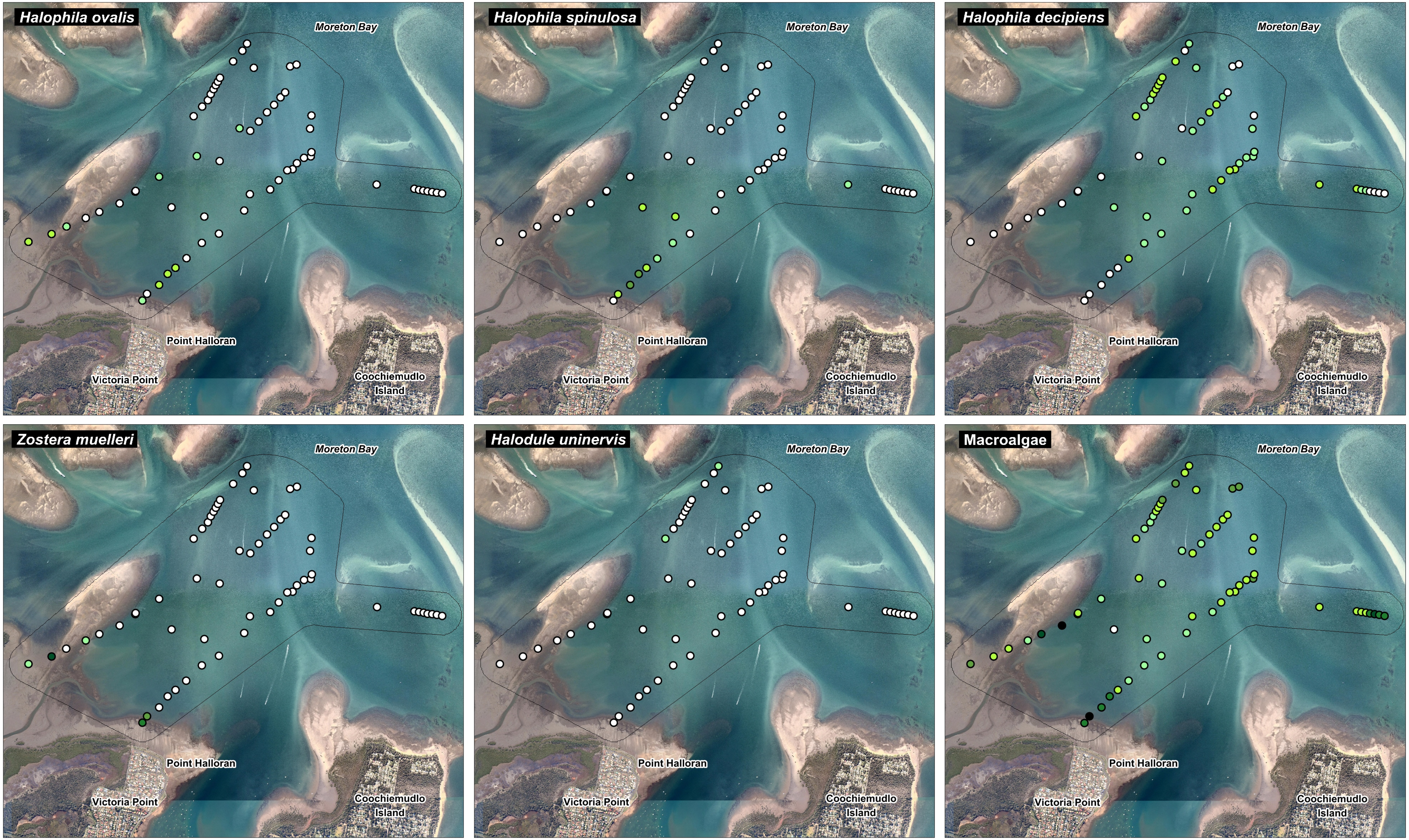

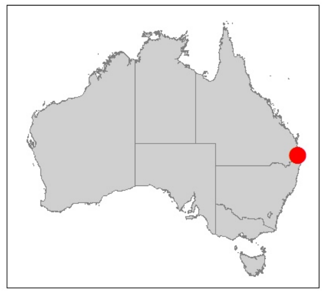

LEGEND

Coverage %

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

Survey Site

PhotoMaps courtesy of NearMap

Title:

Species Distributions at Cleveland in 2016

Figure: **4-3**

Rev: **A**

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Approx. Scale

BMT WBM

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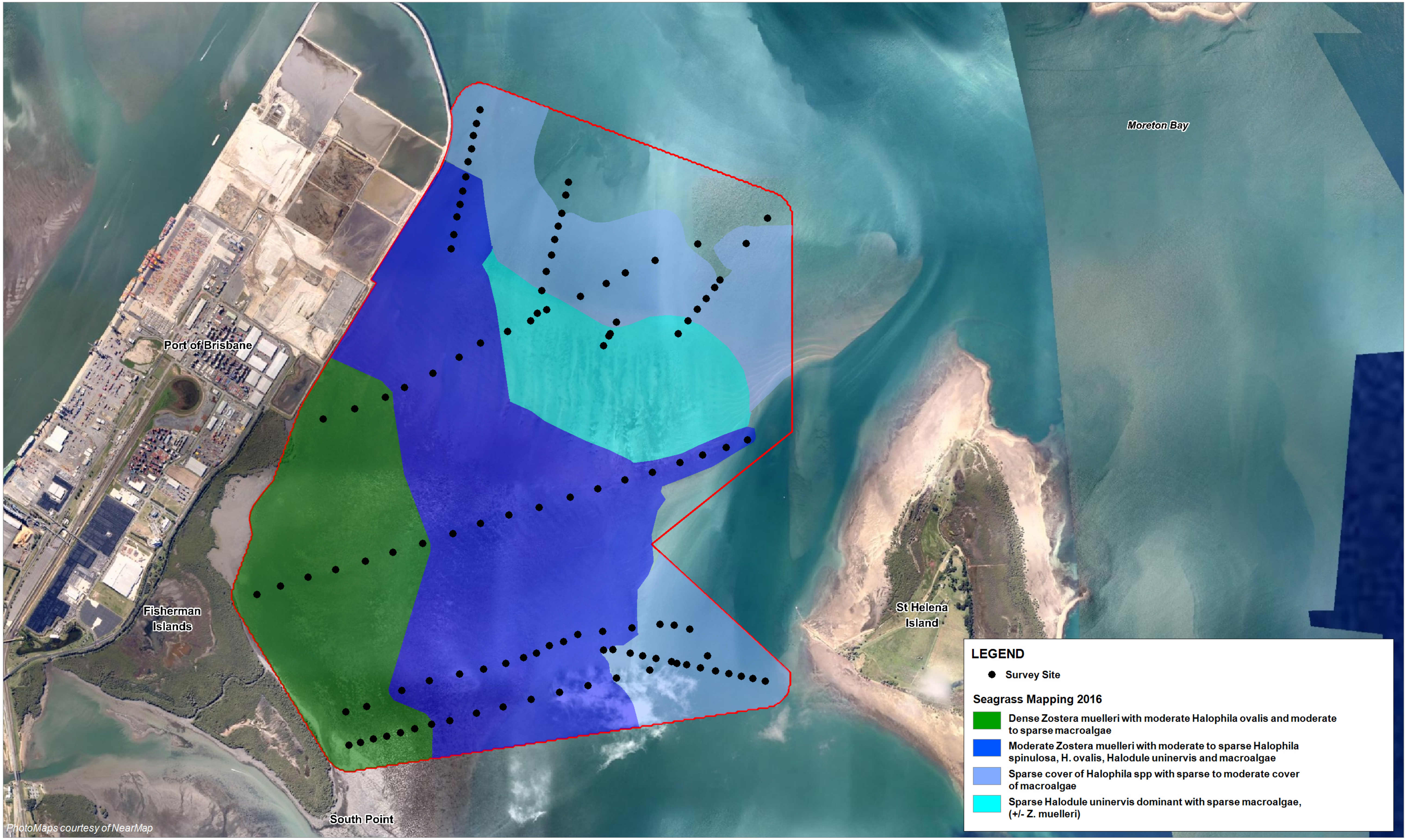

Title:

Seagrass Distribution and Community Structure Adjacent to Port of Brisbane in 2016

Figure 4-4

Rev: C

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Approx. Scale

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4.2 Seagrass Depth Range (SDR) and Assemblage Structure

Figure 4-5 to Figure 4-10 are pictorial representations of seagrass assemblages along depth profile transects[2]. Table 4-1 shows the maximum recorded depths of seagrass species (seagrass depth range – SDR) on depth profiles in the period 2006-2016, along with a rating based on the SDR for each period relative to the historical maximum recorded SDR. Note that as *Halophila 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.

Table 4-1 Comparison of SDRs (maximum recorded depth in meters relative to Australian Height Datum, AHD) of seagrass species on permanent transects at each location in 2006, 2010, 2013, 2014 and 2016

	Transect	Species*	2006	2010	2013	2014	2016	Mean	CoV
Cleveland	P	Ho	-5.9	-6.4	-6.2	-4.8	-3.6 (↓)	-5.5	-19.1
		Hd			-5.1	-6.4	Absent (↓)	-4.7	-26.9
		Hs	Absent	-3.4	-3.5	-4.8	Absent (↓)	-2.0	-84.0
		Zm	-1.3	-0.8	-0.6	-0.7	-0.7 (↔)	-2.7	-85.9
	Q	Ho	-5.7	-6.2	-5.7	-2.7	-2.5 (↓)	-4.7	-30.4
		Hd			-4.6	-4.6	-5.9 (↑)	-4.1	-25.0
		Hs	-3.2	Absent	-3.7	-4.0	-2.9 (↓)	-2.2	-55.4
		Zm	-0.6	-1.5	-1.8	-1.4	-1.0 (↔)	-2.2	-63.4
Manly	J	Ho	-2.2	-4.9	-4.5	-2.0	-2.1 (↔)	-3.5	-34.4
		Hd			-4.5	-4.4	-3.5 (↓)	-3.7	-16.7
		Hs	-2.6	-4.0	-3.4	-3.4	-4.1 (↑)	-2.7	-34.3
		Zm	-2.2	-2.3	-1.6	-1.5	-2.1 (↑)	-2.8	-84.6
	K	Ho	-0.4	-8.8	-5.0	-2.1	-2.2 (↔)	-3.9	-65.0
		Hd			-5.0	-3.7	-4.0 (↑)	-3.9	-22.2
		Hs	Absent	-4.4	-4.0	-3.9	-2.2 (↓)	-2.6	-48.8
		Zm	-2.1	-2.2	-0.4	-2.1	-2.2 (↔)	-2.5	-57.2
Fisherman Islands	F	Ho	-3.8	-5.7	-2.2	-2.0	-1.8 (↓)	-3.4	-41.8
		Hd			Absent	-4.0	-4.1 (↔)	-3.1	-38.2
		Hs	-3.8	-4.3	-2.2	-1.6	-1.8 (↑)	-2.3	-41.2
		Zm	-2.0	-2.5	-1.8	-1.7	-1.6 (↔)	-2.4	-34.6
	H	Ho	-2.6	-4.6	-2.5	-2.4	-2.4 (↔)	-3.4	-33.9
		Hd			-2.9	-5.1	-5.0 (↓)	-3.2	-33.5
		Hs	-2.5	-2.3	-2.5	-2.4	-3.0 (↑)	-2.3	-22.9
		Zm	-1.3	-2.3	-1.5	-2.4	-2.4 (↔)	-2.0	-29.0

SDR relative to historical maximum: Max | 1-20% max | 20-50% max | <50% max | Not applicable

Trend since 2014: ↑ improvement, ↔ stable (within 0.1 m of 2014), ↓ 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 (generic benchmark for the purpose of this study)

[2] Refer to BMT WBM (2013, 2014) for survey results from May 2003 and July 2006.

4.2.1 Spatial Patterns in 2016

Seagrass

Patterns in the species distributions of marine vegetation on depth profiles in August 2016 are as follows:

- *Zostera muelleri* formed dense meadows in the intertidal zone at the landward edge at each location and typically extended into the shallow subtidal waters (maximum *Z. muelleri* SDR = -2.4 m AHD at Fisherman Islands). Intertidal meadows were comprised largely of dense mono-specific stands of *Z. muelleri* with occasional patches of *H. ovalis*. Subtidal meadows were usually mixed with other species, including *H. ovalis, H. spinulosa* and *H. uninervis.*
- *Zostera muelleri* had a broader distribution at Fisherman Islands than at Manly or Cleveland, reflecting differences in habitat availability (i.e. the presence of a broad, low gradient shoal at Fisherman Islands).
- *Halophila decipiens* and *H. spinulosa* were the deepest growing species, reaching depths of -5.9 m (Cleveland transect Q) and -4.1 m (Manly transect J), respectively.
- *Halophila ovalis* was generally more abundant in intertidal and shallow subtidal areas than deeper waters, but was recorded at depths of -3.6 m AHD at Cleveland, -2.2 m AHD at Manly, and -2.4 m AHD at Fisherman Islands.
- *Halophila spinulosa* generally had low cover of less than 5% coverage, with some localised patches of 20% coverage at all three locations.
- *Halophila decipiens* had less than 5% cover on most depth profiles at the three locations. However, on two profiles, one at both Fisherman Islands and Cleveland, it had 10% coverage within subtidal areas. The maximum recorded growing depth of *H. decipiens* -5.89 m AHD (at Cleveland). *Halophila decipiens* was recorded in deeper waters than *H. ovalis*, and were infrequently recorded together (less than 3% of all survey points). *Halophila decipiens* formed either sparse mono-specific meadows (less than 5%) or mixed meadows with *H. spinulosa*.
- *Halodule uninervis* was present in shallow subtidal areas at Fisherman Islands and Cleveland. *H. uninervis* was not recorded at Manly. *Halodule uninervis* was recorded at water depths of -1.23 m to -3.19 m AHD at Fisherman Islands, where it occurred in mixed meadows with *H. ovalis* and *H. spinulosa*. There was also some slight overlap in distribution with *Z. muelleri* at Fisherman Islands. *Halodule uninervis* was not recorded at Manly but recorded in moderate depths up to 5 m at Cleveland, mostly in the northern area of the study area.

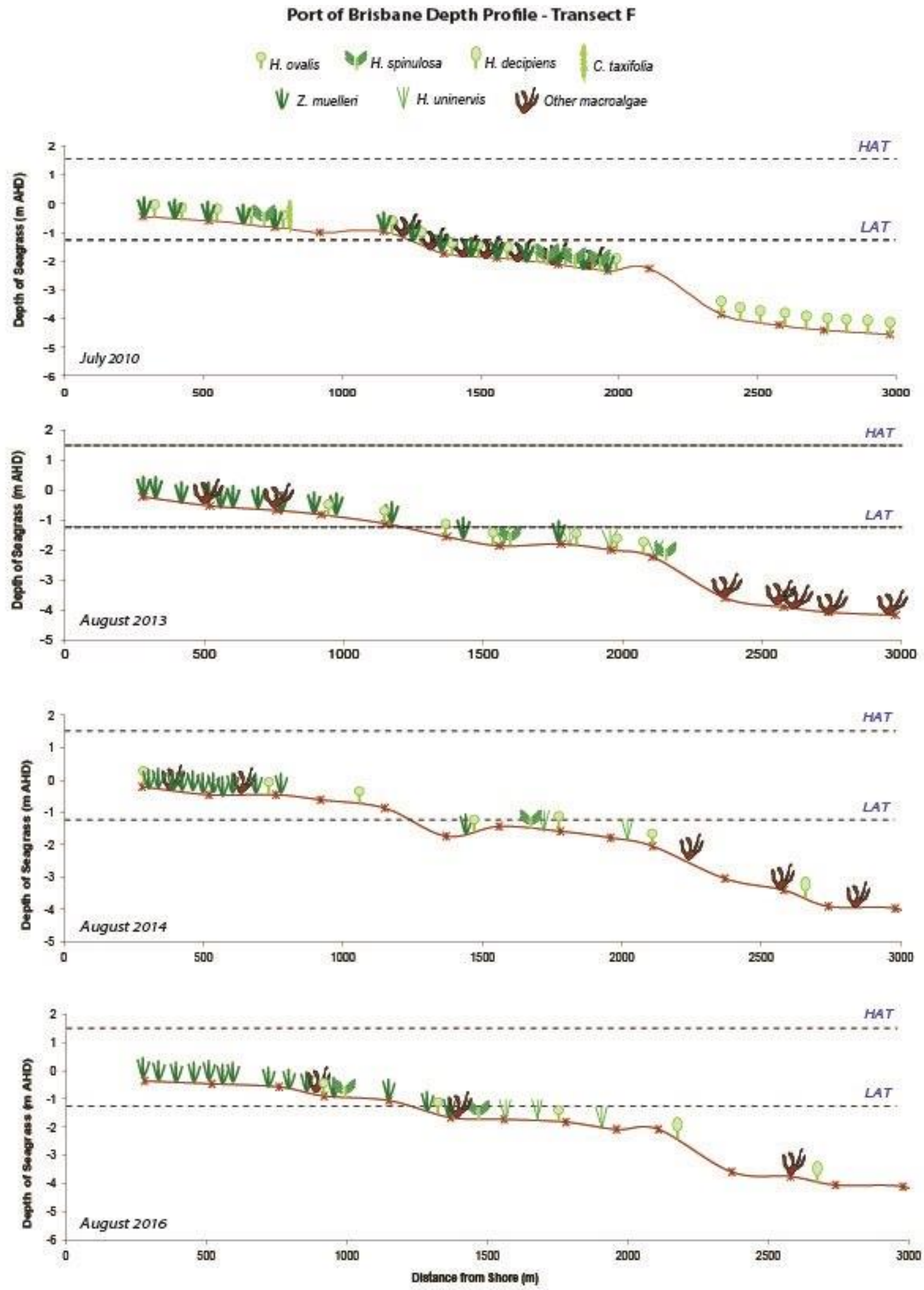

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Figure 4-5 Schematic representation of seagrass species distributions from 2010, 2013, 2014 and 2016 from depth profiling at Transect F at Fisherman Islands

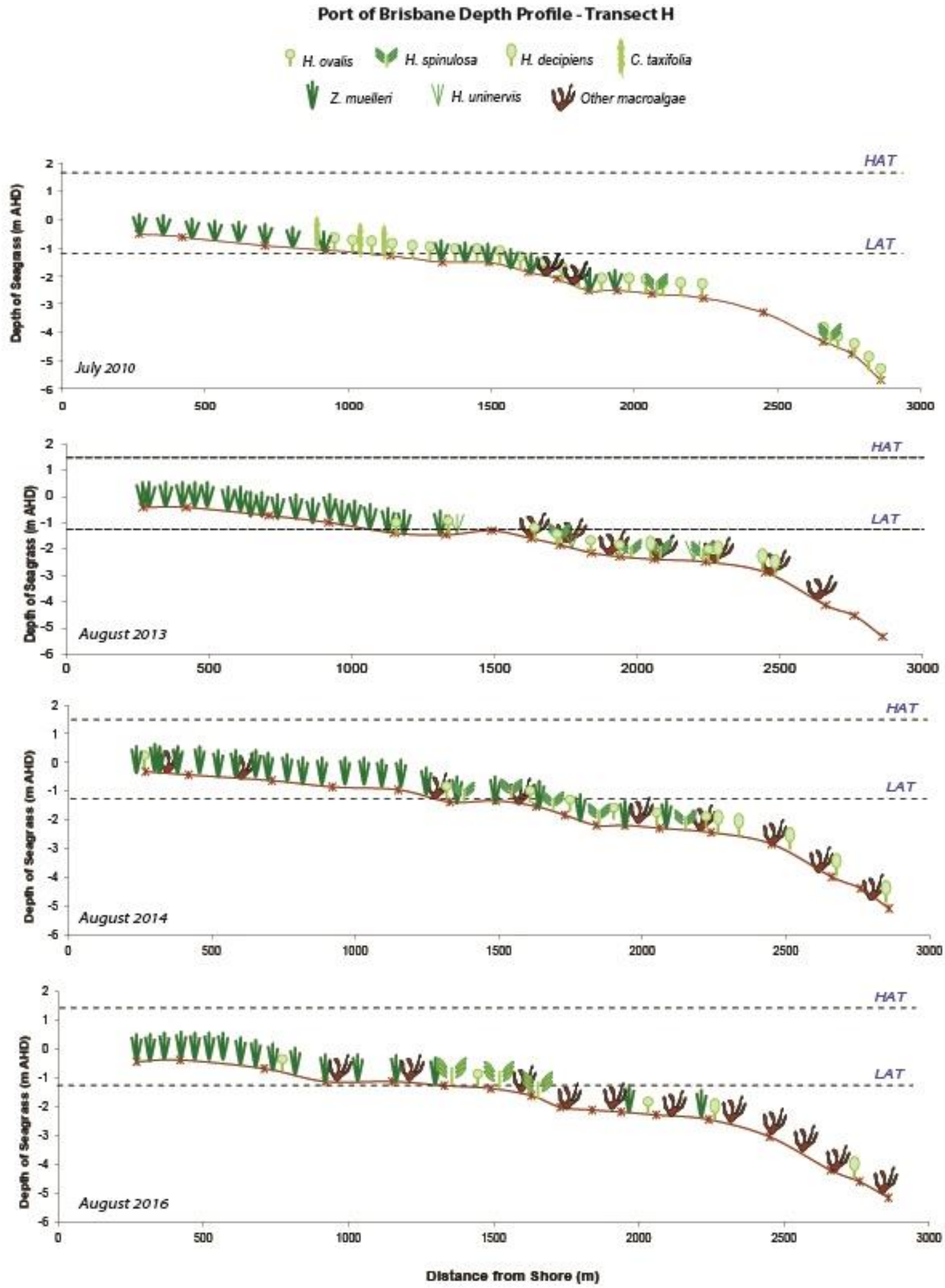

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Figure 4-6 Schematic representation of seagrass species distributions for 2010, 2013, 2014 and 2016 from depth profiling at Transect H at Fisherman Islands

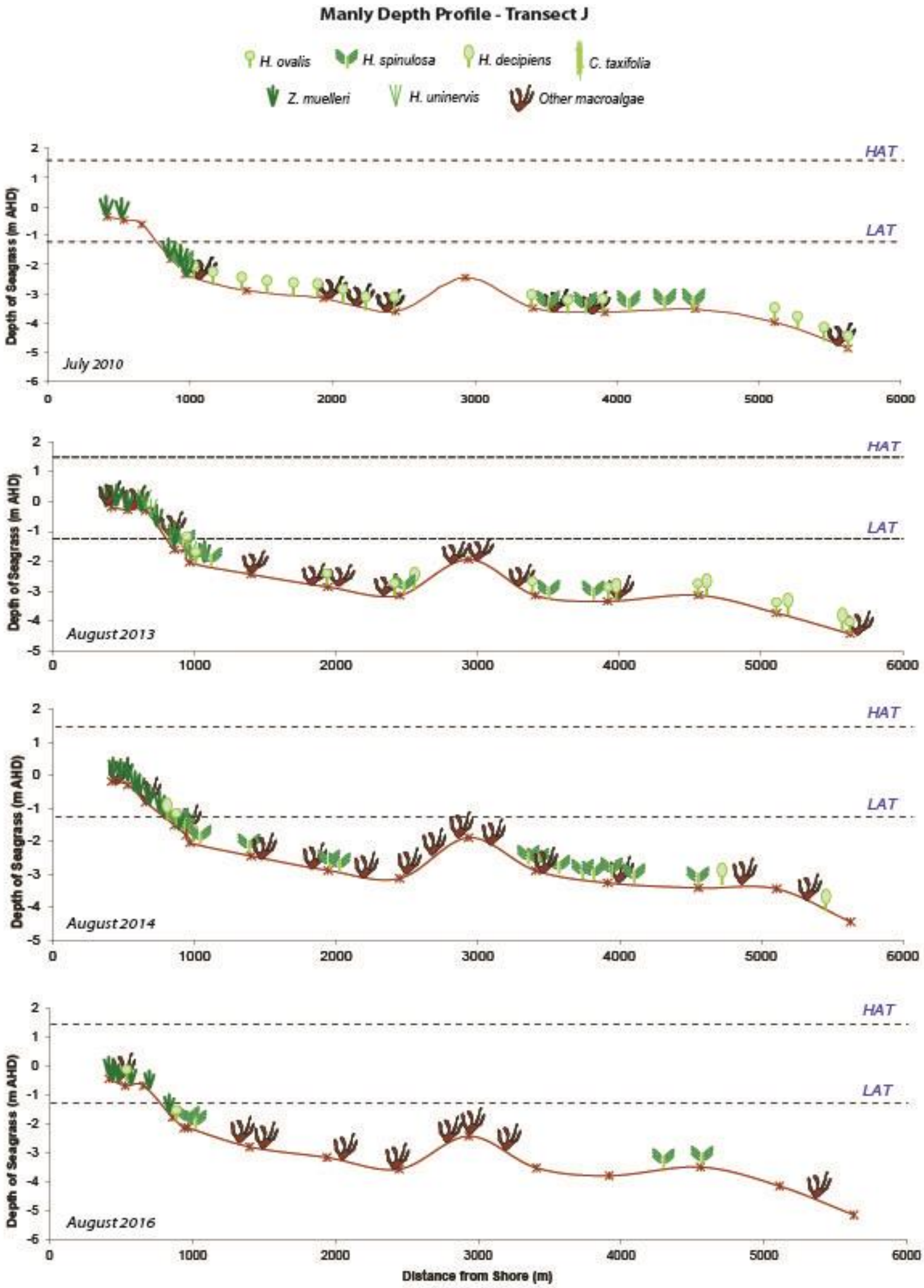

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Figure 4-7 Schematic representation of seagrass species distributions for 2010, 2013, 2014 and 2016 from depth profiling at Transect J at Manly

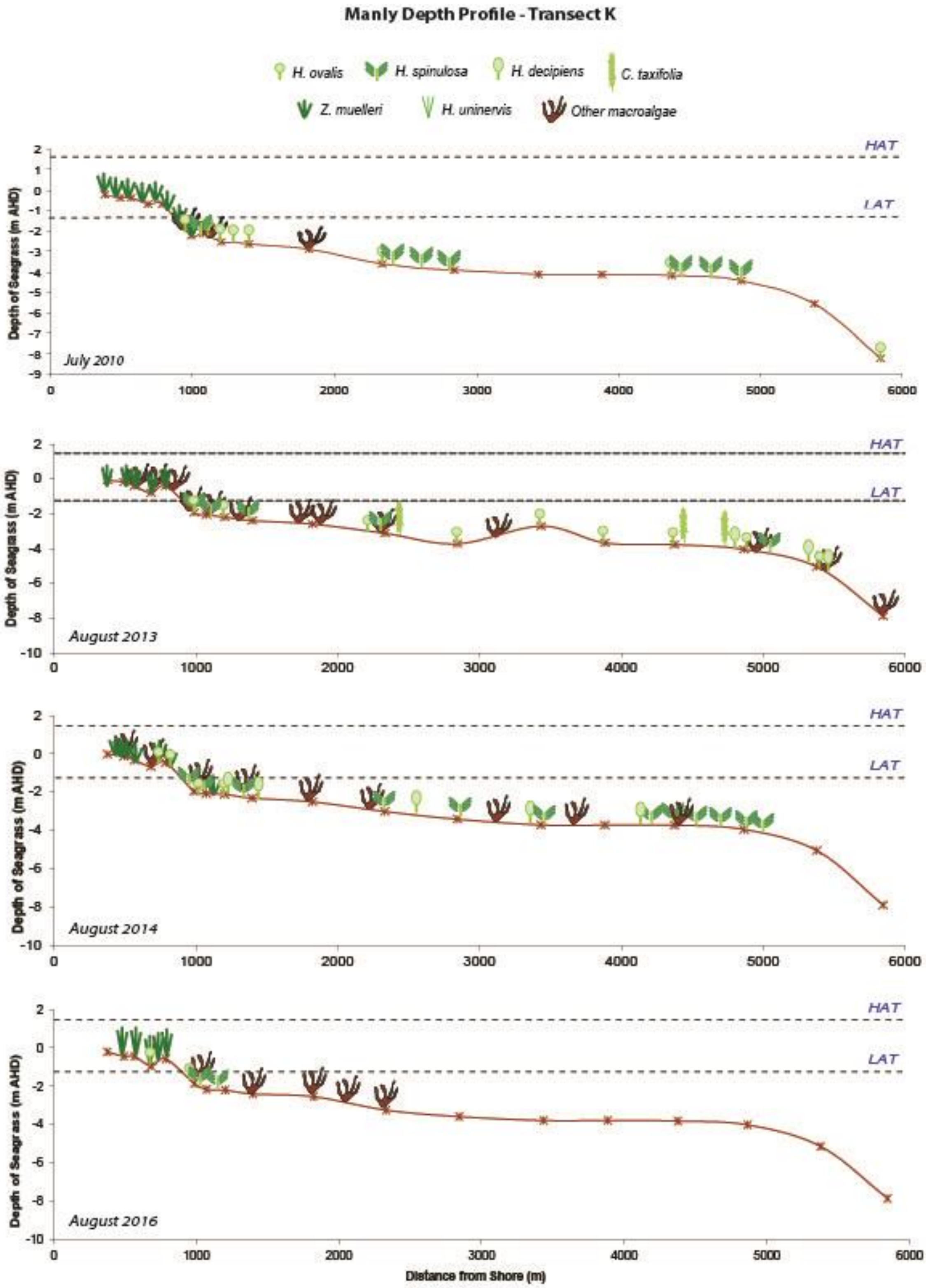

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Figure 4-8 Schematic representation of seagrass species distributions for 2010, 2013, 2014 and 2016 from depth profiling at Transect K at Manly

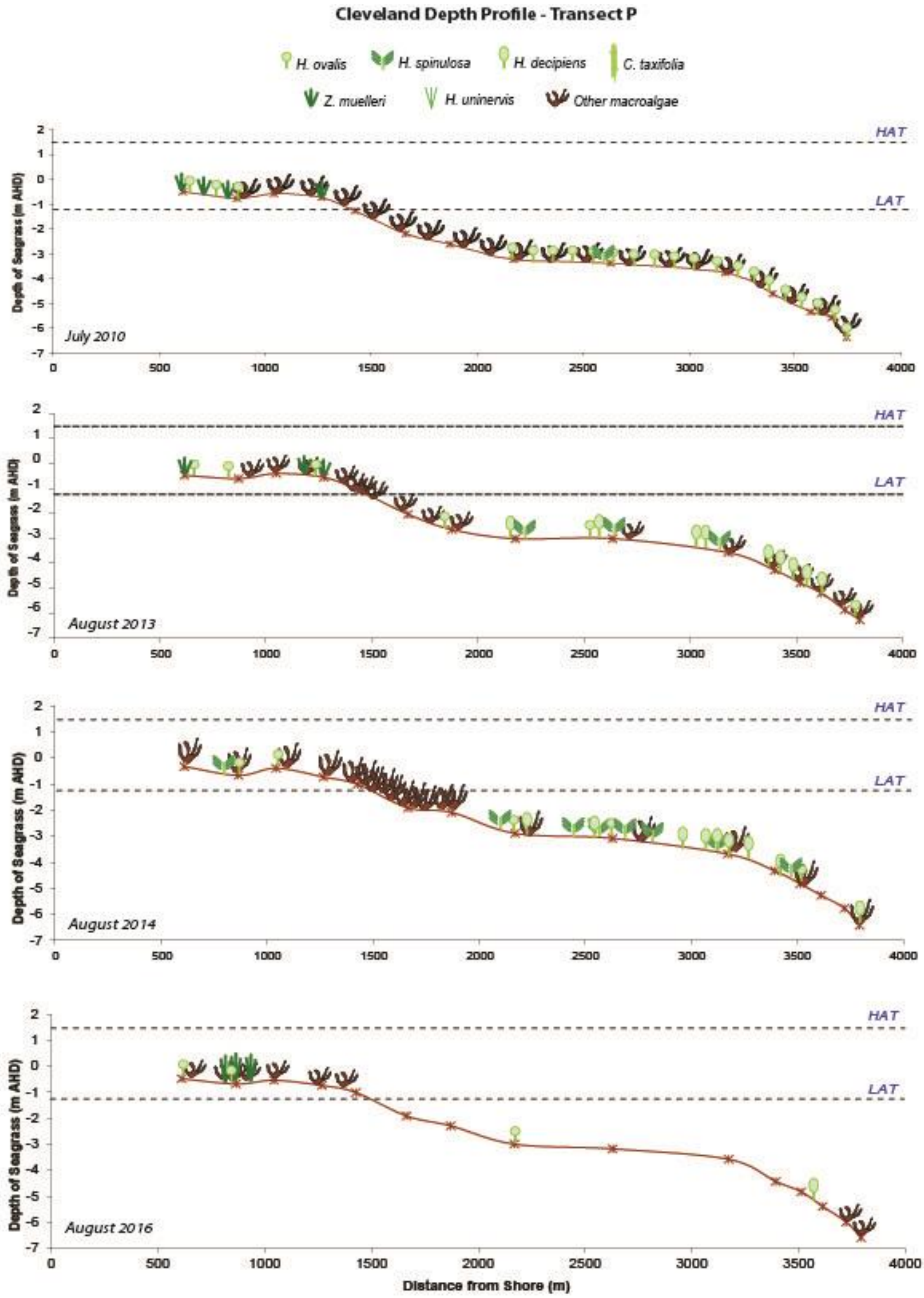

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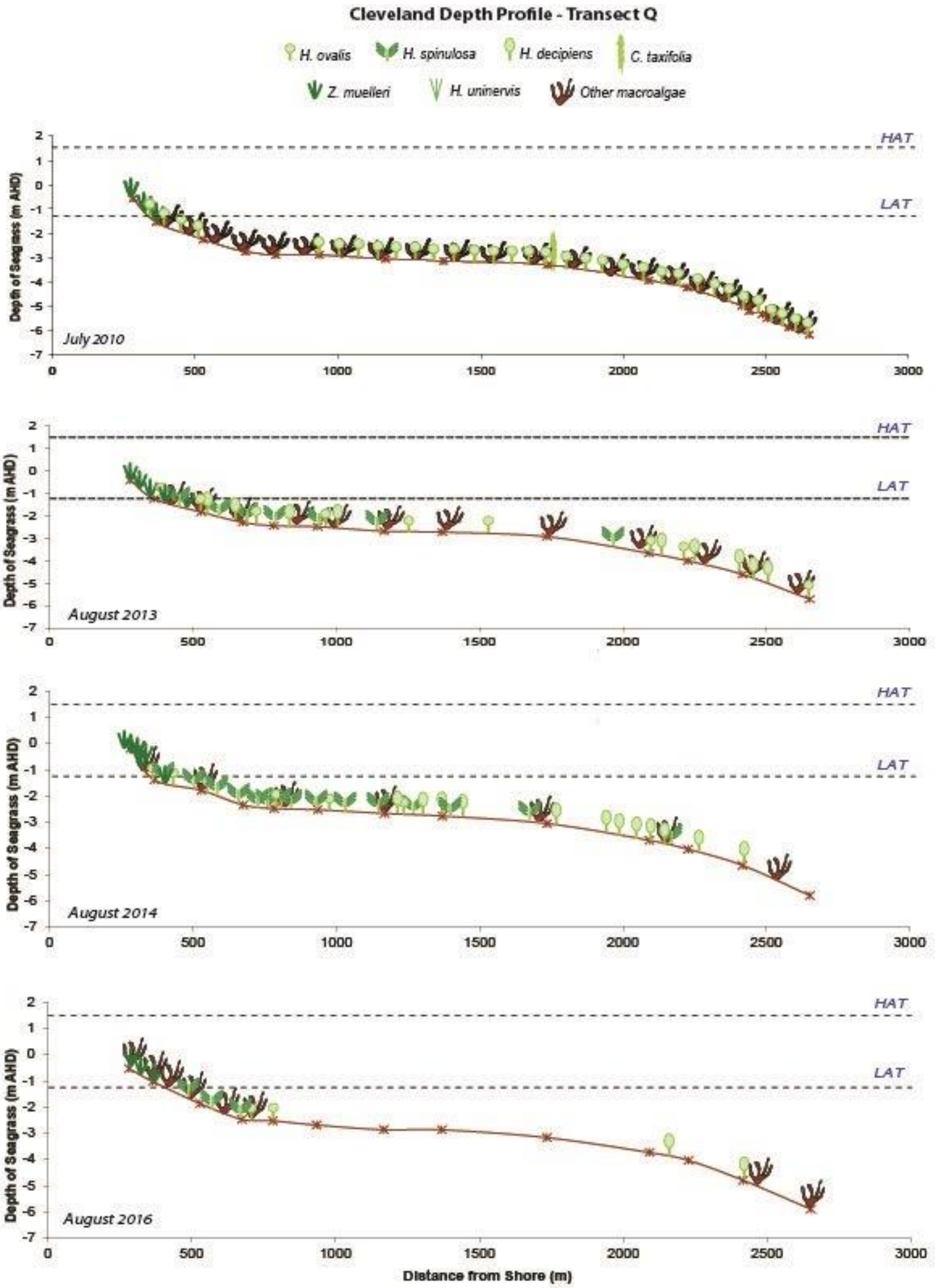
Figure 4-9 Schematic representation of seagrass species distributions for 2010, 2013, 2014 and 2016 from depth profiling at Transect P at Cleveland



J:\B20259.j.dtm_POB Monitoring\8. Seagrass\2016\Depth Profiles\Cleveland Transect Q 2016.jpg

Figure 4-10 Schematic representation of seagrass species distributions for 2010, 2013, 2014 and 2016 from depth profiling at Transect Q at Cleveland

Macroalgae

Macroalgae was recorded on all transects, and were recorded at depths between 0.17 m and 8.91 m. Macroalgae formed both mono-specific and mixed meadows with seagrass.

Consistent with previous surveys, the most abundant macroalgae species in 2016 were *Sporochnus comosus, Hypnea spinella, Spyridia filamentosa* and other filamentous alga comprising *Hincksia (Giffordia) mitchellae, Ectocarpus fasciculatus* and *Lyngbya majuscula* (see Figure A-2). In contrast to previous surveys (pre-2011), *Caulerpa taxifolia* was not a dominant component of the benthic community. Overall, macroalgae were denser at Manly and Cleveland than at Fisherman Islands.

4.2.2 Temporal Patterns

Table 4-1 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.

Overall, the 2010 survey episode generally represented the maximum recorded SDR values for most species and sites. There was a decline in SDR values for most species and transects between 2010 and 2013, and since this time seagrass has been in a state of recovery. Seagrass meadows at Transect H (Fisherman Islands) had recovered in 2014 to 2016, whereas most other sites and species (including Transect F at Fisherman Islands) were still well below the historical maximum.

Zostera muelleri SDR, a key indicator of long-term patterns in water quality, showed complex spatial and temporal patterns. In summary:

- There was a trend of declining SDR over time at Cleveland (transects P and Q) and Fisherman Islands (transect F)
- SDR in 2014-2016 was near or greater than 2010 levels at Manly (transects J and K) and Fisherman Islands (transect H).

The coefficient of variation (CoV) was calculated to assess the degree of temporal variability in seagrass SDR within transects (Table 4-1). With few exceptions, the CoV for SDR was generally higher at Manly (17-85%) and Cleveland (19-86%) than at Fisherman Islands (<42%). This indicates that SDR was typically more stable at Fisherman Islands than control locations.

4.2.3 SDR Water Quality Objective

The *Zostera muelleri* SDR water quality objective (WQO) for Waterloo Bay was used as a benchmark[5] to assess seagrass condition. Compliance with the WQO varied over time and at a variety of spatial scalers. Transects that met the WQO were:

- Fisherman Islands transect H (2010, 2014, 2016) and F (2006 and 2010)
- Manly transect J (2006, 2010, 2016) and K (2006, 2010, 2014, 2016).

[5] the WQO was derived based on the median value based on 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

None of the Cleveland transects met the WQO.

4.3 Edge of Seagrass Meadows

The approximate boundary of the seaward (deep) edge of seagrass meadows at Fisherman Islands, Manly and Cleveland over time are shown in Figure 4-12 to Figure 4-14. The seaward margin of seagrass meadows at Fisherman Islands was consistently shallower than the two control locations (Figure 4-11). At Fisherman Islands, there was an overall expansion of the seaward extent of seagrass meadows at Fisherman Islands in 2016 compared with 2014 (Figure 4-12), but the seaward margin of seagrass meadows in 2016 was slightly less than the maximum extent recorded in 2010.

Temporal trends in seagrass meadow extent at Cleveland were similar to Fisherman Islands. In this regard, there was a decrease in meadow extent between 2010 and 2013, but an overall expansion between 2014 and 2016, despite contractions observed on several transects (Figure 4-14). The similar temporal patterns at Cleveland and Fisherman Islands suggest that processes operating over broad scales (i.e. western Moreton Bay) controlled seagrass meadow extent.

Seagrass meadows at Manly had more complex temporal patterns that were not always consistent with that at Cleveland and Fisherman Islands (Figure 4-13). In this regard:

- There was a major contraction in seagrass meadow extent between 2004 and 2005, which not observed elsewhere. These meadows did not recover to pre-2004 levels until 2010.
- Meadow extent was stable between 2010 and 2013, in contrast to Cleveland and Fisherman Islands
- Meadow extent was similar between 2013 and 2014, but expanded in 2016.

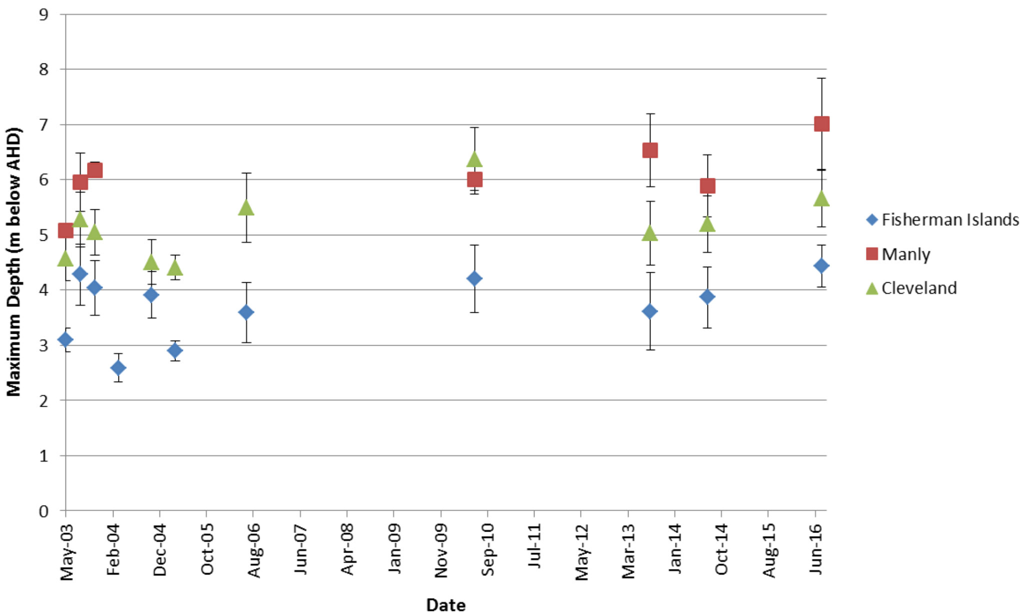
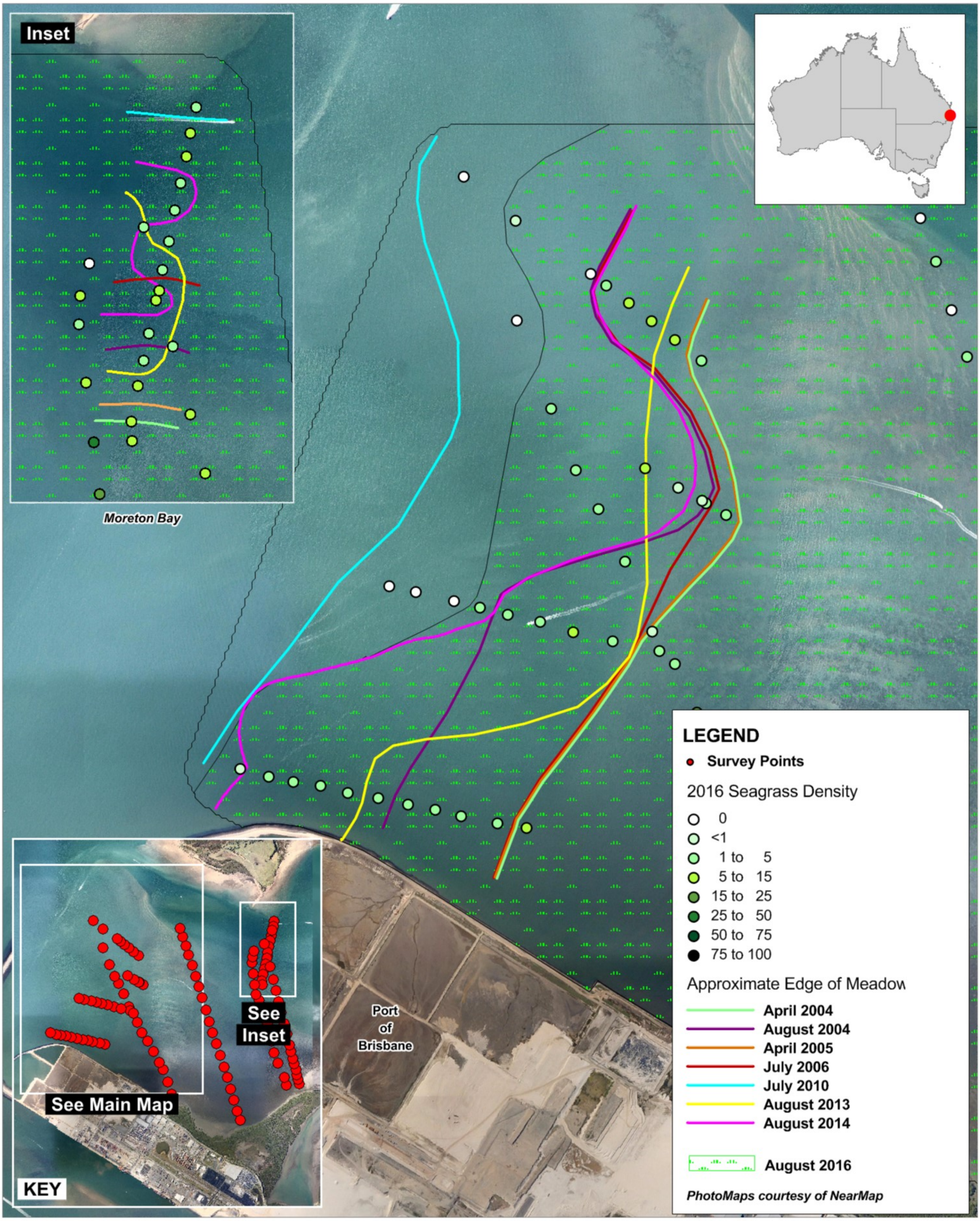


Figure 4-11 Mean (± SE) maximum depth at each location, where edge of meadow transects are replicates



Title:

Temporal Variation in Seagrass Edge of Meadow Adjacent to Port of Brisbane

Figure: 4-12

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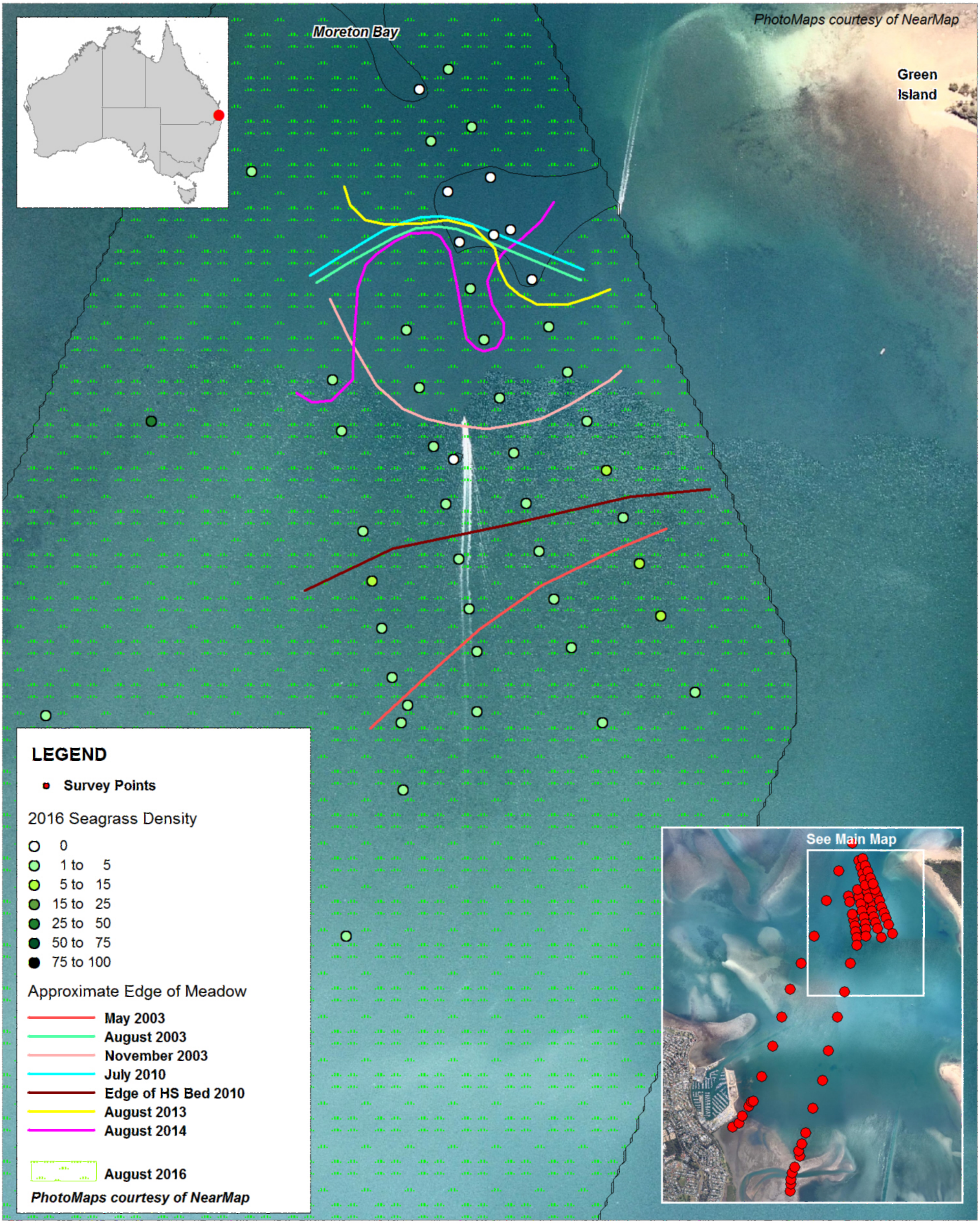

Title:

Temporal Variation in Seagrass Edge of Meadow Adjacent to Manly

Figure: 4-13

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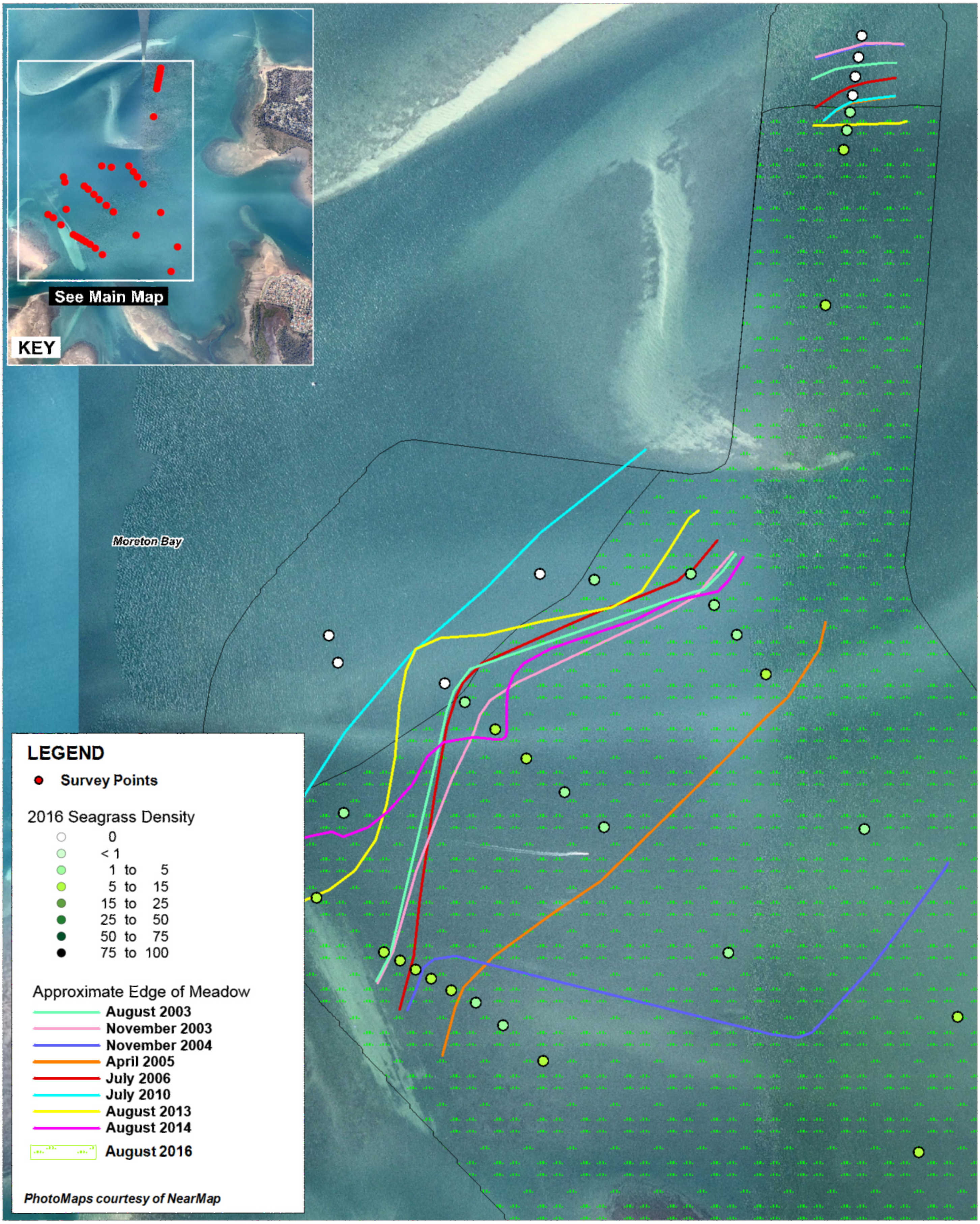

Title:

Temporal Variation in Seagrass Edge of Meadow Adjacent to Cleveland

Figure: 4-14

Rev: C

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Approx. Scale

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5 Discussion

5.1 Species Composition

Seven seagrass species have been consistently reported within Moreton Bay (Young and Kirkman 1975; Hyland *et al*. 1989)[6]: *Zostera muelleri, Halophila ovalis, Halophila decipiens, Halophila spinulosa, Halodule uninervis, Cymodocea serrulata, Syringodium isoetifolium.* Only *S. isoetifolium* and *C. serrulata* have not been recorded in the Port of Brisbane SMP.

Moreton Bay contains a mix of wide-ranging tropical and temperate seagrass species. Moreton Bay is the southern-most distribution limit of *S. isoetifolium*, *H. uninervis*, *H. spinulosa* and *C. serrulata* (Kirkman, 1997). No seagrass species recorded in Moreton Bay are listed as threatened or near threatened under Commonwealth or Queensland legislation.

Kilminster *et al.* (2015) developed a functional model of Australian seagrass life-history strategies (Figure 5-1). All genera found in the study area are classified as colonising or opportunistic taxa, meaning they have adaptations that allow rapid recovery following disturbance (*i.e.* demonstrate recovery on a scale of weeks to months), but low physiological resistance. Colonising or opportunistic taxa are also able to reach sexual maturity quickly (also on a scale of weeks to months) compared with slow growing, persistent seagrass species. No slow growing, persistent seagrass species have been recorded in the study area to date, reflecting the dynamic environmental conditions found here (see Section 5.2).

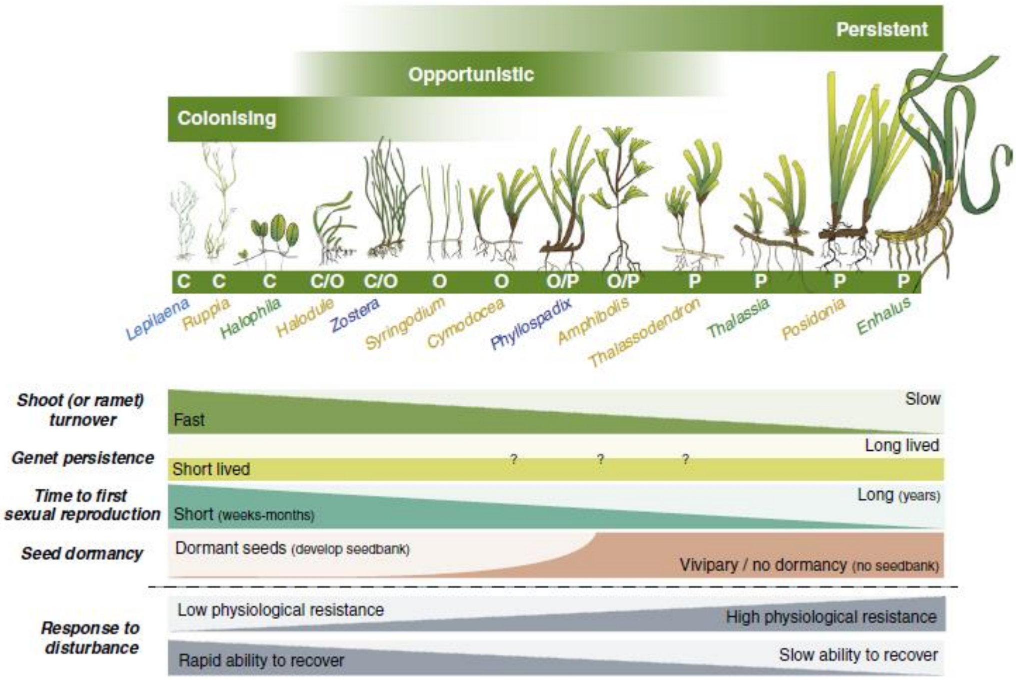

Figure 5-1 Dominant traits of key Australian seagrass genera categorised into colonising (C), opportunistic (O) and persistent (P) seagrasses, with respect to shoot turnover, genet persistence, time to reach sexual maturity and seed dormancy (Source: Kilminster *et al.* 2015)

[6]. Other uncommon species, such as *Halophila minor*, have also been recorded in Moreton Bay but are not considered residents

5.2 Spatial and Temporal Patterns in Assemblages

The extent and composition of seagrass meadows shows great variability in time and space. Subtidal seagrass meadows at all three survey locations show considerable change in composition measured over a range of time scales (seasonal, inter-annual).

The 2016 episode found that while there were contractions and expansions in seagrass meadows at the transect scale, there were an overall trend of a slight expansion in total seagrass meadow extent between 2014 and 2016. This trend was largely driven by the colonisation of *Halophila decipens* in deepwaters on most transects. Temporal trends in the extent (and related to this SDR) were highly variable between species, and were inconsistent among locations and transects within locations.

Numerous physical, physio-chemical and biological processes interact to control spatial and temporal patterns in the extent, distribution and abundance of seagrasses in Moreton Bay (Longstaff and Dennison 1999). These factors include habitat suitability (light availability, sediment condition and type, nutrient availability, water motion), biological interactions (grazing, competition), as well as different growth strategies and tolerances to exposure of the seagrasses themselves. Different combinations of these factors are responsible for the different distributions that are seen throughout the study area.

5.2.1 *Halophila* and *Halodule*

There was an overall expansion in *Halophila decipiens* between 2014 and 2016, but some retractions were observed varying among transects. No consistent temporal trend was observed in other *Halophila* species and *Halodule*, with some species retracting and other expanding, varying among transects. There was however a net expansion in *Halophila spinulosa* at Fisherman Islands, whereas at most other locations this species retracted.

While *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). The results of the 2016 survey suggest that overall growing conditions for *Halophila* species were generally favourable over most (but not all) of the study area in the period leading up to the 2016 survey.

There was also a high degree of small-scale heterogeneity in the distribution of different *Halophila* species (i.e. differences among transects within locations). A number of 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.

5.2.2 *Zostera*

Zostera muelleri was restricted to shallow waters (<2.4 m below AHD). The narrow depth range displayed by *Z. muelleri* is a reflection of the greater light requirement than *Halophila* species (e.g. Abal and Dennison, 1996; Collier and Waycott 2009).

There was great variability in SDR of *Zostera muelleri* among locations during 2016, varying from -0.7 to -1.0 at Cleveland, -2.1 at Manly, and -1.6 to -2.4 m below AHD at Fisherman Islands. 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 *Zostera* 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.

There were great spatial and temporal differences in *Z. muelleri* SDR between transects at Fisherman Islands. Transect F, located in the northern sector Fisherman Islands has shown an overall trend over time of declining SDR values for *Z. muelleri,* but the more opportunistic *Halophila* species were observed to have expanded. Transect F is located on a sand shoal that represents the remnant mouth of the Brisbane River, which is exposed to prevailing north-easterly wind waves and tidal currents (BMT WBM 2015) and is therefore a physically dynamic environment that has not always contained well developed *Zostera* meadows (see Figure 2-1). By contrast, the southern Fisherman Islands transect (transect H) is located in a more sheltered environment (BMT WBM 2015), providing more suitable (and physically stable) habitat conditions for *Zostera* growth.

Notwithstanding this, *Zostera* meadow extent and SDR was far more stable over time within transects at Fisherman Islands (CoV = 29-35%) than Manly (CoV = 57-85%) and Cleveland (CoV = 63-86%). Similarly, SDR for most *Halophila* species also tended to be more stable at Fisherman Islands than at control sites. This suggests that seagrass meadows at the two control locations are more prone to disturbance than at Fisherman Islands.

5.2.3 Macroalgae

Macroalgae has remained a dominant element of the benthic vegetation communities at Fisherman Islands, Manly and Cleveland throughout time. Like seagrass, different macroalgae species show great variation in distribution and cover over time and space.

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 Nino conditions prevailed. However, the distribution and density of *C. taxifolia* declined across the study area post-2010 (Figure 4-5, Figure

4-8, Figure 4-10), and in 2016 was only recorded at 1% of all surveyed sites. Burfeind (2012) reported that the Brisbane River flood in 2011 led to a significant decline of *C. taxifolia* within Moreton Bay, in agreement with the temporal patterns found in the present study.

Many macroalgae species are opportunistic species that are able to thrive in environments that are unsuitable for seagrass growth, and a phase shift to macroalgae dominance can occur where coastal ecosystems are under stress. The Port of Brisbane SMP does not presently focus on quantifying changes in other macroalgae species, and it is recommended that this is incorporated into future surveys.

5.3 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 -1.8 m AHD Cleveland achieved zero percent compliance, Manly achieved 70% compliance, and Fisherman Islands achieved 50% compliance during the period 2006-2016 (Table 4-1). This could suggest that habitat quality at Cleveland is not optimal for limit *Zostera*. At Fisherman Islands, the WQO was not met in 2014 and 2016 at transect F (but had in previous years), and was met in 2014 and 2016 on transect H. As discussed in Section 5.2.2, it is likely that hydrodynamic processes in the vicinity of transect F are not especially favourable for *Zostera* growth.

Table 4-1 shows that the SDR in 2016 on transect H at Fisherman Islands and transect J at Manly was for most species approaching or at the historical maximum SDR, and were therefore in good condition. The 2016 SDR on transect F at Fisherman Islands was well below the historical maximum for all species, and while *Halophila spinulosa* showed improvement since 2014, all other species were steady. The 2016 SDR Cleveland transects and most species on transect K at Manly (except *Zostera*) were also well below the historical maximum, and with few exceptions, had not markedly improved since 2014. These results indicate that seagrass meadows in the study area remain in a state of recovery.

5.4 Impacts of the FPE Seawall

A key objective of the Port of Brisbane SMP was to identify possible broad-scale operational impacts of PBPL activities on the distribution and extent of seagrass meadows. The results of the Port of Brisbane SMP to date do not suggest that PBPL 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, as shown diagrammatically in Figure 5-2. The conceptual diagram seagrass meadow extents should be considered as indicative only, noting differences in mapping methodologies used in different years do not allow quantitative comparisons over time (see Section 2.1). The mapping studies do however provide sufficient evidence to illustrate the direction of change and long term trend in seagrass meadow extent over time. Note that meadow extent in the conceptual diagram may extend past the Port of Brisbane SMP study area, due to additional data to the survey points used (Figure 5-2).

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 would be expected to provide more protection from prevailing wind generated waves from the northerly direction.
- Deposition of fine sediment. The extension of the FPE seawall may be enhancing the deposition of fine sediments within the embayment north and east of Fisherman Islands (BMT WBM 2010; 2015). While fine sediment may provide a source of nutrients, there is uncertainty whether increased sediment loading could reduce light availability.
- 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.

Title:
Conceptual Diagram Showing Changes in Meadow Extent and Reclamation Size

Figure 5-2

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5.5 Recommendations

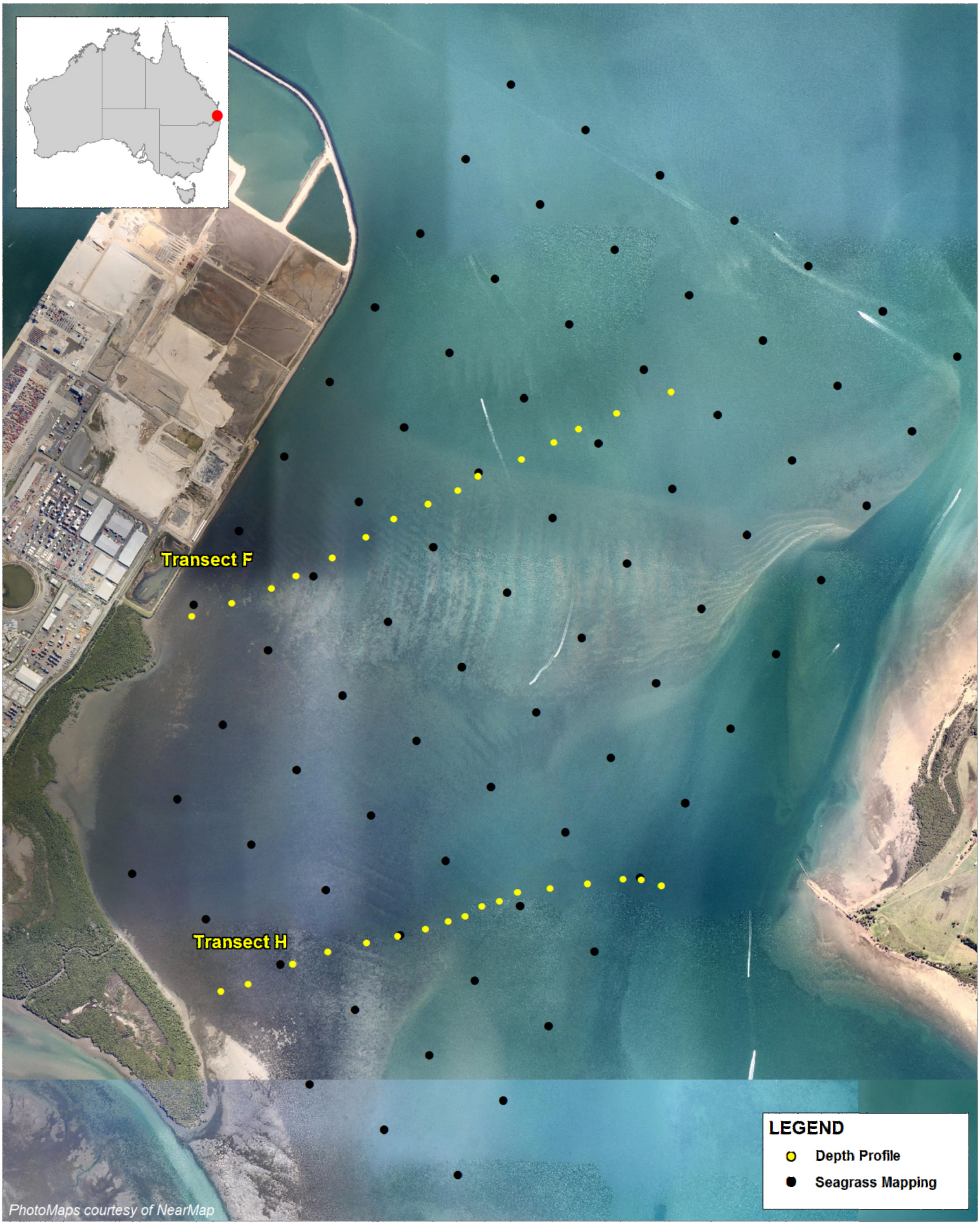
5.5.1 Survey Design Changes

Seagrass species mapping is presently based on interpolations using the best available data to provide indicative visual representation. Interpolation is a useful tool used to make predictions at unknown points using known values at control points. However, in areas where there are large gaps between survey points, interpolations can have low confidence.

It is therefore recommended that:

- A systematic grid style sampling plan be adopted to more accurately map seagrass assemblages at Fisherman Islands, in addition to control sites at Manly and Cleveland
- Existing survey points for the permanent transects are retained to enable future comparisons between the temporal and spatial seagrass distribution and density
- Sampling points for the edge of bed and seagrass mapping transects be re-allocated to the systematic grid.

The survey points recommended for future SMP campaigns at Fisherman Islands are shown in Figure 5-3. This approach would enable a more accurate seagrass map to be developed, while retaining data points of most importance to understanding long-term changes in SDR.



Title:

Recommended Survey Points to Map the Distribution of Seagrass at Fisherman Islands

Figure: 5-3

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5.5.2 Macroalgae

As discussed in Section 5.2.3, ecosystem phase shifts, from seagrass to macroalgae dominance, can occur as a result of water quality degradation (particularly high nutrients and turbidity). It is therefore recommended that more attention is given to surveying key macroalgae species to document any potential future changes in state.

5.5.3 Satellite Imagery

Satellite derived spectral data provides an objective and repeatable method for mapping seagrass extent (particularly in shallows waters with dense meadows). As discussed in Appendix C, satellite imagery provides objectivity and a repeatable means for the classification of seagrass, but can be confounded by other factors (e.g. signal from macroalgae) where data are limited.

It is recommemded that freely available Landsat satelitte imagery are used as a supplementary data source for future seagrass mapping. In combination with a grid-type sampling design, this would provide a more robust means for mapping seagrass meadows across the study area.

6 Conclusions

The key findings of the 2016 survey are:

- Seagrass assemblage structure remains effectively unchanged in the study area over the last 20+ years. Dense *Zostera muelleri* meadows continue persist in intertidal and shallow subtidal environments, and *Halophila* species and *Halodule uninervis* formed sparse, mixed meadows in deeper waters. These broad gradients in assemblage structure mostly reflect light requirements of different seagrass species.
- Overall meadow extent at all sites increased slightly compared to 2014 levels. This followed a period of significant seagrass meadow expansion in 2010 and seagrass declines in 2011 and 2013, which were coincident with flooding events. Seagrass extent and distribution in 2016 was less than 2010 levels, indicating that meadows still remain in a recovery state.
- A comparison of seagrass depth range measurement data for *Zostera muelleri* to both reference site data and historical maximum extent indicate that *Zostera* meadows at Fisherman Islands and Manly remain in a state of recovery, but were generally in good condition. *Zostera* meadows at Cleveland appear to be habitat limited, either by light or availability of suitable substrates.
- 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.

7 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

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

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.

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

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 C, 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

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.

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, *et al*. (2015) Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of the Total Environment 535, 97-109.

Kirkman H (1997) 'Seagrasses of Australia.'

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

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 South East 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.

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, 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

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

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.

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

Appendix A Photo Plates

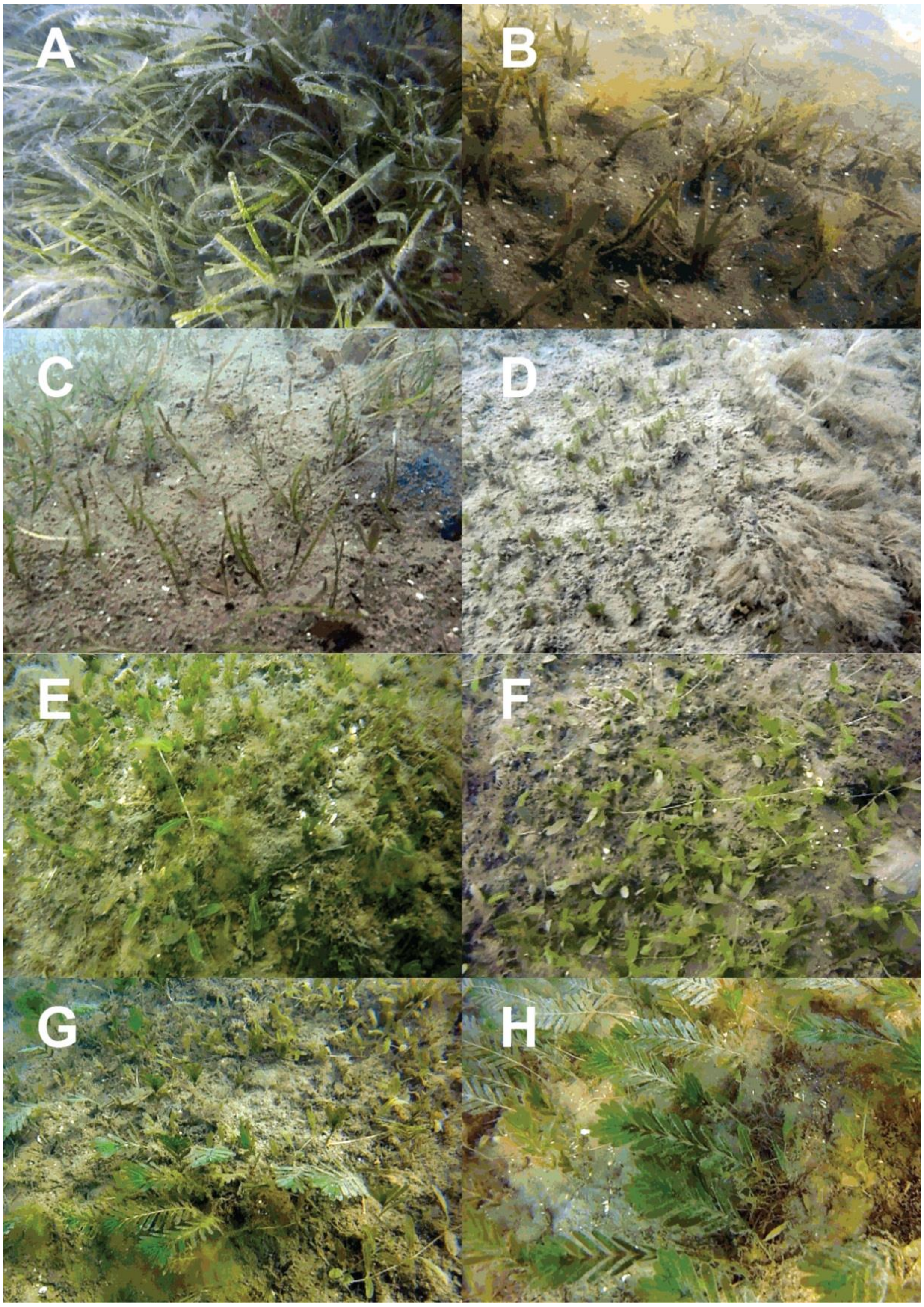


Figure A-1 Seagrass species: *Zostera muelleri* (A); *Z. muelleri* and filamentous algae (B); *Halodule uninervis* (C); *Halophila ovalis* with *Sporochnus comosus, Hypnea spinella* (D); *H. ovalis* and *Halophila decipiens* (E); *H. decipiens* (F); *H. decipiens* and *Halophila spinulosa* (G); *H. spinulosa* (H).

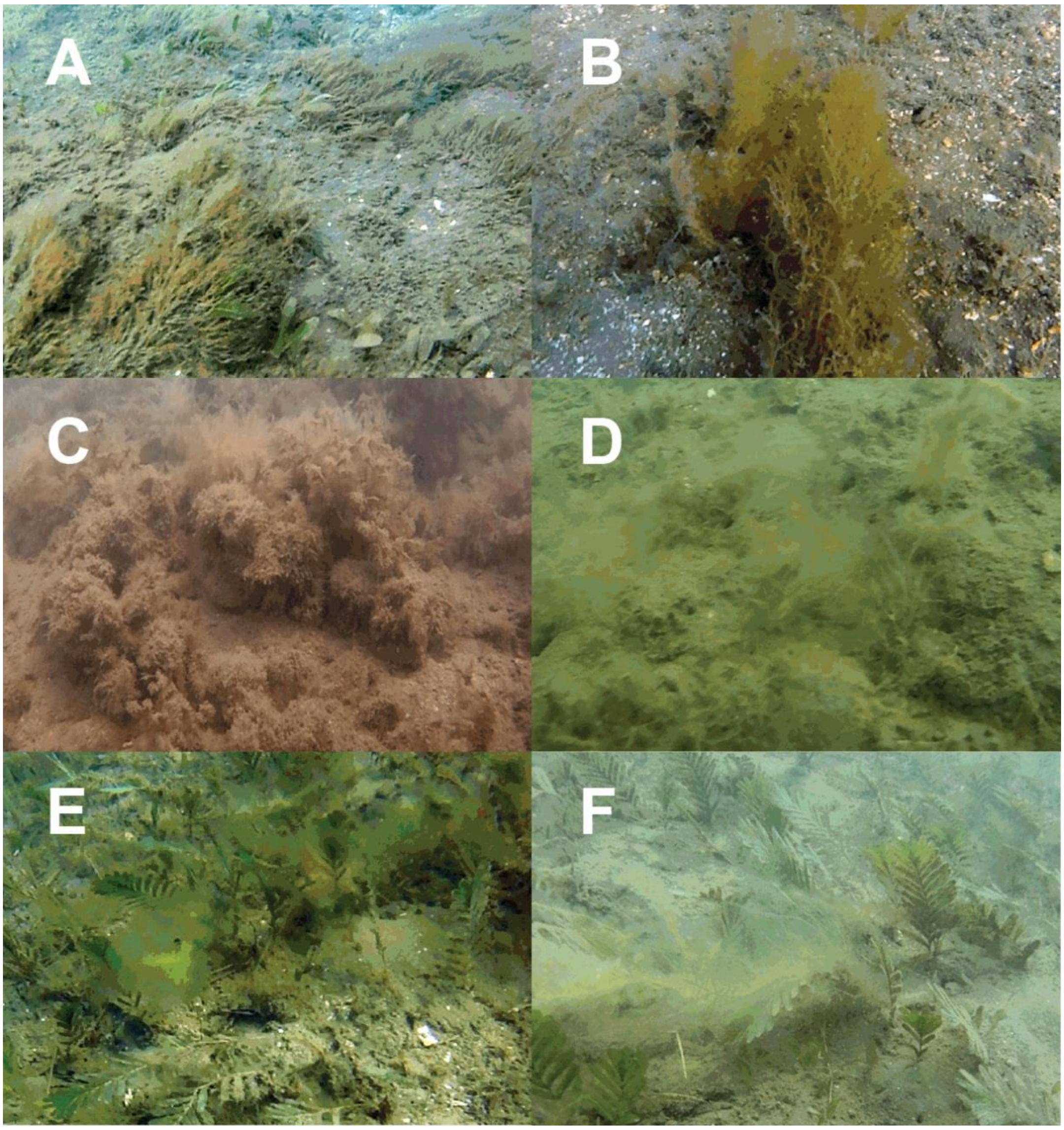
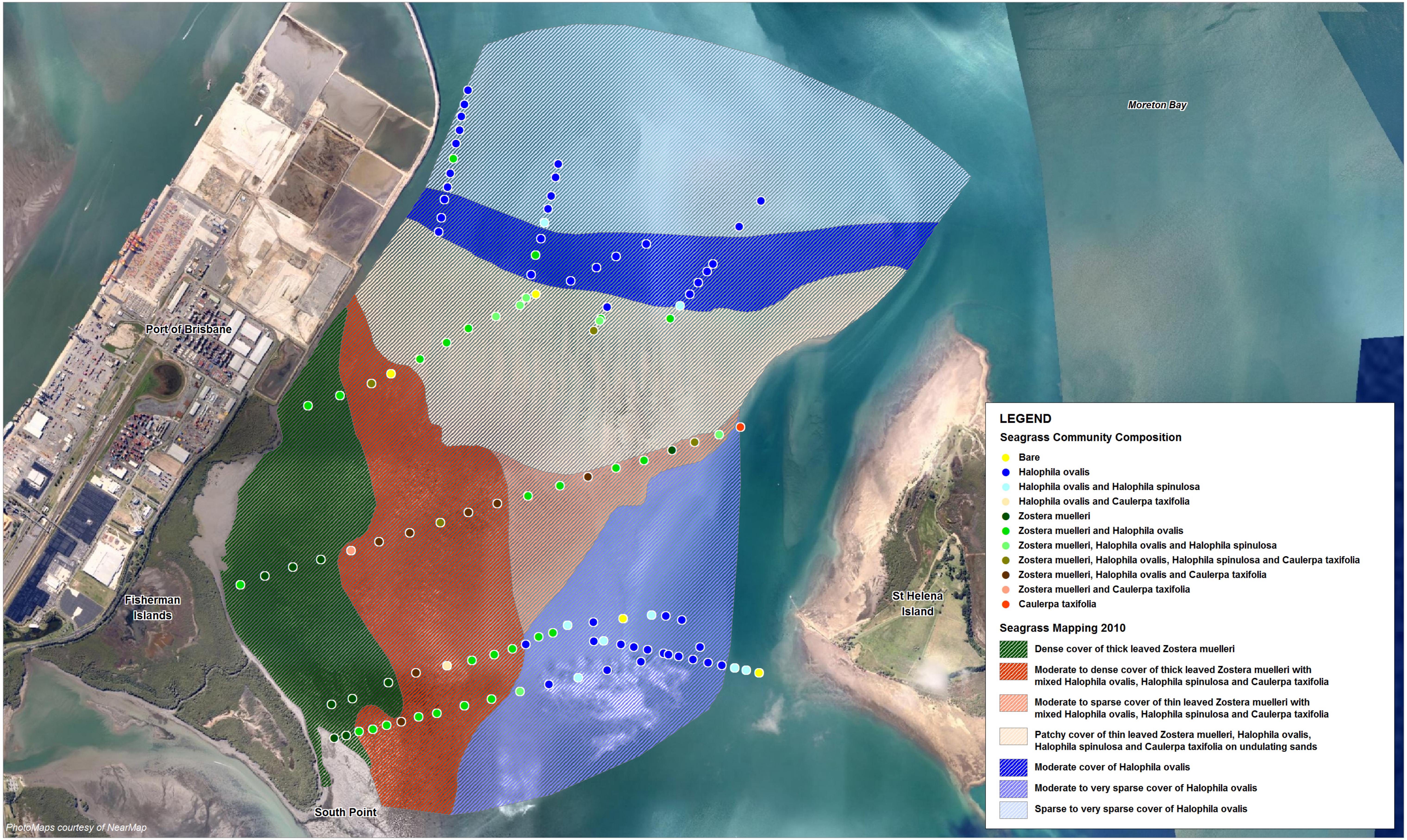


Figure A-2 Macroalgae: Brown algae *cf Hypnea spinella* with *Halophila decipiens* (A); *Sporochnus comosus* (B); high cover of mixed turfing algae (C); Filamentous algae c-f *Ectocarpus fasciculatus* (D); Filamentous algae *cf Ectocarpus fasciculatus* with *Halophila spinulosa* (E); Filamentous algae *cf Hincksia (Giffordia) mitchellae* with *H. spinulosa* (F).

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



Title:

Broadscale Patterns in Seagrass Distribution and Community Structure Adjacent to Port of Brisbane

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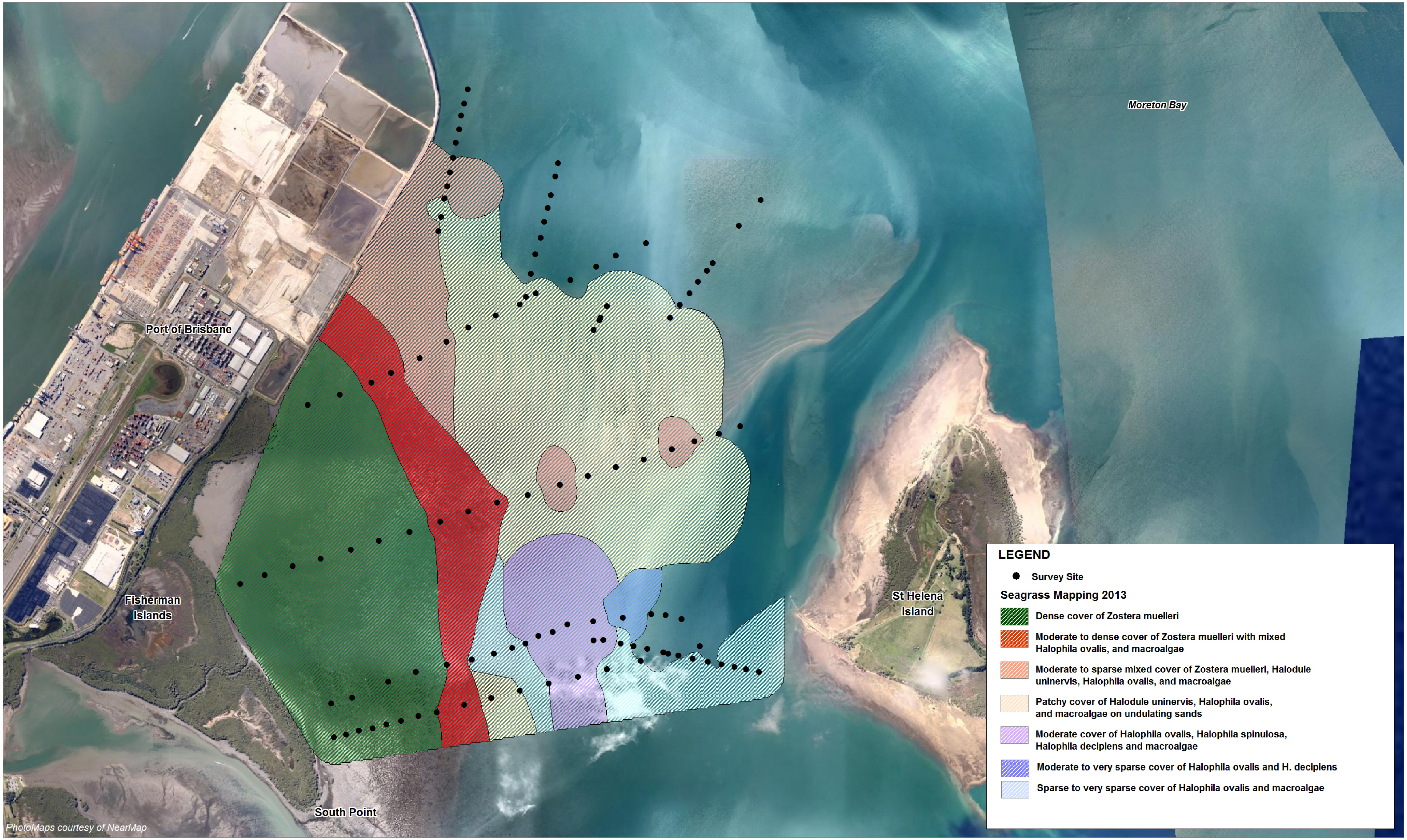

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Seagrass Distribution and Community Structure Adjacent to Port of Brisbane

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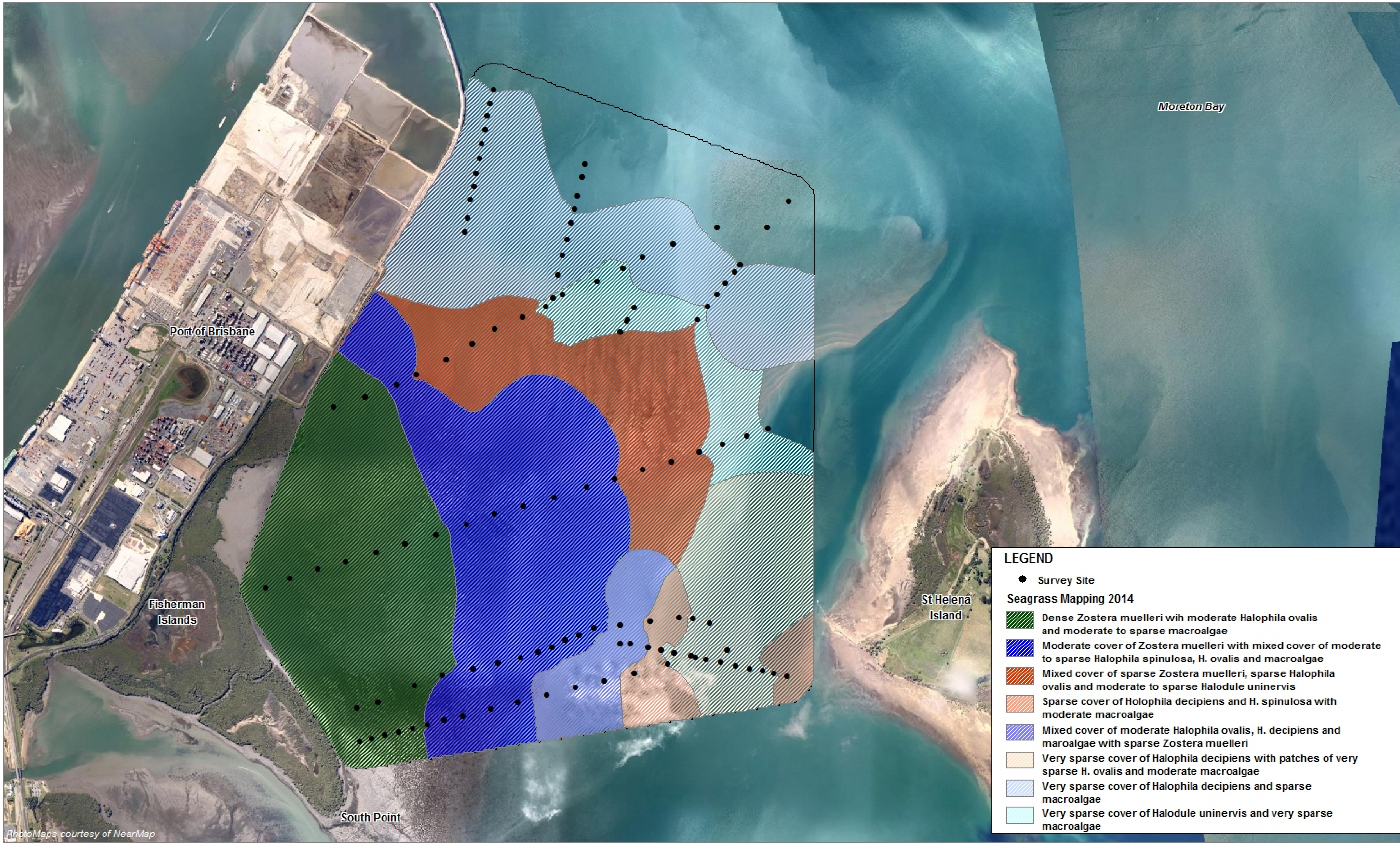

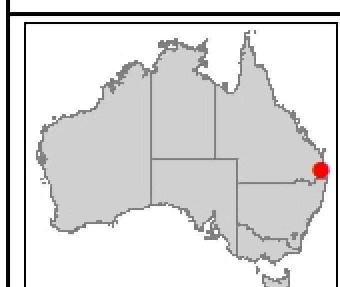

Title:

Seagrass Distribution and Community Structure Adjacent to Port of Brisbane in 2014

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Appendix C Future Monitoring Recommendations

C.1 Monitoring Program Objectives

WBM (2002) developed the PBPL Seagrass Monitoring Program on the basis of a review and testing of a wide range of seagrass monitoring methodologies. The broad objectives of WBM (2002) were to: (i) develop a monitoring program; and (ii) collect pre-construction (baseline) data for the Future Port Expansion Project. Subsequent reports refined the objectives, with a focus on understanding changes in seagrass meadow extent and condition over time, and determining possible linkages between port activities and changes in seagrass assemblages (see Section 1.2).

The PBPL Seagrass Monitoring Program objectives were assessed with reference to SMART principles, i.e.:

- Specific: Concrete, detailed, and well defined so that you know where you are going and what to expect when you arrive
- Measureable: Numbers and quantities provide means of measurement and comparison
- Achievable: feasible and easy to put into action
- Realistic: Considers constraints such as resources, personnel, cost, and time frame
- Time-Bound: A time frame helps to set boundaries around the objective.

The objectives generally meet most SMART principles, but are not time-bound, and are not always specific. The objectives should be redrafted and refined on this basis.

Based on the SMART principles, the specific objectives of this study will be to:

- Determine on an annual basis (during winter), spatial patterns in seagrass assemblage structure along depth gradients at Fisherman Islands and control locations
- Quantify seagrass depth range (SDR) on an annual basis (during winter) for key seagrass species, and with reference to historical SDR data, determine whether there is evidence of long-term changes in environmental conditions
- Map the distribution of seagrass assemblages at Fisherman Islands on an annual (during winter) basis
- Based on the above objectives, identify any long-term changes in seagrass assemblages at Fisherman Islands that may indicate broad-scale operational impacts of PBPL activities.

C.2 Design and Indicators

Some of the key aspects of effective monitoring programs are that they are repeatable, objective and provide sufficient resolution to detect changes. The PBPL Seagrass Monitoring Program focuses on characterising spatial and temporal patterns in seagrass meadow and assemblage structure at Fisherman Islands relative to patterns at ‘control’ locations remote from port activities. This approach still remains accepted practice.

PBPL Seagrass Monitoring Program is based on two key indicators:

- Seagrass depth range (SDR) – which is one of the most widely used seagrass monitoring indicators for assessing long-term changes in ambient water clarity/light conditions (e.g. Abal and Dennison 1998; ANZECC/ARMCANZ 2000; EHMP 2006).
- Seagrass meadow composition and extent – which is derived using a variety of methods and is typically of interest to managers in terms of understanding the state of the seagrass resource.

The current placement and orientation of seagrass transects is based on the survey design created in 2002; which has maintained a high degree of similarity to the original design, allowing for longer-term analyses of changes in spatial pattern and depth.

The two different indicator types serve two purposes – SDR is most useful for providing an objective measurement of ambient environmental conditions, whereas seagrass meadow composition and extent is more of interest in terms of understanding the seagrass resource.

The present program measures SDR for all seagrass species on both fixed transects, as well as supplementary 'edge of meadow' transects to measure changes in the maximum growing depth of deep water species. Most SDR assessments tend to focus on *Zostera muelleri*, a long-lived species that is intolerant of long term changes in light climate. *Halophila* spp. and *Halodule uninervis* are considered ephemeral species whose extent and biomass tends to change markedly over short time-scales measured in weeks to months (Kilminster *et al*. 2015), and are therefore not reliable indicators of long–term (i.e. greater than months) changes in ambient conditions. The edge of meadow transects, while providing some context regarding temporal variability in total meadow extent, is not as critical in the context of understanding patterns in long –term changes in ambient conditions.

The permanent transects provide a repeatable, objective means for measuring changes in seagrass assemblages over the length of transects. Data from the permanent transects and edge of meadow transects are used to create seagrass assemblage maps, through interpolations and aerial photograph interpretation. The broad spacing between transects is not optimal for creating assemblage maps from interpolations. This is especially the case for the *Halodule*-dominated assemblage in north-eastern section of Fisherman Islands, which has complex spatial patterns in areas between transects, and cannot be effectively resolved.

Two-dimensional species distributions are extremely useful in understanding broad spatial changes and the monitoring program could provide improved 2d spatial cover by sampling at grid intervals rather than along transects, or by re-apportioning some of the sampling effort to filling large gaps between transects. A grid-based approach would provide a better 2d representation of interpolated seagrass area, but re-apportioning sampling effort would result in a loss of compatibility with past datasets.

C.3 Pilot Study of Satellite Imagery

C.3.1 Background

Rolfsema *et al. (*2014) found that excellent 2d spatial representations of seagrass meadows and species cover could be achieved at East Banks using remote sensing approaches. Seagrass in the intertidal area has been mapped using satellite imagery (WBM 2003a), but due to high turbidity, the analysis was limited to waters shallower than 2m, excluding much of the deeper water and more transient species.

Seagrass has been successfully mapped from deeper turbid areas with remotely sensed data using a modified Lyzenga algorithm (Sagawa *et al.,* 2010). The technique requires ground-truthing data for the distribution of seagrass and a bathymetry layer to calculate benthic reflectance. Benthic reflectance from non-vegetated substrates across a range of depths are compared to that of optically deep reflectance, to determine the effect of depth on benthic reflectance. This index is known as the BRI or benthic reflective index.

We performed a preliminary analysis of BRI on a Landsat 8 scene acquired on July 7th 2016, to examine the utility of this technique for monitoring seagrass at Fisherman Islands. Twenty points were used to develop the attenuation relationship for the formula described in (Sagawa *et al.,* 2010). Pixels were classified using unsupervised and supervised (Maximum Likelihood) techniques in ArcMap 10.3.1. Supervised classifications were generated using different interpolated density categories from the present ground-truthing study to determine the lowest densities that could be distinguished.

C.3.2 Pilot Study Findings

and show, respectively, the results of supervised and unsupervised classifications of seagrass assemblages at Fisherman Islands. Visual assessments of the preliminary maps indicate more exaggerated seagrass coverage than what is currently present.

The unsupervised class that corresponded best with the known distribution of seagrass at Fisherman Islands also included some areas without seagrass, along the batters of the main shipping channel and excluded some intertidal banks where seagrass is present. The most accurate seagrass map produced using supervised classification based on the interpolated >25% cover polygon. Attempts to classify using lower percent cover estimates resulted in large areas of open water misclassified as seagrass meadow. Meadows with low cover tend to occur in deeper waters where there was also a consistent macroalgal reflectance signal. While macroalgal and seagrass reflectance signatures differ, the ubiquitous nature of macroalgae throughout the study area makes discrimination of small seagrass reflections within this macroalgal layer more difficult, particularly in deeper water where there is also more signal loss,. Increasing the amount of survey points in the study area would be expected to increase the data available to train supervised classification, thus resulting in a more reliable seagrass distribution map.

Figure C-1 Preliminary map of seagrass and macroalgae based on supervised classification from Landsat 8 data and field data (sampling points with >25% seagrass cover)

Figure C-2 Preliminary map of seagrass and macroalgae based on unsupervised classification based on 30 classes from Landsat 8 data

C.3.3 Mapping of Assemblage Structure Using Spectral Signatures

When seagrass and algae species (eg. *Calerpa taxifolia*) are exposed, they can be seperated from each other based on the specteral signature (WBM, 2003a). Spectral signatures are a record of how much sunlight is reflected and absorbed by a feature (such as seagrass) and are used in image processing packages to discriminate image pixels containing different substrate types. With increasing water depths seagrasses exhibit significant different specteral signatures.

Halophila spinulosa was optically dark and distinctly different from that of *Zostera muelleri*, *Halophila ovalis* and *Calurpa taxifolia* (Figure C-3). In contrast, *Zostera muelleri* and *Halophila ovalis* exhbited very similar specteral signatures, suggesting they could not be mapped seperately using their specteral signatures.

The main finding from modelling the spectral signature of the seagrass at the water surface with increasing depths of water over the substrate was the differences in spectral reflectance signatures between the seagrasses remained over 5% to a depth if 2.0 m (Figure C-4). Based on this finding, the mapping of seagrass in clear waters using image classification would be limited to 0 m - 2 m depths to reliably discriminate the different seagrass species from each other. Given the turbid nature of the water in the vicinity of the Fisherman Islands site, it is expected that mapping would be strictly limited to an hour either side of low tide and may not be possible in areas with any type of water cover, thus *Halophila* species are unlikely to be mapped.

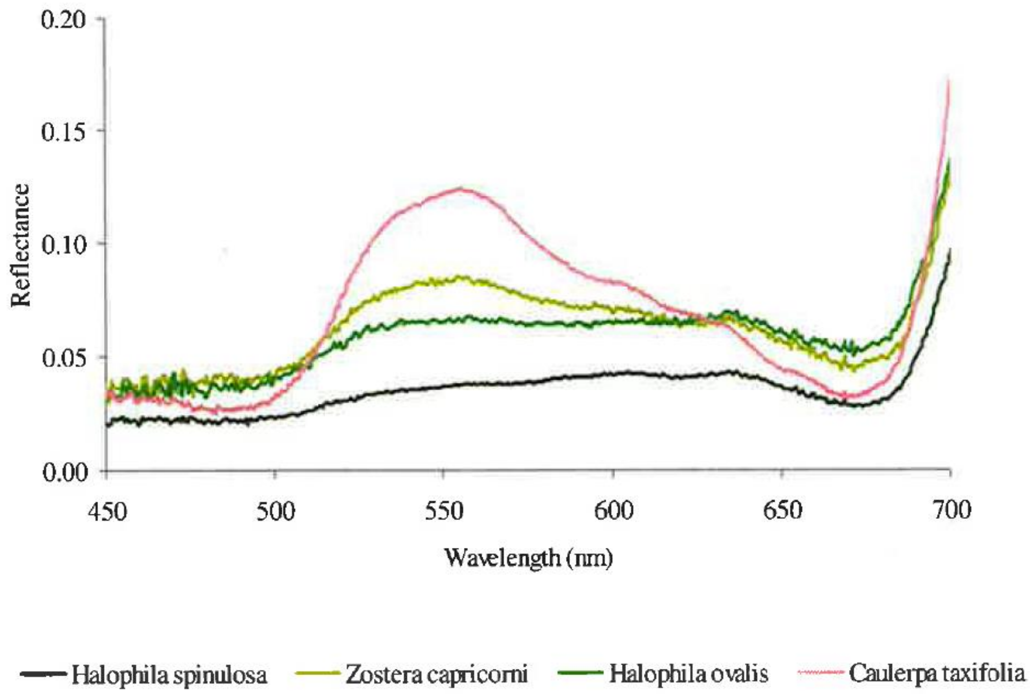
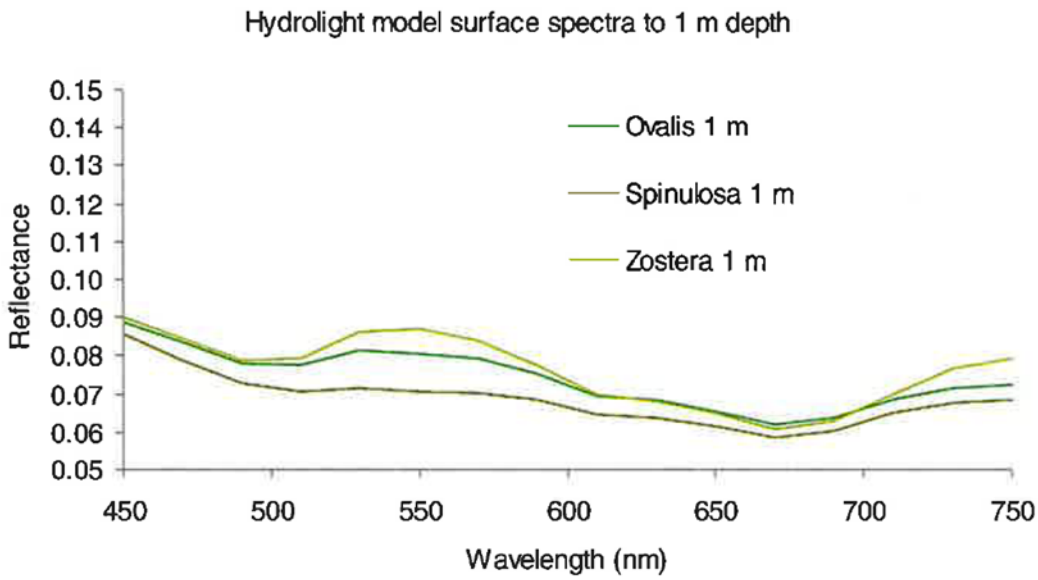


Figure C-3 Reflectance of submereged seagrass and algae types measured above the water surface in direct sunlight using an Analytical Spectral Device VIR-NIR spectrometer, 15 cm from the target with a 6° field of view and a Spectralon® reference panel (WBM, 2003a)



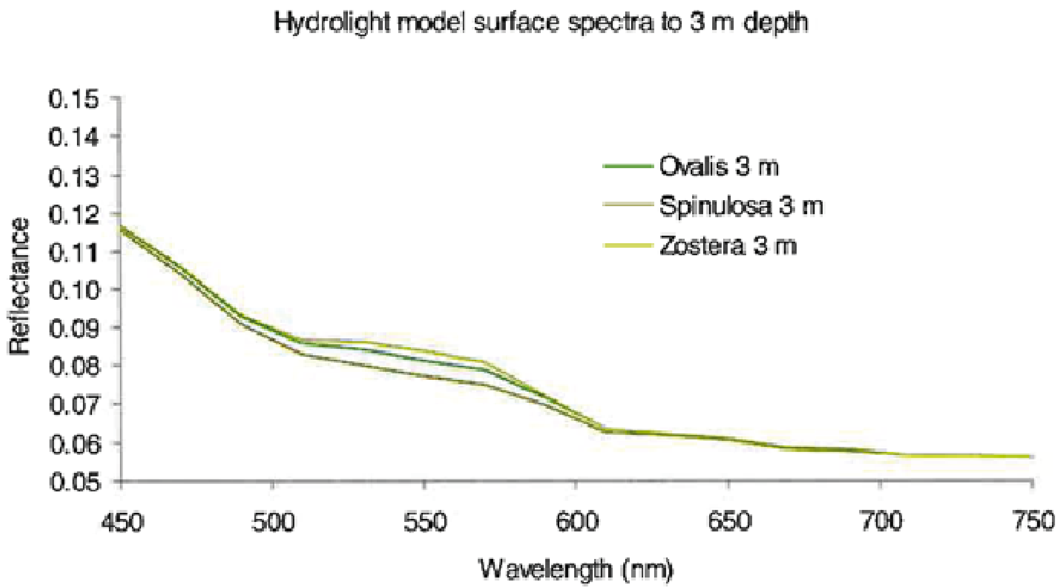


Figure C-4 Estimated water leaving reflectance signatures of seagrass species modelled for different water depths using Hydrolight 4.0 and the optical properties of Deception Bay (WBM, 2003a)

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