Port of Brisbane Mangrove Health Monitoring Program 2018 – Final Report

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Synopsis:	**A report outlining the findings of mangrove condition assessments carried out in 2017-18.**

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Executive Summary

Background

The mangrove forests of the lower Brisbane River are among the largest in western Moreton Bay, and represent a key environmental value for the area. Mangroves and saltmarsh surrounding the Port of Brisbane have been monitored since the 1990s, and sampling techniques have evolved over time. This report outlines the methodology and findings of the 2017-18 period.

The specific objectives of this study were to:

- Map historical changes in mangroves, saltmarsh/saltpan at the Port and Bulwer Island;
- Map changes in mangrove health between 2017 and 2018 using remotely sensed data and ground surveys;
- Identify potential drivers of mangrove degradation in key investigation areas, namely Fisherman Islands, Whyte Island and Bulwer Island; and
- Examine changes in mangrove health using remote sensing data and health scores developed by the then Department of Employment, Economic Development and Innovation (DEEDI)[1] at Bulwer Island, associated with changes to the revetment wall designed to improve fish passage and prevent stranding.

Historical Trends in Estuarine Vegetation Communities

Mapping of communities using aerial photography shows that communities at the mangrove-saltpan interface and the seaward fringe of mangroves were highly dynamic, with gains and losses occurring at timescales measured in months to years. However, in the period 2009 to 2018, there was a net seaward and landward expansion of mangrove forests at Fisherman Islands and Whyte Island, and a commensurate reduction in saltmarsh/saltpan habitat.

Temperate and sub-tropical saltmarsh is a listed threatened ecological community under the *Environmental Protection and Biodiversity Conservation Act 1999*. This community is threatened by a range of pressures, including clearing, changes to hydrology and sea level rise. Historical tidal data shows that sea levels have increased at an approximate rate of 3 mm/year at Brisbane Bar, which is expected to facilitate mangrove invasion into saltmarsh/saltpan areas.

Broad-scale Temporal Patterns

NDVI is a spectral index that estimates the amount of green biomass. Cyclic changes in NDVI were recorded over the 2017-18 monitoring period. Consistent with the long-term analysis of Landsat imagery (BMT WBM 2016), NDVI values (i.e. higher canopy chlorophyll) were higher in winter than summer months (Figure 1).

Long-term NDVI patterns tracked both 12-month antecedent rainfall and monthly rainfall (with a lag of 2-3 months). NDVI was highest in July 2017, reached a minima in January 2018, and increased at most sites through May-July 2018. There was a decline in NDVI between July and August 2018, following an extended dry autumn and winter period. These results are consistent with the hypothesis that rainfall is a key driver of temporal changes in mangrove health.

[1] now Department of Agriculture and Fisheries

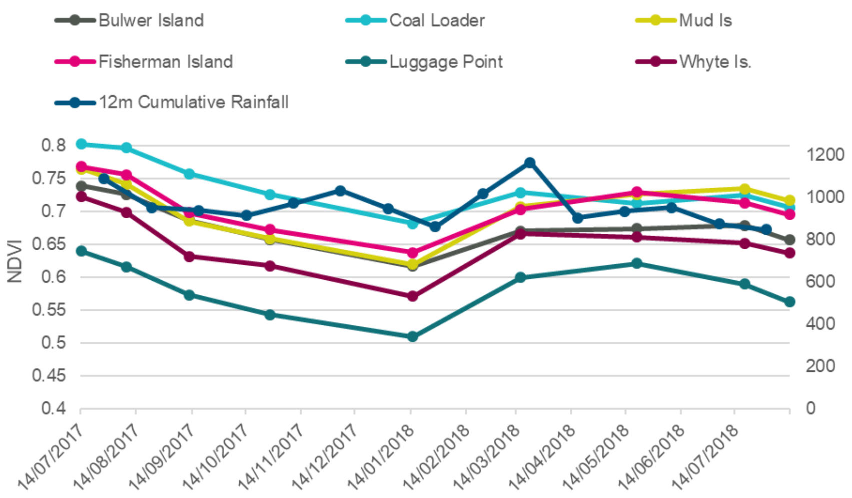


Figure 1 Temporal changes in NDVI with respect to 12-month cumulative rainfall at Test sites, from July 2017 to August 2018

Mangrove Condition

The highest NDVI values were recorded on the seaward fringe containing well flushed tall *Avicennia* dominated closed and partially open forest. Key locations of mangrove die-back or poor health were:

- Fringing mangroves along the southern and northern margins of Fisherman Islands;
- The western extremity of the Coal Loader; and
- The southern extremity of Whyte Island.

There was a net decline in mangrove condition between August 2017 and 2018, although mangrove areas at the mangrove-saltpan were observed to slightly improve over time.

Bulwer Island Fish Passage Works

In 2016, PBPL undertook mangrove rehabilitation works to improve fish passage and connectivity between Bulwer Island and the Brisbane River. This involved the partial removal of the seawall on the seaward fringe of Bulwer Island.

Between July 2017 and July 2018, NDVI showed both improvements (landward fringe) and patchy reductions (central areas) at Bulwer Island. Between 2016 and 2018, NDVI increased across most of the site, the exception being small pockets of tree-fall near the bund-wall opening. These tree-falls appeared to be a result of scour, as evidenced by the exposure of cable roots. Ongoing monitoring is required to assess effects (either positive or negative) to mangrove forests resulting from further changes to hydrology.

Recommendations

It is recommended that future assessments continue to use high-resolution satellite imagery on an annual basis for assessing broad-scale trends in mangrove health, and rapid ground inspections to assess sub-canopy environmental conditions.

While the DEEDI health scoring methodology showed an increase in average health between baseline surveys and 2018, the ability to detect changes depended on the placement of sites overlapping with small patches of impact. The semi-quantitative nature of the DEEDI scoring methodology is also open to observer bias and interpretation, which is problematic for long term trend detection. It is recommended that remote sensing provide the basis for ongoing monitoring, with rapid ground-truthing of sub-canopy conditions.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

The lower Brisbane River and Waterloo Bay area supports extensive mangrove forests and saltmarsh communities. The mangrove forests of Fisherman Islands and Whyte Island (see Figure 1-1) are among the largest in western Moreton Bay (Accad *et al.* 2016), and the structure and form of these communities is unique to this area (Davie 2011).

Mangroves and saltmarsh surrounding the Port of Brisbane (particularly at Fisherman Islands and Whyte Island/Wynnum) have been monitored since the 1990s (WBM 1992; CSIRO 1992; BMT WBM 2016) but variability in assessment techniques and observer bias made long-term health assessments difficult. The Port of Brisbane Mangrove Monitoring Program was revised in 2016 to provide a more robust objective means for mapping and characterising patterns in mangrove condition (BMT WBM 2016).

BMT WBM (2016) found a strong association between 12-month cumulative rainfall and normalized difference vegetation index (NDVI), producing quasi-cyclical patterns in health and rainfall. In the longer term, patterns in health were associated with SOI and the El Niño–Southern Oscillation (ENSO) cycle. The medium-term trends in average NDVI at most investigation areas included higher NDVI values in the period 1987-89 (coincident with strong La Niña conditions); consistent, moderate NDVI values in the period 1990-2005; a decline in NDVI in 2006-08 (during the final years of the Millennium Drought); and a slight rise in NDVI post 2009, following the end of the Millennium Drought. The overall long-term trend from 1987 to 2016 was of declining NDVI values, without evidence of recovery (to pre-Millennium drought conditions).

This 2018 assessment report was prepared to update the mangrove and saltmarsh/saltpan health assessment to cover the period between the winters of 2017 and 2018 for wetland areas surrounding the Port of Brisbane.

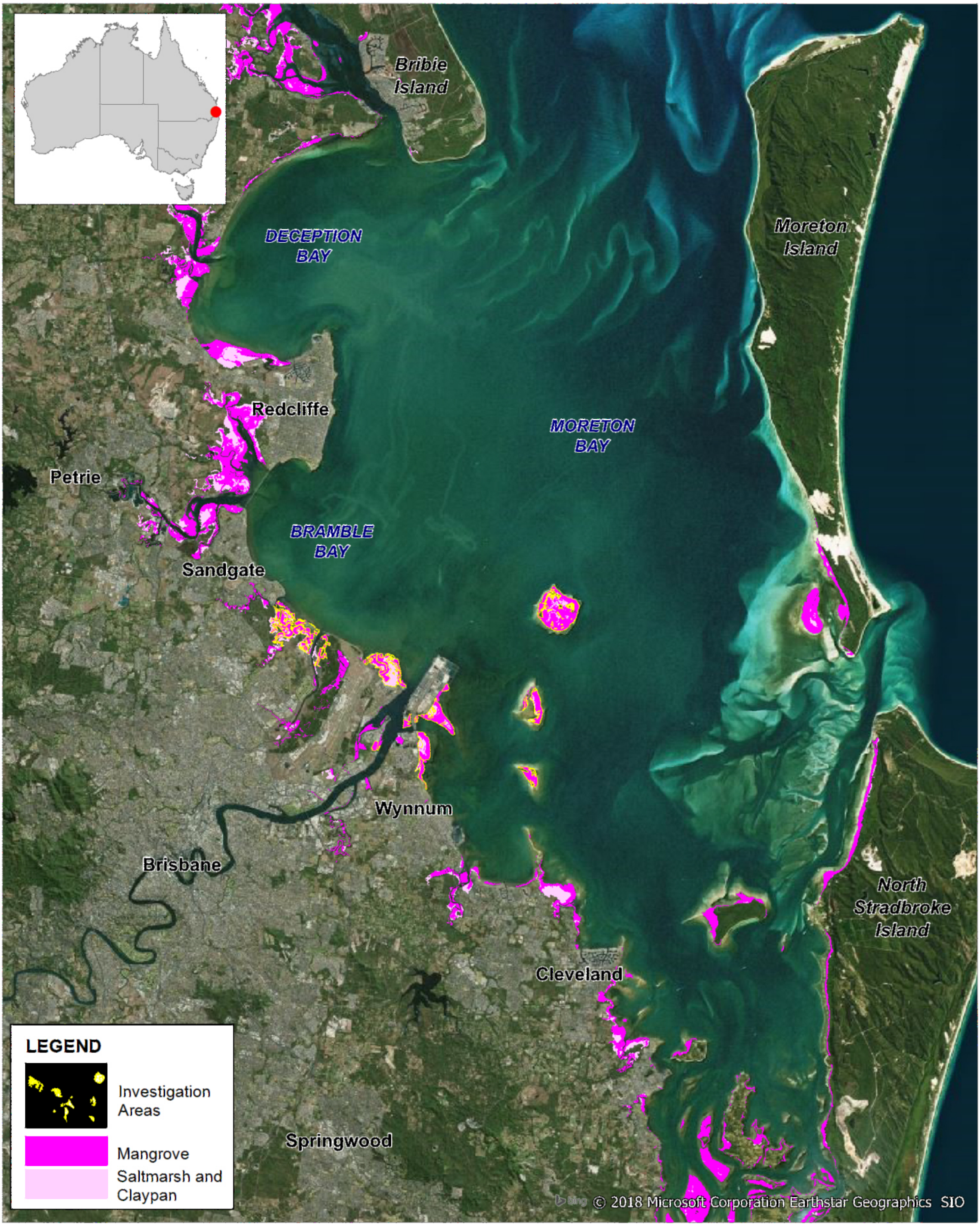
In addition to NDVI change mapping and ground-truthing, a focal assessment was also made at Bulwer Island to examine the responses of mangrove communities to fish passage works. Sections of the bund wall surrounding mangroves at Bulwer Island were removed to reduce the incidence of fish stranding occurring inside the wall and to promote fish passage and better habitat utilisation. Mangroves were monitored at Bulwer Island using the same methodologies used in baseline studies in 2014 and 2016.

Finally, changes in mangrove and saltmarsh extents across the port were measured for 1955 to 2018. The results were interpreted in the context of local and catchment environmental impacts and broader estuarine dynamics recorded across Moreton Bay.

1.2 Aims and Objectives

The aim of the present study is to describe spatial and temporal patterns in mangrove vegetation structure and condition, and potential drivers controlling patterns in condition. The specific objectives of this study were to:

- Map changes in mangrove health between 2016 and 2017 using remotely sensed data and ground surveys.
- Identify potential drivers of mangrove degradation in key investigation areas, namely Fisherman Islands, Whyte Island and Bulwer Island.
- Examine changes in mangrove health using remote sensing data and health scores developed by the Department of Employment, Economic Development and Innovation (DEEDI) at Bulwer Island, associated with changes to the revetment wall designed to improve fish passage and prevent stranding.
- Map the recruitment (and dieback) of mangroves and saltmarsh at Fisherman Islands and Whyte Island using 1989, 2012 and 2018 aerial imagery and the 1955-2012 Moreton Bay estuarine mapping study prepared by the Queensland Herbarium.



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Locality plan showing 2012 mangrove and saltmarsh extent based on data in Accad et al. (2016)

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2 Methodology

2.1 Estuarine Habitat Mapping 1955-2018

Spatial data for the mangrove and associated communities of Moreton Bay, Queensland, Australia: change in extent 1955-1997-2012 (Queensland Herbarium, June 2016), was sourced from Environment and Science, Queensland Government, licensed under Creative Commons Attribution 4.0.

High resolution digital aerial photography for years 1978, 1983, 2009 and 2018 were ortho-rectified and examined in MapInfo. The differences in image quality and resolution between years prevented the development of an automated change detection process. The extent of broad mangrove and saltmarsh (samphire and claypan) communities at Fisherman's, Whyte and Bulwer Islands were manually digitised. Other natural resource information including tidal and topographic data were also examined to assist aerial photograph interpretation.

2.2 Remote Sensing and Validation

2.2.1 Approach

BMT WBM (2016) determined boundaries of marine vegetation communities based on the 1955 baseline mapping from Accad *et al.* (2016). These were used as regions of interest for querying mangrove health at Port of Brisbane monitoring sites and surrounding sites to examine broad-scale patterns. Sentinel-2 imagery (10 m resolution, 12-band) was used to investigate changes in mangrove health for the whole of the study area over nine instances from the following capture dates:

- 14th of July 2017;
- 8th of August 2017;
- 12th of September 2017;
- 27th of October 2017;
- 15th of January 2018;
- 16th March 2018;
- 20th May 2018;
- 19th of July 2018; and
- 13th of August 2018.

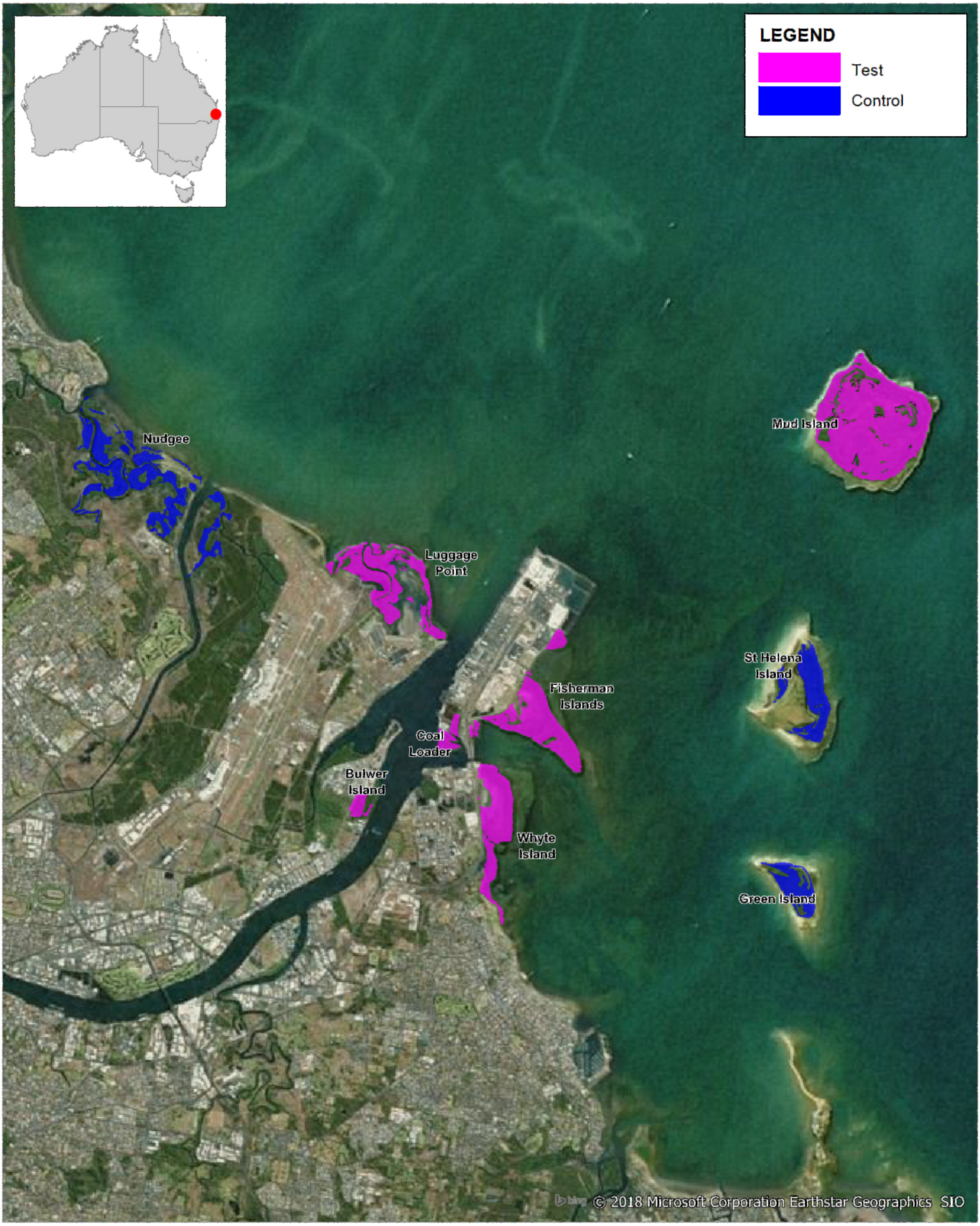
While BMT WBM (2016) used Landsat imagery to compile a long-term assessment of mangrove health, the objectives of the present study were to assess changes that had occurred in the past 12 months. Therefore, Sentinel-2 data were used in preference to Landsat due to its higher resolution. NDVI was calculated from all Sentinel-2 scenes.

2.2.2 Investigation Areas

The Mangrove Health Monitoring Program previously focused on investigation areas at Fisherman Islands (including the coal loader) and Whyte Island/Wynnum foreshore. There are several additional mangrove areas on the northern bank of Brisbane River that have undergone some form of direct modification in the last 50 years and provide contextual information for assessing temporal trends in modified areas. These were considered 'test' areas compared to other mangrove investigation areas without any direct modification ('control') which were also evaluated to provide contextual information on background variability. The area (hectares) and pixel counts for these investigation areas are detailed in Table 2-1, and the extent of these areas are shown in Figure 2-1. Sentinel-2 images provided between 2,293 and 44,460 pixels per investigation area (depending on size of the investigation areas), which was considered to be of sufficient resolution to assess broad temporal trends in mangrove health index (NDVI).

Table 2-1 Investigation area details

Treatment Type	Investigation Area	Area ha	No. Pixels
Test	Fisherman Islands (main)	181.6	18,161
Test	Fisherman Islands (coal loader)	22.9	2,293
Test	Whyte Island/Wynnum	143.9	14,389
Test	Luggage Point	265.8	26,579
Test	Bulwer Island	29.3	29,25
Control	Nudgee Wetlands	366.6	36,667
Control	King Island	68.0	6,803
Control	St Helena Island	126.0	12,596
Test	Mud Island	444.6	44,460
Total		**1648.7**	**164,873**



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Test and Control Investigation Areas

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2.2.3 Data Processing

Atmospherically-corrected bottom-of-atmosphere (BoA) Sentinel-2 data (Level-2A products) were produced using the Sen2Cor processor (version 2.4.0), developed by the European Space Agency. Level-1C top of atmosphere products were corrected for atmosphere, terrain, and cirrus cloud density using Sen2Cor within the Sentinel Application Platform (SNAP).

NDVI data were determined from each 10 x 10 m pixel using the index is shown below:

$$NDVI = (NIR - Red) / (NIR + Red)$$

where *NIR* is the near infra-red BoA reflectance, *Red* is the BoA reflectance of the red band.

Band-math and atmospheric correction was performed using SNAP 5.0, Sen2Cor, and the Sentinel-2 toolbox (S2TBX). Raster calculations and area of interest queries were performed using ArcMAP 10.3.1, and presented in MapInfo 15.0.

2.2.4 Rainfall Data

BMT WBM (2016) showed a strong correlation between cumulative 12-month rainfall and NDVI. Therefore, rainfall data was downloaded from the Bureau of Meteorology from July 2016 to August 2018, to enable this comparison.

Rainfall data were downloaded from two Bureau of Meteorology weather stations located near the study area: 040320 Fort Lytton and 040842 Brisbane Airport. There is an incomplete rainfall record for the two stations over the monitoring period, where data from May 2017 from Fort Lytton was used to complete the Brisbane Airport rainfall record. BMT WBM (2016) showed a significant correlation in rainfall between the two stations ($r^2 = 0.93$, $p<0.01$), and on this basis, it was considered appropriate to combine data from the two stations to provide a complete monthly rainfall record. Monthly total and cumulative 12-monthly rainfall for the Brisbane Airport are shown in Figure 2-2. Extreme rainfall associated with ex-severe tropical cyclone Debbie from March 2017 is included in the 12-montly cumulative rainfall. Discussion on temporal trends in rainfall are discussed in Section 4.1.

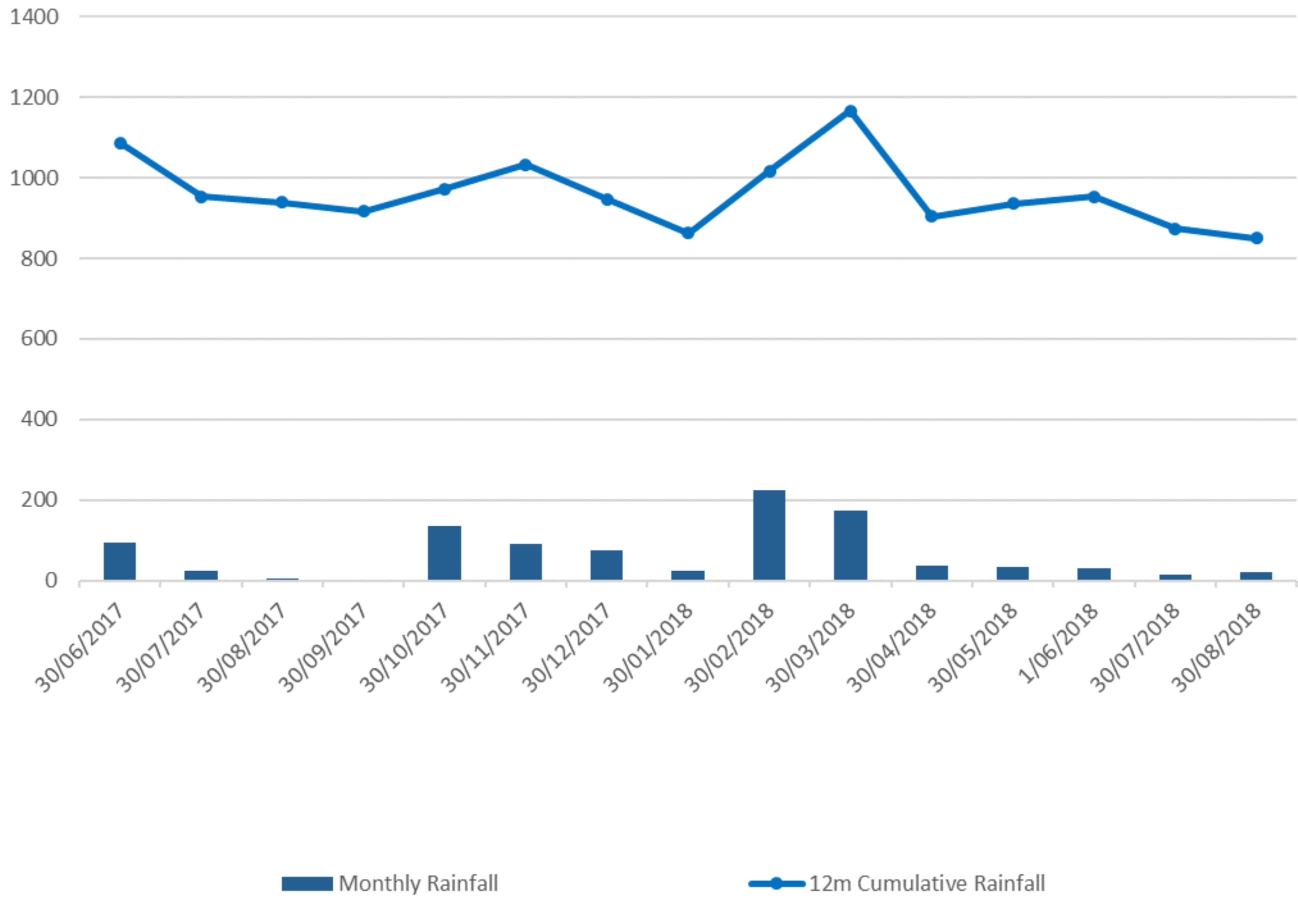


Figure 2-2 Monthly total rainfall and 12-monthly rainfall for the Brisbane Airport (station 040842 and 040320)

2.2.5 Assumptions and Limitations

The orthorectification of Sentinel-2 imagery can have up to 12.5 m geolocational error, meaning that 1-2 10 m pixels from each capture may be misaligned. Therefore, rectification errors can occur within 1-2 pixels and contribute to some errors along edge of mangrove forests. It is also noted that where the canopy is sparse (salt-pans and dieback regions), variable soil moisture can dominate the signal. Therefore, some interpretation is required in such areas.

Between 2015 and 2017 the overall pattern of change was similar between the high-resolution images and the Sentinel-2 images, thus, only Sentinel-2 was used in 2017-2018.

2.3 Bulwer Island Vegetation Assessment

The 2018 survey was a re-survey of the marine plant surveys previously conducted in 2014 and 2016. Mangrove health condition assessments were conducted at 25 sites throughout Lot 1273, of which 12 sites were assessed in the 2014 surveys and 13 sites were included in the 2016 surveys. The 2016 surveys included an additional six sites located in Lot 1261/1260; however, this area has since been cleared for development. Sites 1-25 had baseline (2014 and 2016) and 2018 data. The survey methodology at each site was consistent with that used for the previous 2014 and 2016 baseline surveys.

Assessments were undertaken using techniques adapted from the data collection protocols for mapping and monitoring mangrove communities in Queensland (DEEDI, 2011). A hand-held GPS was used to locate each site which consisted of a 5 x 5 m area marked with flagging tape.

In each site, the following information was recorded:

- Qualitative description of mangrove health (i.e. good, fair, poor, recently dead or regrowth);
- Number of trees of each species and the number of dead trees;
- Circumference at breast height of the three largest trees within the site;
- Canopy cover, canopy colour, pneumatophore (root) deformity rating;
- Visual evidence of disturbance (e.g. insect damage, anthropogenic or natural disturbances, erosion, weeds, litter, seagrass wrack etc.);
- Relative abundance of macroalgae and macroalgal mats on sediment and roots; and
- An estimate of the number of seedlings and saplings (per 1 m^2).

Site photographs were taken to make comparisons between surveys and to make site comparisons in future monitoring.

Guidelines for health score ratings, as shown in Table 2-2, were based on the recommendations from DEEDI (2011). These indices were averaged to provide an average health score for each site, then presented graphically and thematically in GIS.

Table 2-2 Mangrove Health Rating Indices (DEEDI 2011)

Parameter	Health Score				
	1	2	3	4	5
Leaf colour	no leaves	brown	yellow	y-green	green
Insect Damage	very high	high	some	little	none
Seedling Abundance	none	<1/m^2	common	like a patchy carpet	like a carpet
Epicormic Growth	trunk like a "bottlebrush"	high	some	little	none
Pneumatophore Deformity	most	many	some	few	none

3 Results

3.1 Changes in Estuarine Community Extent - 1955 to 2018

Figure 3-1 and Table 3-1 summarise overall changes in the extent of estuarine vegetation communities between 1955 and 2018 at Fisherman Islands (including the Coal Loader area), Whyte Island and Bulwer Island investigation areas based on the analysis of historical aerial photography.

Table 3-1 Changes in Estuarine Vegetation Extent 1955-2018 – Fisherman Islands, Whyte Island and Bulwer Island

Community	Area (ha) by year						
	1955	1978	1983	1997	2009	2012	2018
Mangroves	481.1	366.6	375.7	278.0	252.0	262.7	273.9
Saltmarsh	37.5	126.6	134.4	54.3	77.3	66.6	55.7
Total estuarine vegetation	518.6	493.2	510.1	332.3	329.3	329.3	329.6
Total mangrove change from previous mapping period		-114.5	+9.1	-97.7	-26.0	+10.7	+11.2
Total saltmarsh change from previous mapping period		+89.1	+7.8	-80.1	+23.0	-10.7	-10.9
Total change in estuarine habitat from previous mapping period		-25.4	+16.9	-177.8	-3.0	0.0	+0.3

There were major changes in estuarine vegetation at Fisherman and Whyte Islands associated with the construction of the causeway, road bridges, and rail links between the islands to the mainland in the mid 1970's (refer to). Over 100 ha of mangroves were directly removed and nearly 60 ha of non-vegetated saltpan/saltmarsh habitat were created to the north of Fisherman Islands and in the north-east of Whyte Island as a result of land reclamation.

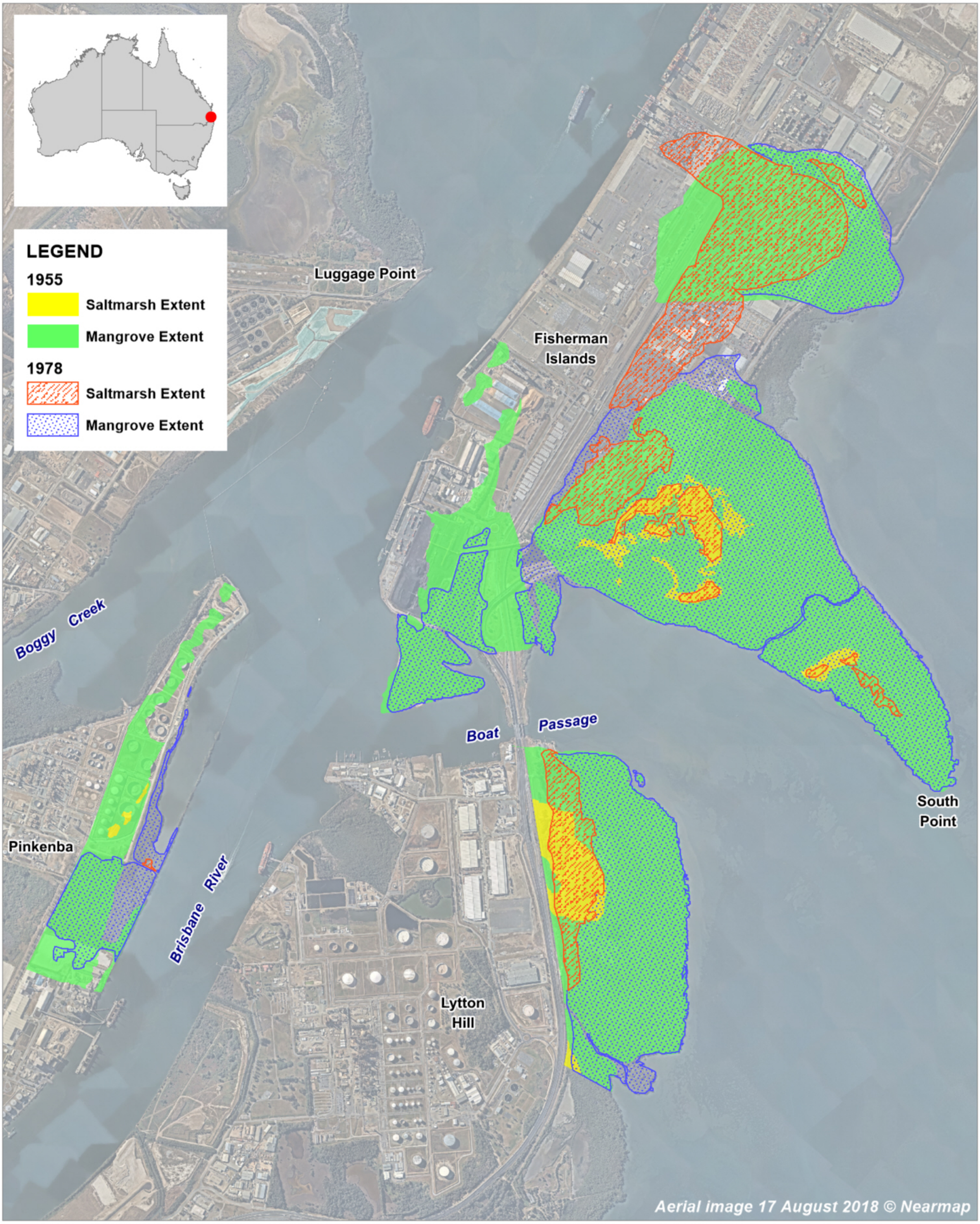
Following these major construction works there was a period of estuarine community recovery and adaptation to the modified hydrological and coastal processes resulting in an overall 9 ha increase in mangrove cover and more than 7 ha increase in saltmarsh habitat by 1983. Most of the changes occurred to the north of Fisherman Islands where mangrove expansion occurred seaward and there was mangrove incursion into reclaimed and saltmarsh habitats. Over 10 ha of mangrove dieback was also detected in the middle of Whyte Island during this period.

Major port expansion works in the 1990's resulted in the removal of nearly 180 ha of estuarine habitat (approximately 100 ha of mangroves and 80 ha of saltmarsh), predominantly from Fisherman Islands. Seaward mangrove expansion continued to occur north of Fisherman Island at a rate of approximately 0.5 ha/year. There was also localised mangrove dieback and conversion to saltmarsh/claypan habitat in the centres of Fisherman Islands and Whyte Island probably due to hydrological modifications associated with port expansion and regional drought conditions.

No major construction works occurred at the port between 1997 and 2018 and estuarine habitats remained relatively stable. Between 1997 and 2009 localised patches of mangrove converted to saltmarsh (25 ha in total) at the upper tidal limits in in the centres of Fisherman and Whyte Islands. Seaward mangrove expansion continued to occur north of Fisherman Island at a rate of approximately 0.2 ha/year. From 2009 to 2018, approximately 11 ha of mangroves colonised saltmarsh communities at the upper tidal limits in the centres of Fisherman and Whyte Islands. Seaward mangrove expansion also continued to occur north of Fisherman Island at a rate of approximately 0.25 ha/year.

Pre-development at the Port **2018**

Figure 3-1 Port of Brisbane 1955-2018



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1955 - 1978

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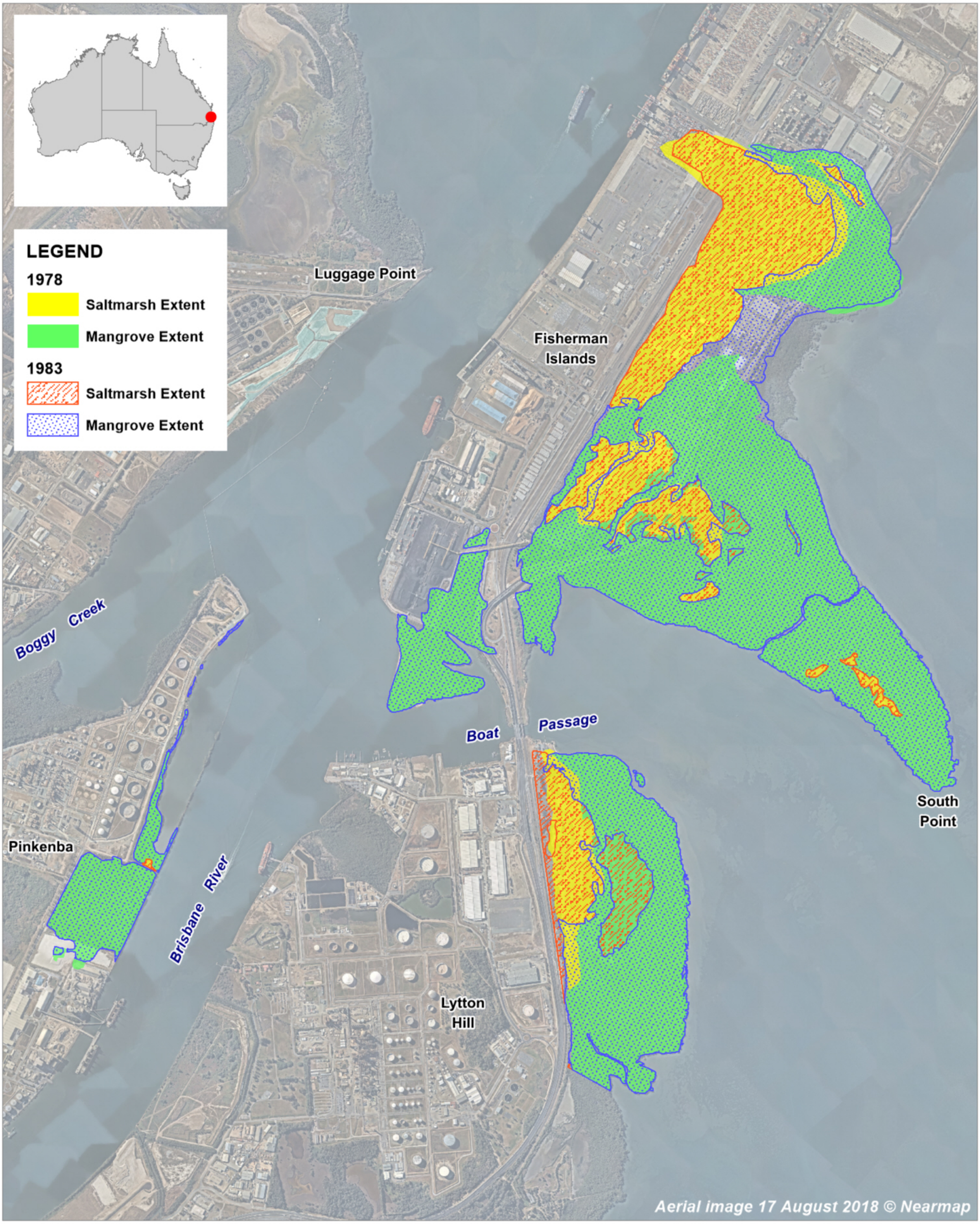

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1978 - 1983

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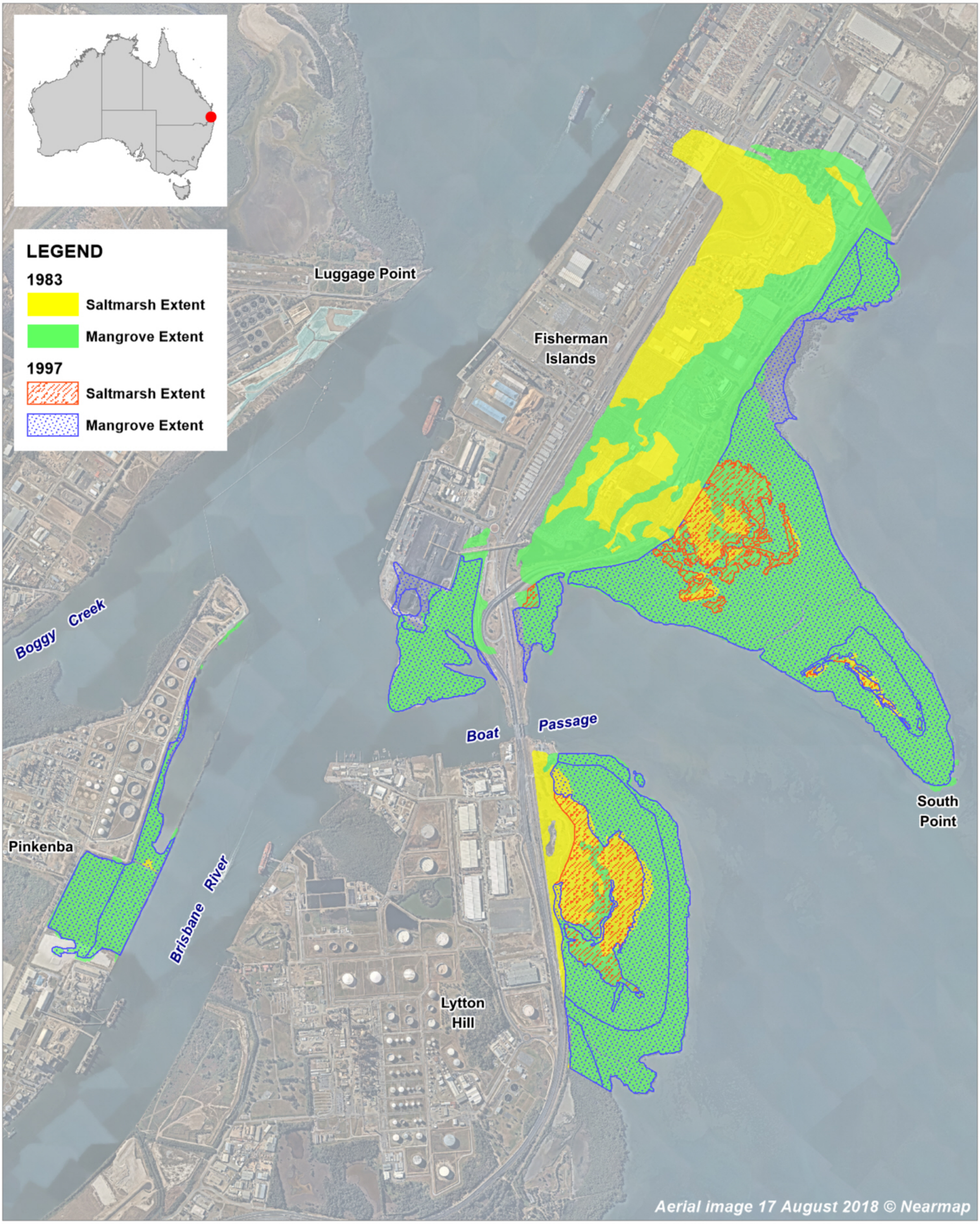

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1983 - 1997

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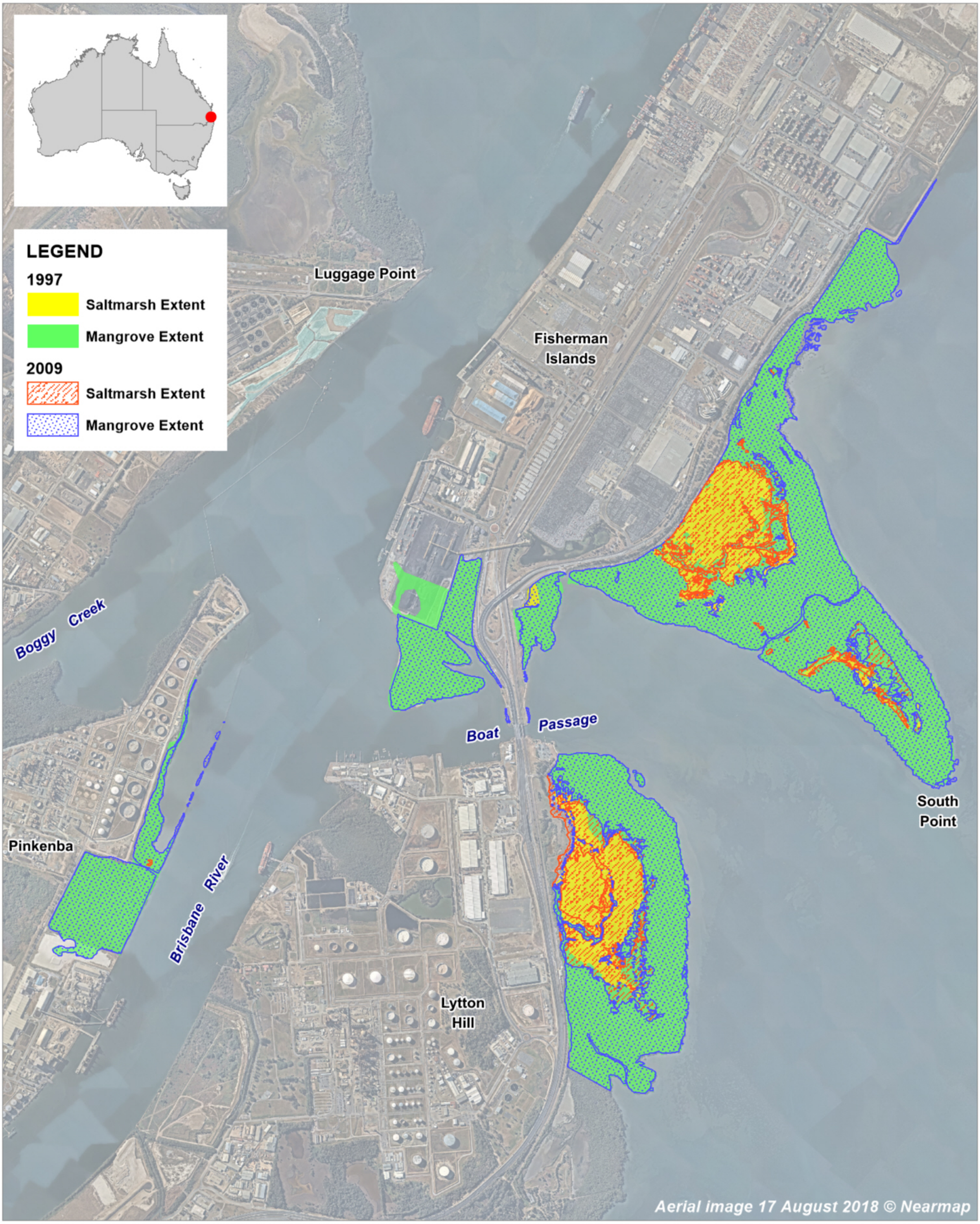

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1997 - 2009

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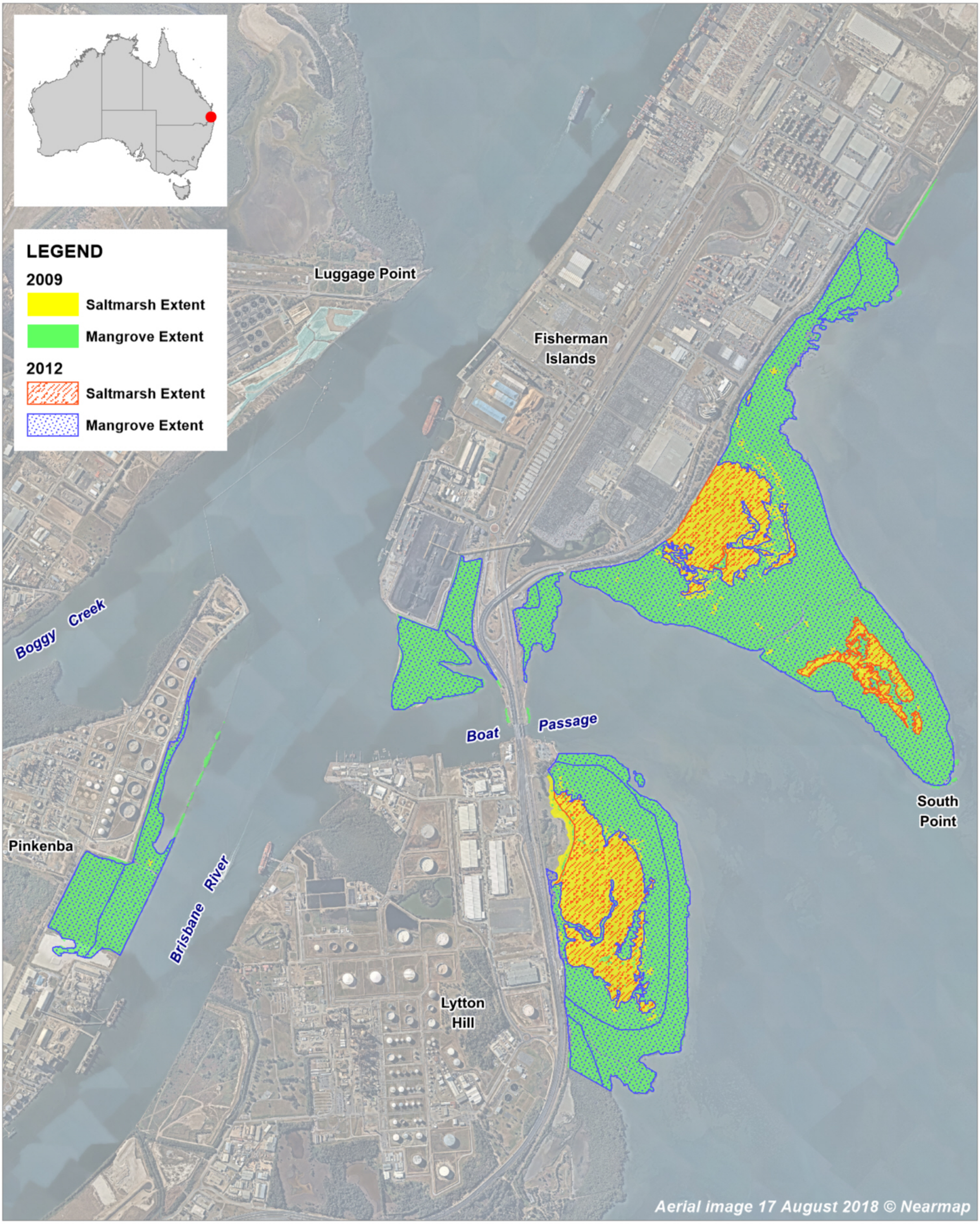

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2009 - 2012

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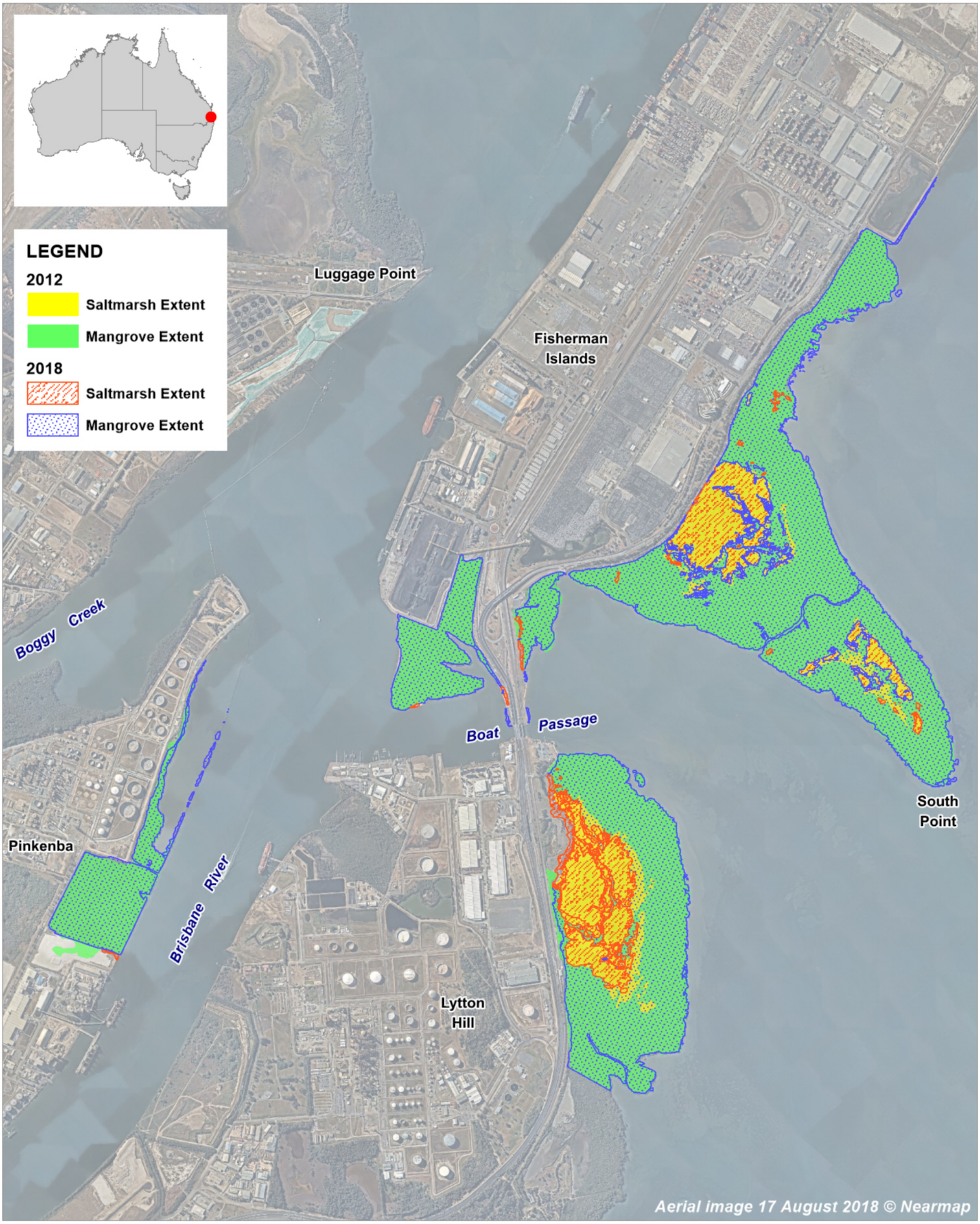

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2012 - 2018

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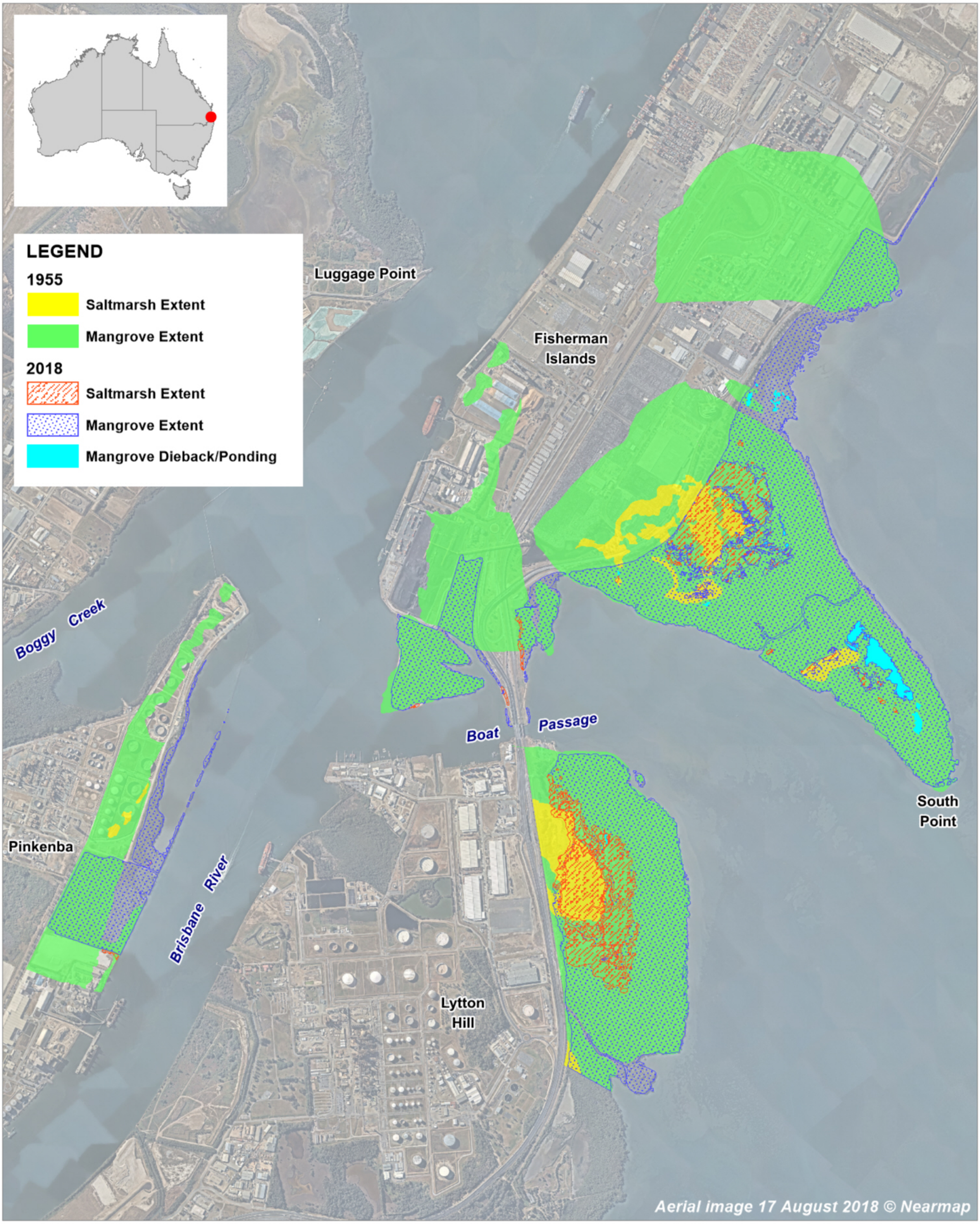

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1955 - 2018

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3.2 Contemporary Trends in NDVI

NDVI time series are shown in Figure 3-9 and Figure 3-10, and as spatial representations in Figure 3-11. Control and test sites exhibited a similar temporal pattern in NDVI and temporal trajectories were largely consistent among island and mainland sites, and between test and control sites.

At inter-annual time scales, NDVI scores were higher in July 2017 than July 2018 at both test and control sites.

At seasonal time scales, NDVI was higher in winter than summer at all investigation sites. Over the 12-month period, all sites showed the previously observed decline in NDVI through the summer months with the lowest values occurring in January 2018 at all sites. This differs from trends in 2016-17 where the minima varied among sites between November and February. The highest NDVI values were observed in July 2017 at all investigation sites. NDVI scores had declined at all investigation sites between July 2018 and August 2018.

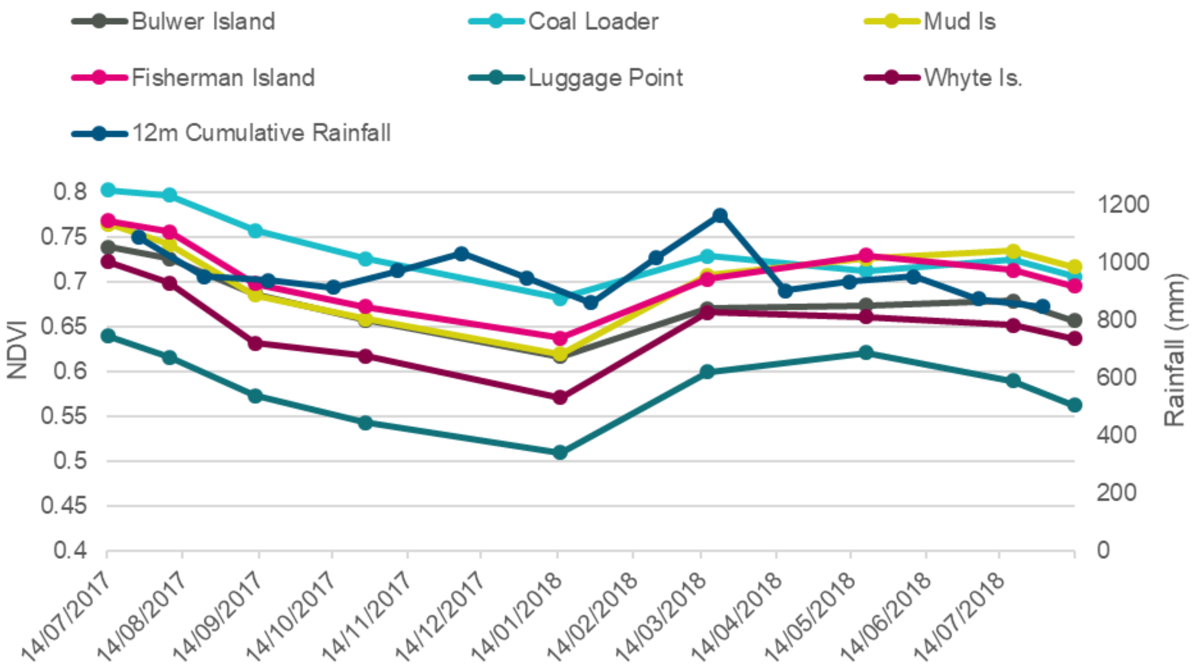


Figure 3-9 Temporal changes in NDVI with respect to 12-month cumulative rainfall at Test sites, from July 2016 to August 2017

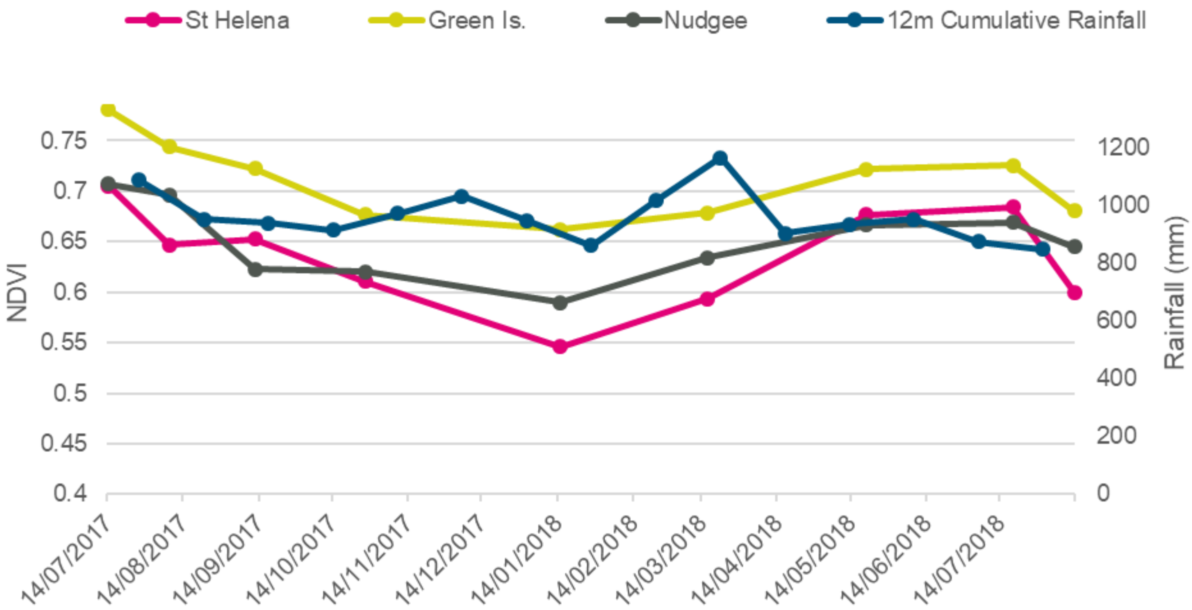
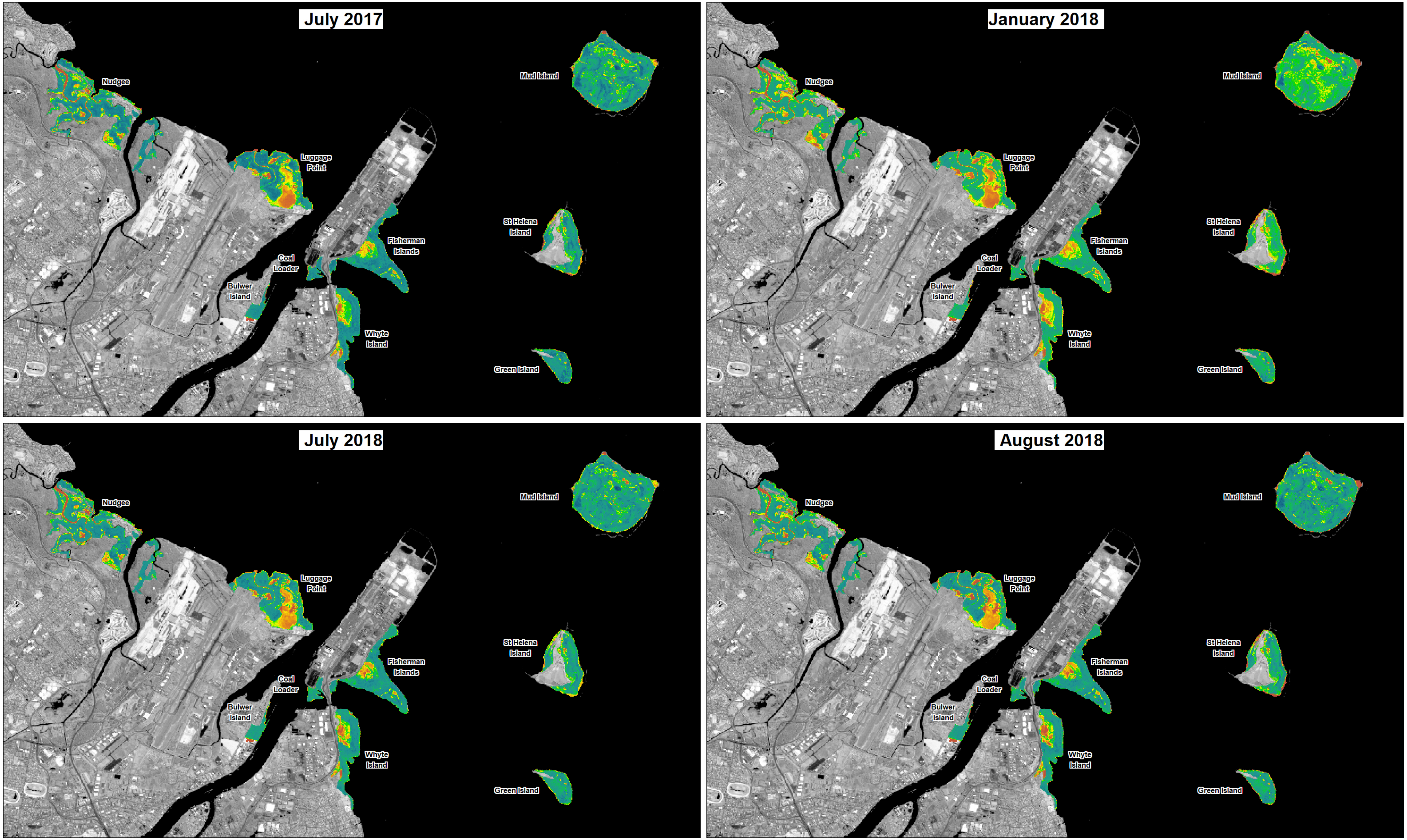


Figure 3-10 Temporal changes in NDVI with respect to 12-month cumulative rainfall at Control sites, from July 2016 to August 2017

Temporal differences in NDVI are mapped in Figure 3-12 to Figure 3-14. Blue areas depict an increase NDVI over time, red areas represent reductions in NDVI. In summary:

- July 2017 to March 2018 (Figure 3-12) - reduction in NDVI in mangrove areas at Luggage Point, Mud Island, St Helena Island, and King Island Lower magnitude reductions in NDVI were recorded at Whyte and Fisherman Islands, Mud Island, and Nudgee.
- July 2017 and July 2018 (Figure 3-13) – there was great variability in NDVI among and within sites. Nudgee wetlands, Mud Island, Fisherman Islands, and St Helena Island were relatively neutral. There was an increase (northern portion) and decrease (southern portion) in NDVI over time at Whyte Island, whereas NDVI declined over time at the Coal Loader and Bulwer Island. This change in NDVI across the 12-month (July 2017-18) period was used to identify potential dieback areas to be assessed in ground-truthing (see Section 3.3).
- August 2017 and 2018 (Figure 3-14) – consistent reduction in NDVI scores across the all sites.



LEGEND

NDVI Score

0 — 0.5 — 1.0

Title:

NDVI at investigation sites in July 2017, January 2018, July 2018, and August 2018

Figure: 3-11

Rev: A

N

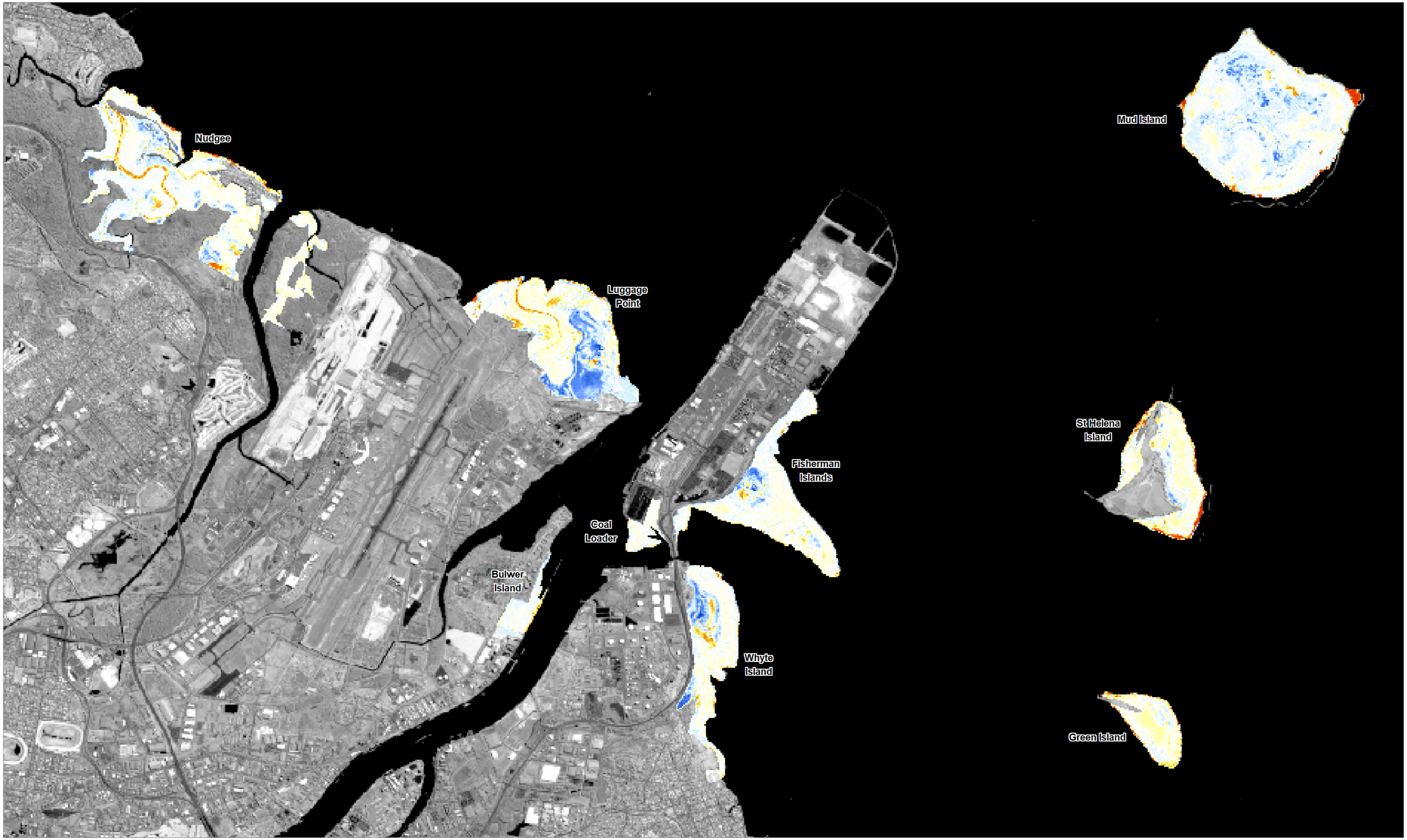
0 2.5 5km

Approx. Scale

BMT

www.bmt.org

Filepath: \\BMT-BNE-FS01\drafting\B20259_I_BRH Port of Brisbane DLR\DRG\Mangrove_2018\ECO_003_NDVI_4_plot_181017.WOR



LEGEND

NDVI Change Score

-1.5 0 1.5

Title:

Changes in NDVI between July 2017 and March 2018

Figure: 3-12

Rev: A

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

N

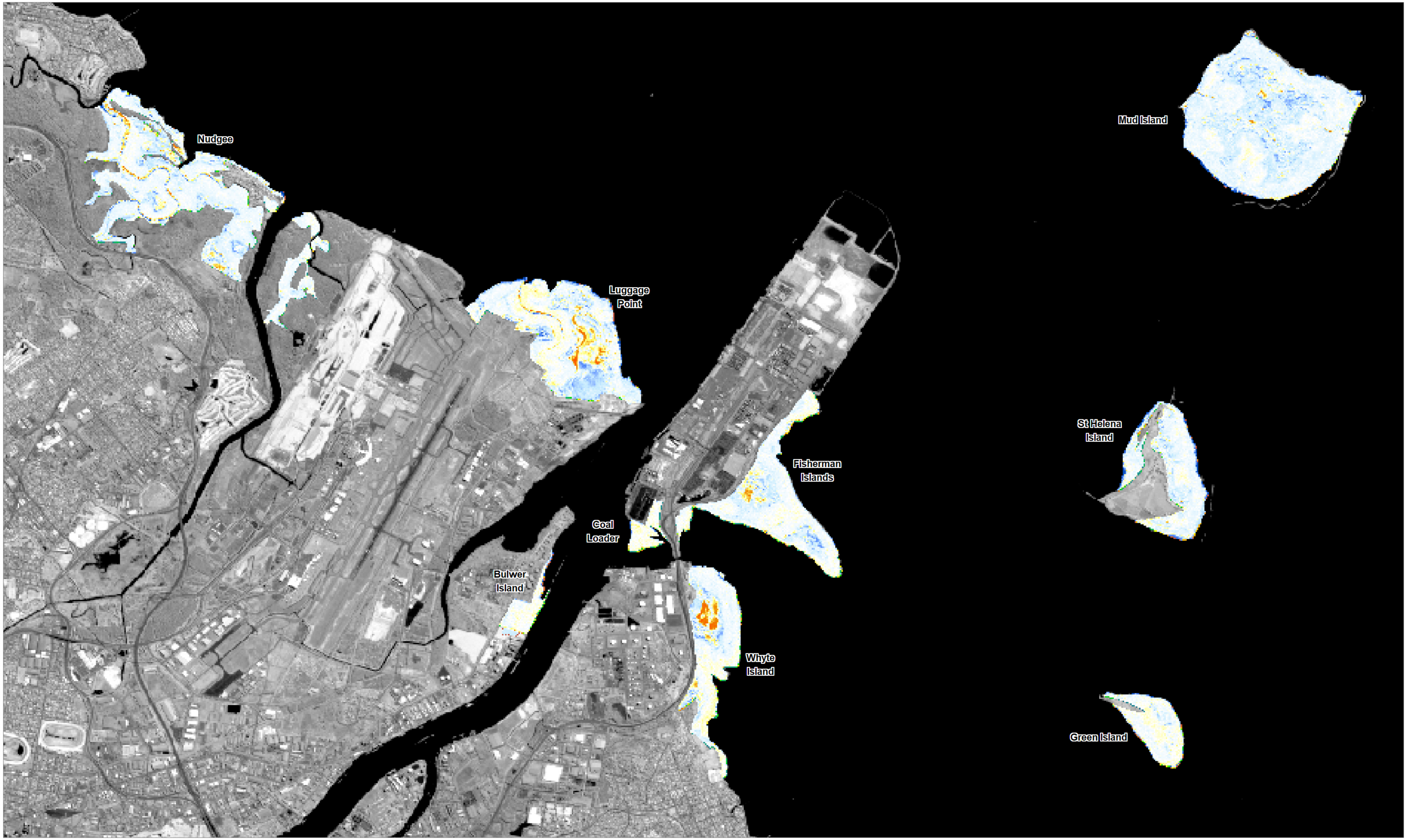
0 1 2km

Approx. Scale

BMT

www.bmt.org

Filepath: \\BMT-BNE-FS01\drafting\B20259_I_BRH Port of Brisbane DLR\DRG\Mangrove_2018\ECO_004_NDVI_change_July17-Mar18_181017.WOR



LEGEND

NDVI Change Score

-1.5 0 1.5

Title:

Changes in NDVI between July 2017 and July 2018

Figure: 3-13

Rev: A

N

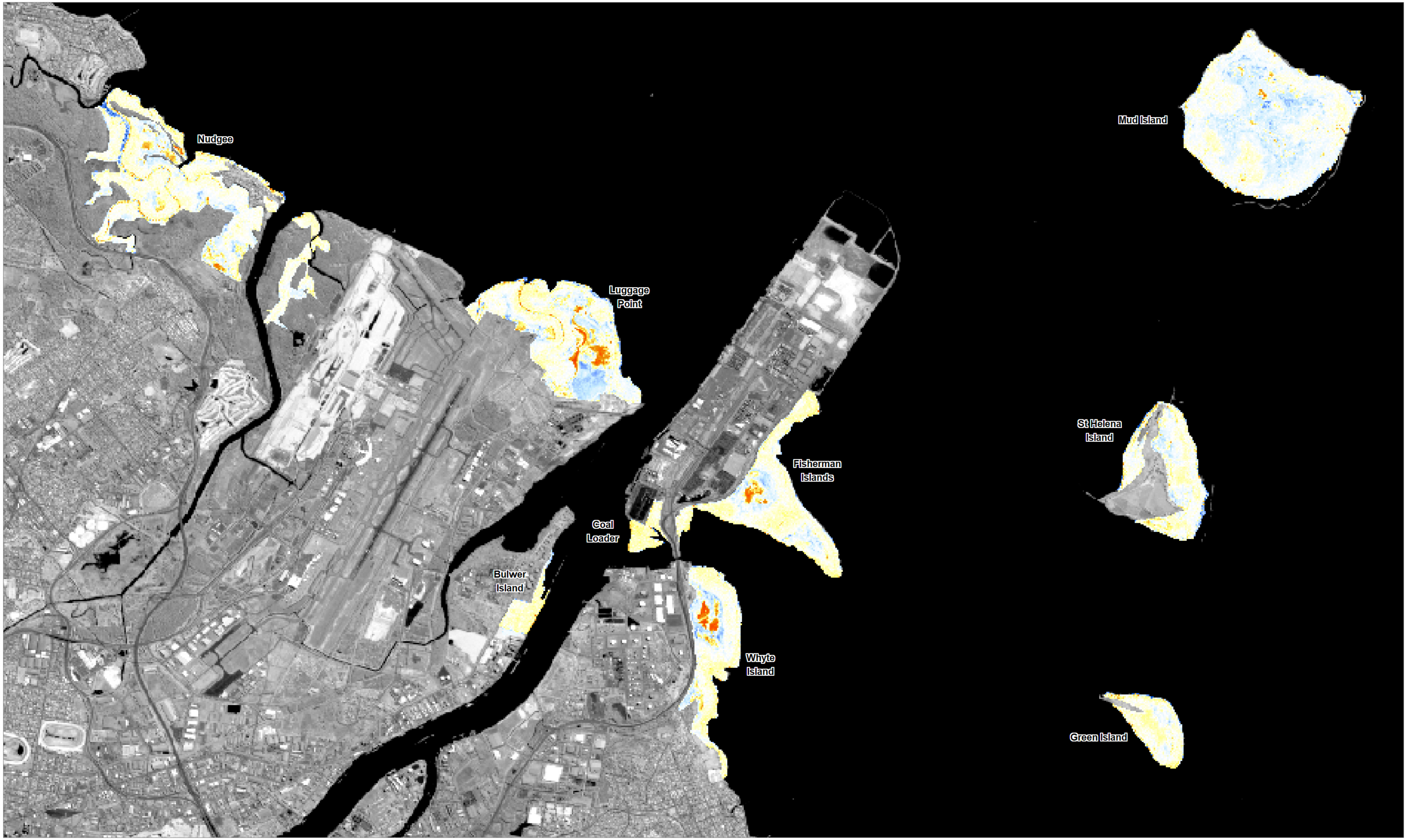
0 1 2km

Approx. Scale

BMT

www.bmt.org

Filepath: \\BMT-BNE-FS01\drafting\B20259_I_BRH Port of Brisbane DLR\DRG\Mangrove_2018\ECO_005_NDVI_change_July17-July18_181017.WOR



LEGEND

NDVI Change Score

-1.5 0 1.5

Title:

Changes in NDVI between August 2017 and August 2018

Figure: 3-14

Rev: A

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

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0 1 2km

Approx. Scale

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3.3 Ground-truthing of NDVI Changes

Ground-truthing conducted on the 30-31st of August confirmed the presence of contemporary dieback areas, recent tree-falls and canopy thinning in areas where NDVI between July 2017 and July 2018. Areas where mangrove condition declined over the 12-month period are depicted in Figure 3-16, with points indicating ground-truthing effort used to check NDVI change maps. Unlike 2016-17 monitoring, where small dieback patches were set against a backdrop of canopy improvement, the present study showed more diffuse and broad reductions in NDVI associated with canopy thinning and fallen branches. Field observations at six broad areas with NDVI declines are described below.

Area 1 – Northern Fringe of Fisherman Islands (*Avicennia* dominated community)

Area 1 at the northern seaward fringe of Fisherman Islands had both large tree-falls and large gaps in the canopy (Figure 3-15). Recent dieback (within the last 12 months and within the previous week) was evident along the seaward fringe of the mangroves, as well as within the forest (Figure 3-19).

Figure 3-15 Area 1: Recent dieback along the mangrove fringe, showing fallen trees and parts of trees with leaves varying from green to brown.

Title:

Changes in NDVI, Ground-truthing and Areas of Concern

Figure: 3-16

Rev: A

N

0 400 800m

Approx. Scale

BMT

www.bmt.org

Filepath: \\BMT-BNE-FS01\drafting\B20259_I_BRH Port of Brisbane DLR\DRG\Mangrove_2018\ECO_007_NDVI_change_Ground_truthing_FI_WI.WOR

Area 2 – Southern shoreline of Fisherman Islands (*Avicennia* dominated community)

Area 2 is located within along the southern shoreline of the main peninsula of Fisherman Islands. Several large tree falls were observed in the fringing *Avicennia* dominated community and within 30-50 m of this fringe. Several large trees had recently lost all or large parts of the canopy, as indicated by the presence of branchlets and yellowing and brown leaves on fallen branches (Figure 3-17). Older tree falls (large stags) were also present, suggesting that this may be an ongoing, but accelerating phenomenon. Although only a few trees were completely defoliated or had fallen, apparent canopy thinning was widespread (Figure 3-20).

Figure 3-17 Area 2: Recent fallen *Avicennia* as whole trees along the shoreline (left) with numerous dropped branches within 50m of the fringe (right)

Area 3 – Western Fisherman Islands near Port Drive (*Avicennia* dominated community)

Mangrove condition in this area was similar to Area 2, consisting of some broad-scale canopy thinning and occasional dropped branches and dead trees (Figure 3-18). There appeared to have been a change in sediment dynamics at this location, with cable roots of many *Avicennia* visible along the fringe, and sand deposits present 20-30 m behind the fringe. There were also several trees without branchlets, suggesting that defoliation had also occurred here in the past. Individual and partial tree falls were observed in aerial imagery over the past 12 months (Figure 3-21).

Figure 3-18 Area 3: Fallen *Avicennia* along the shoreline showing recently browned leaves (left), cable roots exposed indicating erosion (right)

Area 4 – Coal Loader at Fisherman Islands (*Avicennia* dominated community)

Several large *Avicennia* had partially or completely defoliated canopies, and several large branches had fallen (Figure 3-23). Near the shore, a deep sand ridge had buried the bases of *Aegiceras* and pneumatophores of *Avicennia,* while further towards the Brisbane River, sediment had been scoured away from the bases of mangroves, exposing lateral roots. The position of the sand ridge can be seen on Figure 3-22, with the largest changes in canopy cover occurring on and surrounding this feature.

Figure 3-19 High-resolution aerial imagery of canopy conditions at Area 1 in the north of Fisherman Islands in July 2017 (top), January 2018 (middle) and July 2018 (bottom). Yellow polygons show changes in canopy

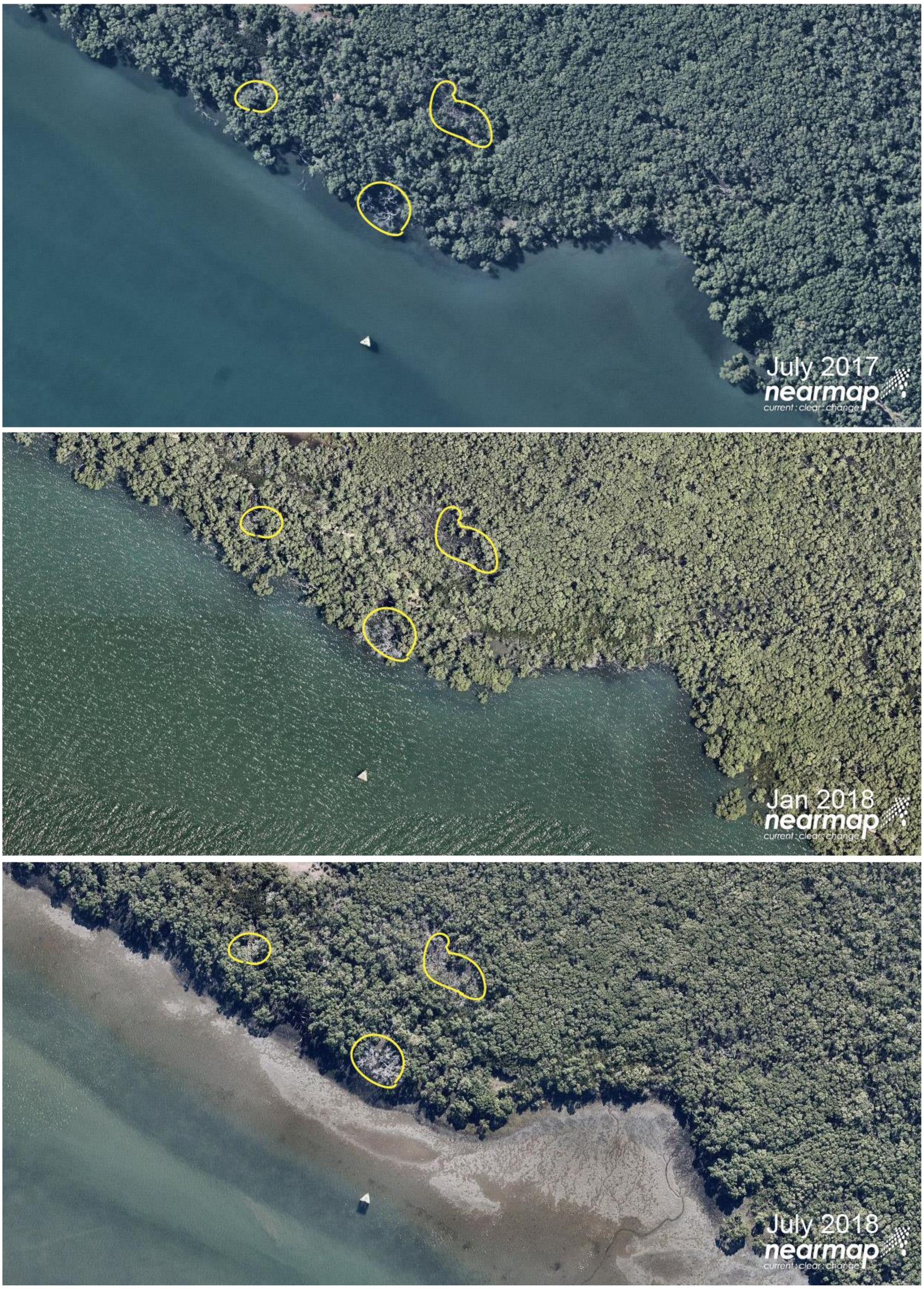


Figure 3-20 High-resolution aerial imagery of canopy conditions at Area 2 in along the southern shore of Fisherman Islands in July 2017 (top), January 2018 (middle) and July 2018 (bottom). Yellow polygons show changes in canopy

Figure 3-21 High-resolution aerial imagery of canopy conditions at Area 3 in along the south-western extremity of Fisherman Islands in July 2017 (top), January 2018 (middle) and July 2018 (bottom). Yellow polygons show changes in canopy

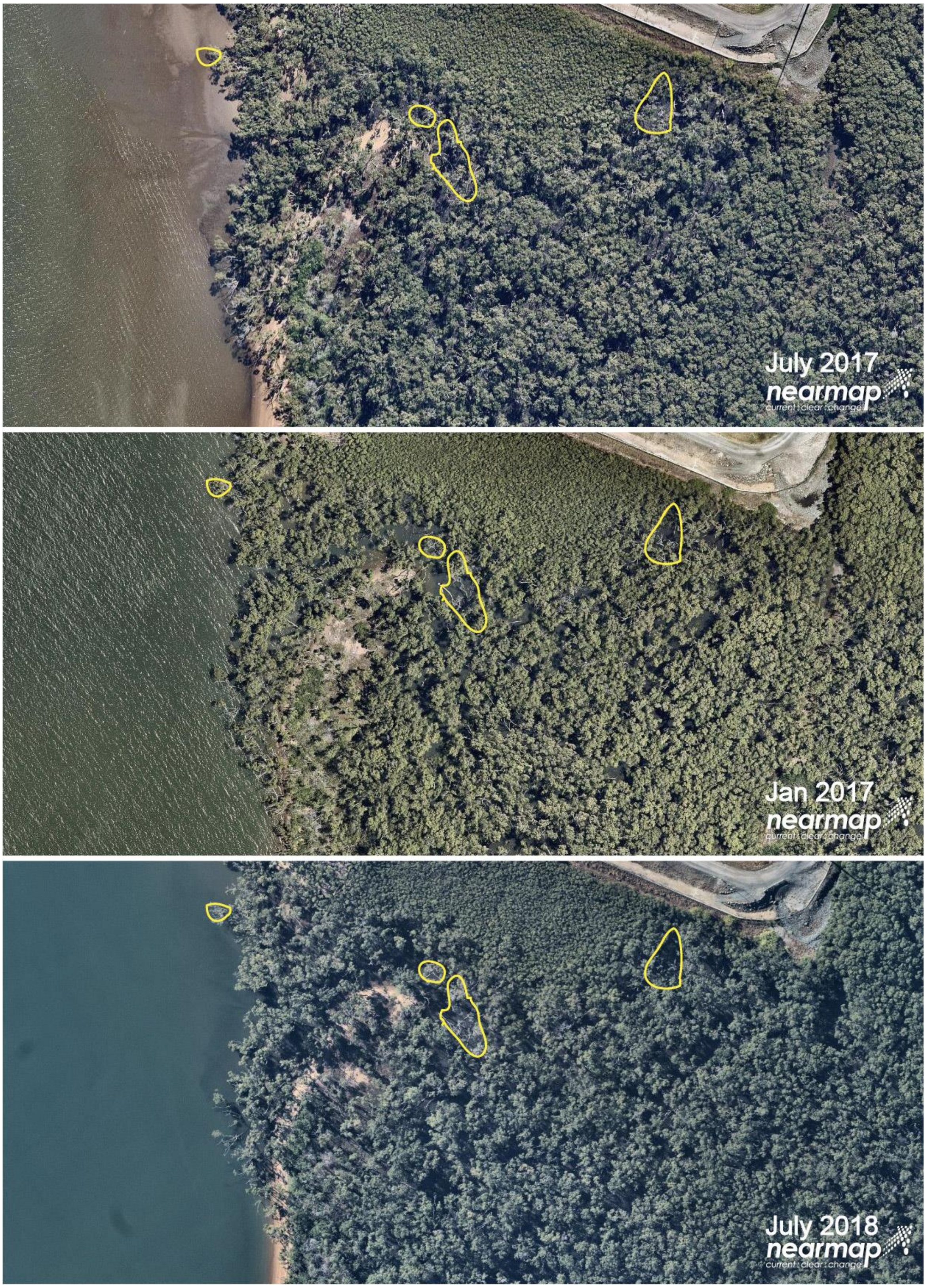


Figure 3-22 High-resolution aerial imagery of canopy conditions at Area 4 just south of the Coal Loader in July 2017 (top), January 2018 (middle) and July 2018 (bottom). Yellow polygons show changes in canopy

Figure 3-23 Area 4: defoliated *Avicennia* along the Brisbane River shore (top left); old dieback (top right); new dieback (lower left); large tree falls further inside the forest (lower right)

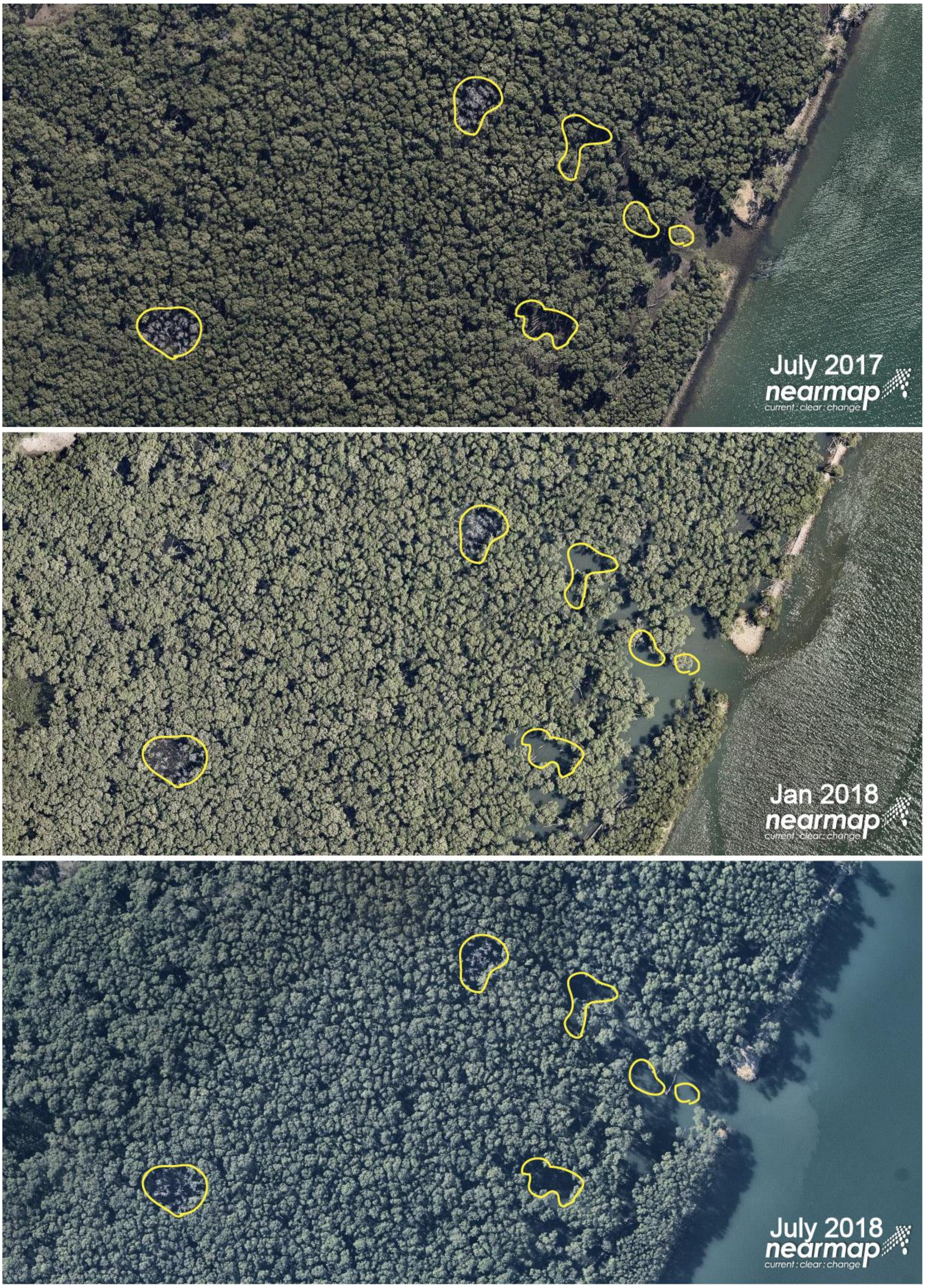


Figure 3-24 High-resolution aerial imagery of canopy conditions at Area 5 near the central bund wall removal section of Bulwer Island in July 2017 (top), January 2018 (middle) and July 2018 (bottom). Yellow polygons show changes in canopy

Figure 3-25 Area 6: Thinning canopy in the background with healthy regrowth in the foreground

Area 5 – Bulwer Island (*Avicennia* dominated community)

Area 5 was located at Bulwer Island near the BP products wharf. NDVI change mapping showed both areas of decline and improvement in NDVI between 2017 and 2018 ("I:\B20259_I_BRH Port of Brisbane DLR\JPG\Mangrove health 2018\181203\Figure 3-27.JPG"

Figure 3-27). The increase in NDVI occurred towards the western extent (distant from revetment works conducted in 2016). Some NDVI reduction was observed around the opening of the culvert, and centrally. It is likely that the opening has resulted in better tidal connectivity to the back of the forest, but land-form changes around the revetment wall openings have reduced canopy cover and NDVI (see Section 3.4 for more detail). Reductions in canopy NDVI appear to be the result of pockets of canopy defoliation and tree-falls (see Section 3.4).

Area 6 – Whyte Island boardwalk (*Avicennia* dominated community)

Area 6 was located at the southern end of Whyte Island and corresponded to a small patch of mangrove dieback just south of the trail to the mangrove boardwalk. Partial canopy defoliation was observed on larger (5-7 m canopy) within the central canopy observed from a lookout. Mangrove regrowth was observed immediately adjacent to the trail to the boardwalk, resulting in the improvement to the NDVI score (Figure 3-25). The changes in canopy cover can be seen in Figure 3-26.

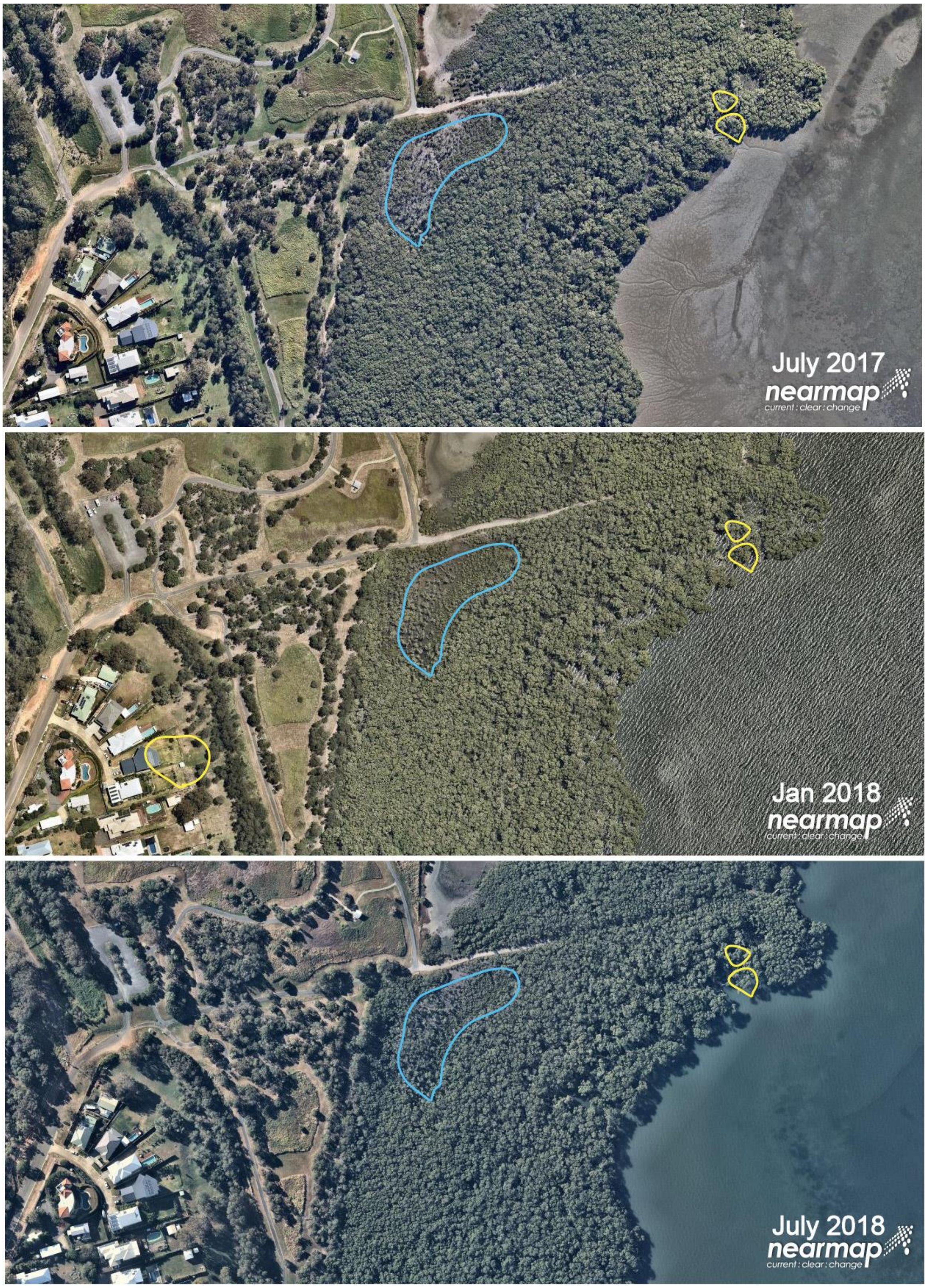
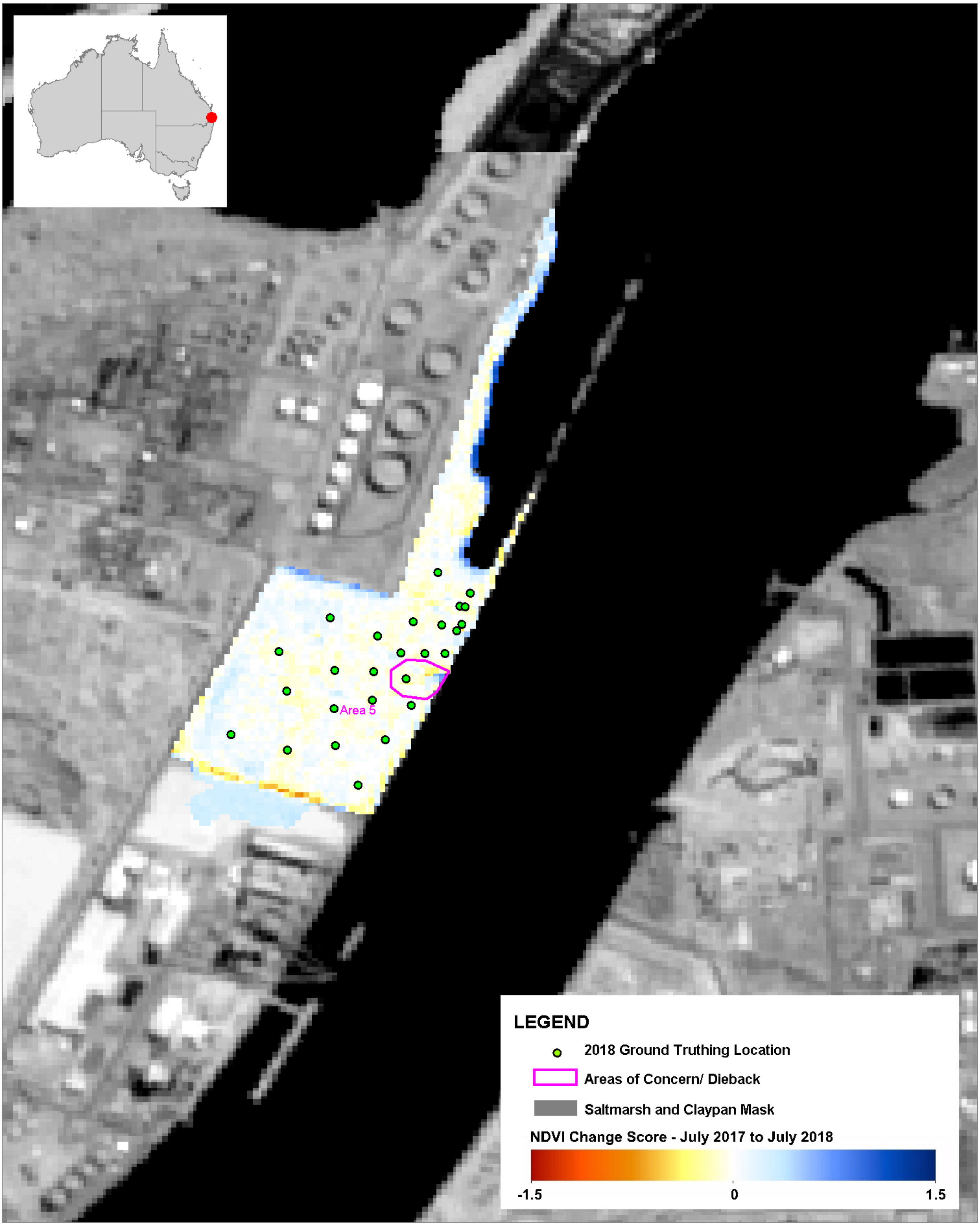


Figure 3-26 High-resolution aerial imagery of canopy conditions at Area 6 at the Whyte Island in July 2017 (top), January 2018 (middle) and July 2018 (bottom). Yellow polygons show reductions in canopy and blue polygons show regrowth



Title:
Changes in NDVI, Ground-truthing and Areas of Concern at Bulwer Island

Figure: 3-27

Rev: A

N

0 150 300m
Approx.Scale

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www.bmt.org

Filepath: I:\B20259_I_BRH Port of Brisbane DLR\DRG\Mangrove 2017\ECO_009_171012_2017_Bulwer_AOC.wor

3.4 Mangrove Health at Bulwer Island

As per previous surveys, four mangrove species were recorded in the monitoring sites (Figure 3-28). The grey mangrove (*Avicennia marina*) numerically dominated all survey sites, except Site 25 which was dominated by yellow mangrove (*Ceriops australis*). *Ceriops australis* was also recorded at Site 24 while the river mangrove (*Aegiceras corniculatum)* was present at Site 12 and the red mangrove (*Rhizophora stylosa*) was recorded at Site 1, albeit in sapling form. Similar to previous survey findings, three other mangrove species were observed in the northern extent of the study area outside of quadrats, including: *Excoecaria agallocha*, *Bruguiera gymnorhiza* and *Acrostichum speciosum.*

Species composition and abundance from the 2018 survey for each site is presented in Figure 3-28, with results from the 2014 and 2016 combined as a baseline. The total number of trees in each site during the 2018 surveys had reduced or remained unchanged at all sites except sites, 9 and 19. All other sites had between a 7 to 62% reduction in abundance or they remained unchanged. The two sites that recorded an increase in abundance (sites 9 and 19), increased by 14 to 20%, respectively. Tree abundance in the 2018 survey varied from three (Site 7) to 16 trees (Sites 12 and 25) at a site while 2014 and 2016 surveys recorded a higher abundance with a range from 3 (Site 7) to 31 (Site 12) trees.

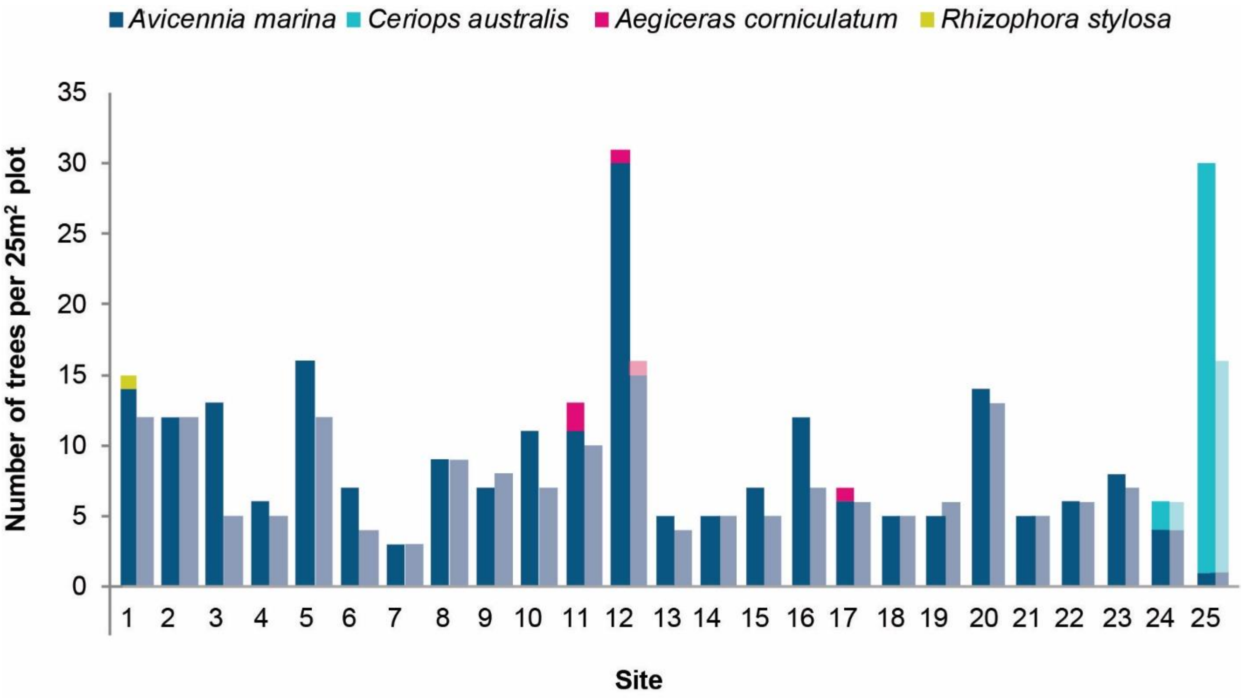


Figure 3-28 Mangrove species composition and relative abundance in during the baseline and in 2018 (half-tones)

Sites 12 and 25 had the two highest tree counts in the baseline and 2018 surveys; during the baseline they had 30 and 31 trees, respectively. Site 12 was dominated by *A. marina* which made up 30 of the overall 31 trees and Site 25 was dominated by *C. australis* with 29 of the 30 trees recorded. While abundance at Site 12 and 25 has significantly decreased from previous surveys, these two sites also had the highest tree counts in the 2018 surveys with a total of 16 in each consisting of 15 *A. marina* in Site 12 (and one *A. corniculatum*) and 15 *C. australis* (and one *A. marina*) in Site 25.

Apart from site 25, all other sites were dominated by *A. marina.* There was a decrease in mangrove abundance at sites 9 and 19, and nine sites had a 20% or more reduction in abundance (Figure 3-28). This was due to attrition of small trees within the sub-canopy. However, photographic monitoring also suggested that in several cases near the revetment wall opening, there had been a loss of mature trees, with many large fallen trees within and adjacent to quadrat sites (See Appendix A). Numerous fallen trees were observed near the bud wall opening and at site 14 and 15. Tree counts are detailed in Table 3-2.

Table 3-2 Mangrove species (non-seedling) recorded during 2014, 2016 and 2018 surveys (note: shaded sites are located in an area cleared for development)

Survey year	Site	grey mangrove *Avicennia marina*		yellow mangrove *Ceriops australis*		river mangrove *Aegiceras corniculatum*		red mangrove *Rhizophora stylosa*	
		2014	2018	2014	2018	2014	2018	2014	2018
2014 vs 2018	**1**	14	12	-		-	-	-	-
	2	12	12	-	-	-	-	-	-
	3	13	5	-	-	-	-	-	-
	4	6	5	-	-	-	-	-	-
	5	16	12	-	-	-	-	-	-
	6	7	4	-	-	-	-	-	-
	7	3	3	-	-	-	-	-	-
	8	9	9	-	-	-	-	-	-
	9	7	8	-	-	-	-	-	-
	10	11	7	-	-	-	-	-	-
	11	11	10		-	2	X	-	-
	12	30	15		-	1	1	-	-
Year	**Site**	**2016**	**2018**	**2016**	**2018**	**2016**	**2018**	**2016**	**2018**
2016 vs 2018	**13**	5	4	-	-	-	-	-	-
	14	5	5	-	-	-	-	-	-
	15	7	5	-	-	-	-	-	-
	16	12	7	-	-	-	-	-	-
	17	6	6		-	1	X	-	-
	18	5	5	-	-	-	-	-	-
	19	5	6	-	-	-	-	-	-
	20	14	13	-	-	-	-	-	-
	21	5	5	-	-	-	-	-	-
	22	6	6	-	-	-	-	-	-
	23	8	7	-	-	-	-	-	-
	24	4	4	2	2	-	-	-	-
	25	1	1	29	15	-	-	-	-

Mangroves were given two health ratings; a subjective overall health category and an average health score calculated based on the DEEDI (2011) scoreable indices. Similar to the baseline surveys, signs of stress were recorded throughout the study area. All sites were assigned an overall health category of 3 or 4, similar to the baseline surveys (Figure 3-29). Six of the 25 sites (2,5,8,17,19, 24) had higher health category scores in 2018 than in the baseline, while six sites (4,6,9,18,20,21) had lower health category scores in 2018 than in the baseline surveys.

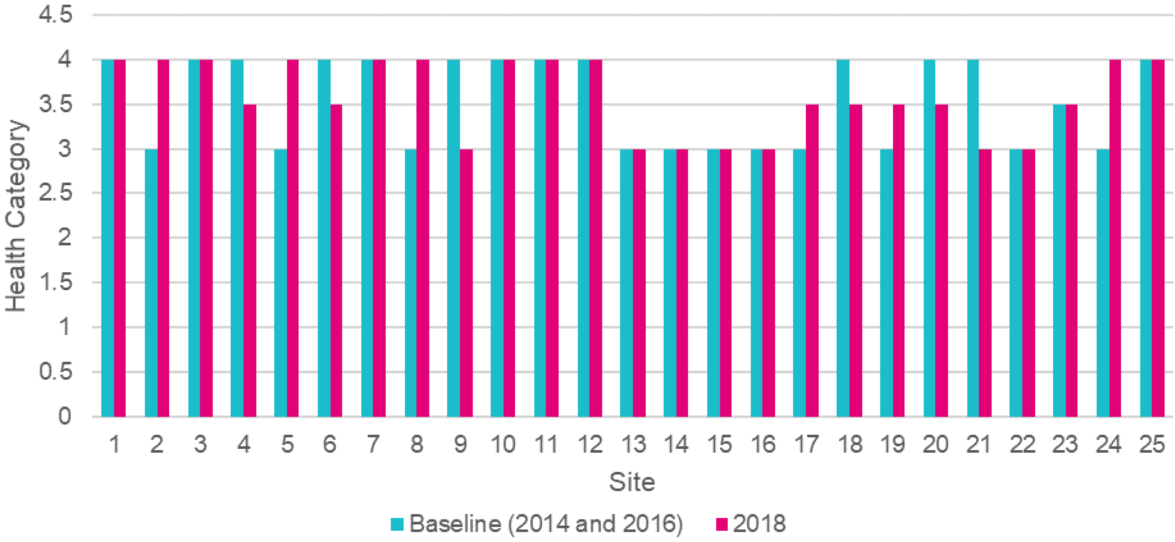


Figure 3-29 Overall health category ratings for the baseline and 2018

Average health scores based on DEEDI (2011) scorable indices showed that all sites except two (sites 21 and 23) had higher average scores in 2018 than they did in baseline surveys (Figure 3-30). Features that sites typically scored poorly included the extent of macroalgae growing on pneumatophores, seedling rating, and the presence of epicormic growth. Thematic mapping of averaged health scores is shown in Figure 3-31. This shows the position of sites and colour-categorised health scores. The biggest improvements were located to the north of the site. Interestingly, sites near the southern revetment wall opening had relatively unchanging health scores, but ground-truthing suggested significant levels of tree-fall, canopy opening, and sediment bed-level changes.

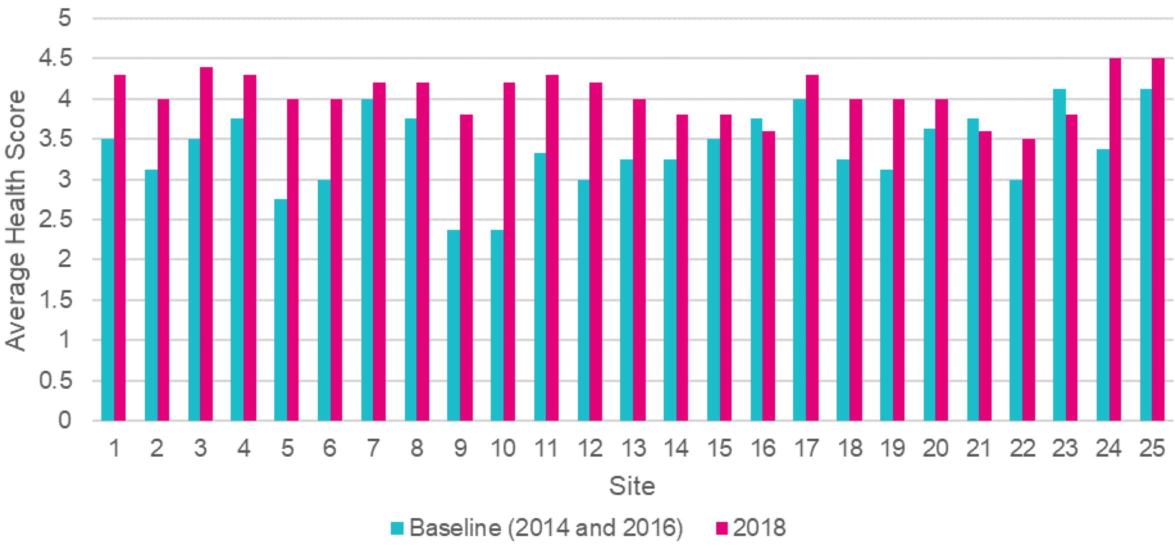
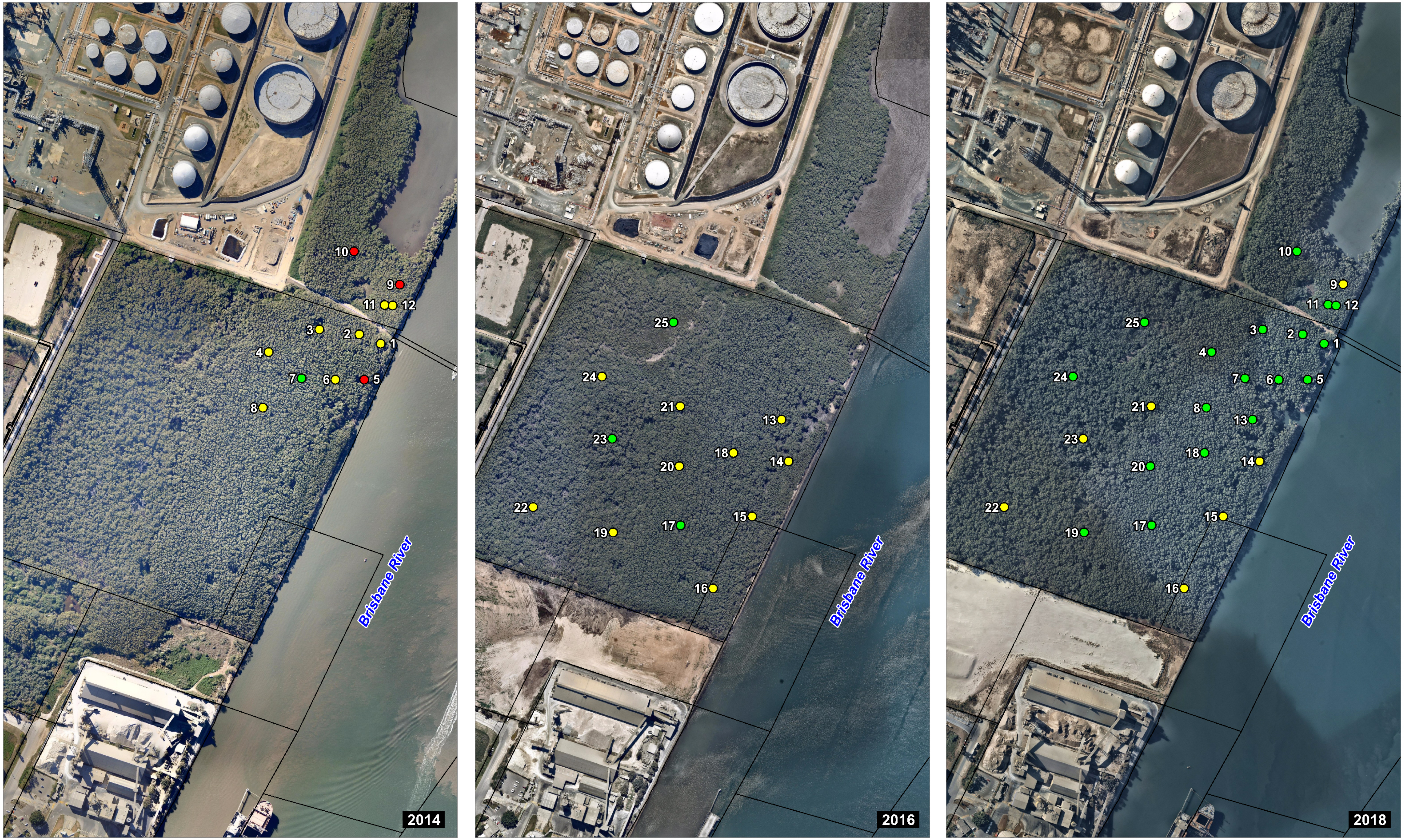


Figure 3-30 Average health score based on DEEDI (2011) scoreable metrics

In addition to the quadrat monitoring performed at Bulwer Island, NDVI scores between July 2016 and July 2018 were compared to examine the change in canopy health occurring between the two time periods (before and after revetment wall works). This analysis shows that NDVI scores (canopy health) were generally higher in July 2018 than they were in 2016, with the exception of several pockets located around the central revetment wall opening. These small areas are coincident with large tree falls, creating holes in the canopy. The NDVI results between 2016 and 2018 are generally consistent with quadrat-based monitoring, which suggested that health scores had mostly improved, but that there was evidence of major tree falls near the central opening of the revetment wall.



Average Mangrove Health Rating Index (DEEDI 2011)

- 2.0 to 2.9
- 3.0 to 3.9
- 4.0 to 4.9

Aerial Photography by nearmap

Title:

Mangrove Health Score in 2014, 2016 and 2018

Figure: 3-31

Rev: A

N

0 100 200m
Approx Scale

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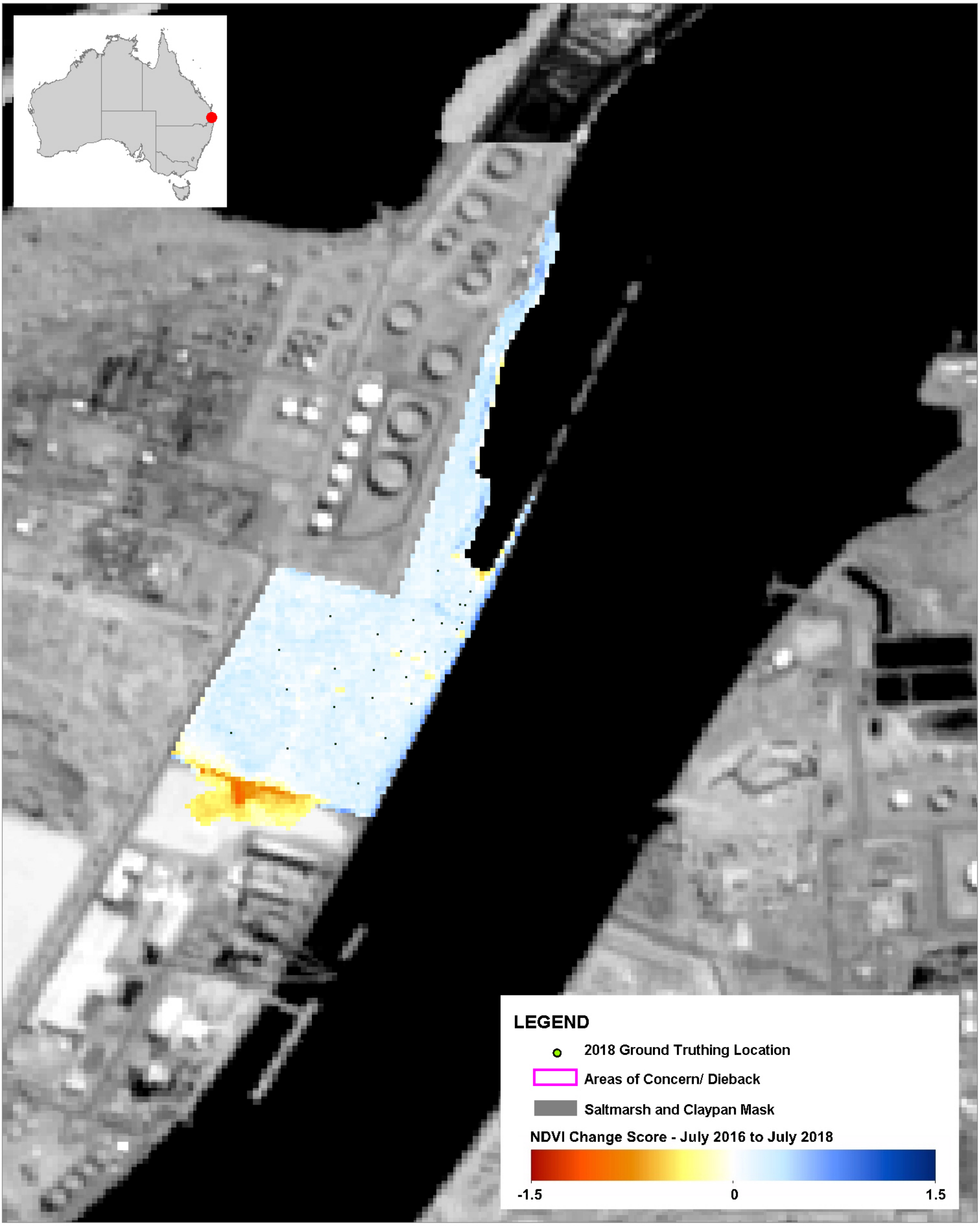

Title:

Changes in NDVI, from July 2016 to July 2018 at Bulwer Island

Figure: 3-32

Rev: A

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Approx.Scale

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4 Discussion

4.1 Estuarine Vegetation Changes 1955 - 2018

Figure 4-1 is a timeline of changes in estuarine vegetation communities and drivers based on analysis of aerial photograph described in Section 3.1.

There has been a net loss of approximately 207 ha of mangrove forest at Fisherman Islands, Whyte Island and Bulwer Island since 1955. Most losses were associated with reclamation and clearing works prior to the 2000's (see also BMT WBM 2016). As discussed in more detail below, since the 2000s there has a trend of mangrove expansion, both landward (typically 1-2 ha/year at Fisherman and Whyte Islands, but stable at Bulwer) and to a far lesser extent seaward (~0.2 ha/year at Fisherman and Whyte Islands, but stable at Bulwer). The 2018 mangrove forest extent at the three locations was approximately 274 ha.

Historical patterns in saltmarsh/saltpan habitat are more complex. The 2018 extent of saltmarsh/saltpan habitat is 55.7 ha compared to 37.5 ha in 1955, representing a net increase of 18.2 ha. The expansion in saltmarsh/saltpan habitat was mostly a result of reclamation works (i.e. placement of dredged material on mangrove and terrestrial areas) and mangrove die-back. Since the 2000s, there has been a long-term reduction in this habitat type, mostly due to mangrove re-colonisation.

4.1.1 Landward Expansion of Mangroves

There are several interacting processes that are likely to be driving the contemporary trend of mangrove encroachment into saltmarsh/saltpan areas. Most areas of mangrove encroachment into saltmarsh/saltpan occurred in areas previously occupied by mangrove forest. At all three locations, small-scale, localised shifts in mangrove and saltmarsh boundaries were observed in the years following major reclamation/clearing works (between 1978-1983, and 2000s), with a trend of mangrove and to a lesser extent saltmarsh/saltpan community recovery. These small-scale patterns most likely reflect adaptation to the modified hydrological and coastal processes.

Reclamation works at Fisherman Islands and Whyte Island involved the placement of dredged material on mangroves and saltmarsh/saltpan habitat, thereby increasing bed levels. It is known that mangroves can rapidly (measured in months to 10s of months) recruit and recolonise areas with suitable tidal hydrology (inundation levels). However, the rate of mangrove recolonisation in saltmarsh/saltpan areas has been a relatively slow process (measured in years). This suggests that there was an incremental, slow improvement to habitat conditions for mangroves in the saltmarsh/saltpan. This could be a result of:

- Progressive reductions in bed levels due to substrate settlement/compaction;
- Long-term changes to local hydrology; or
- Sea level rise, which has increased at an average rate of approximately 3mm/year at the Brisbane Bar since 1980 (Figure 4-2).

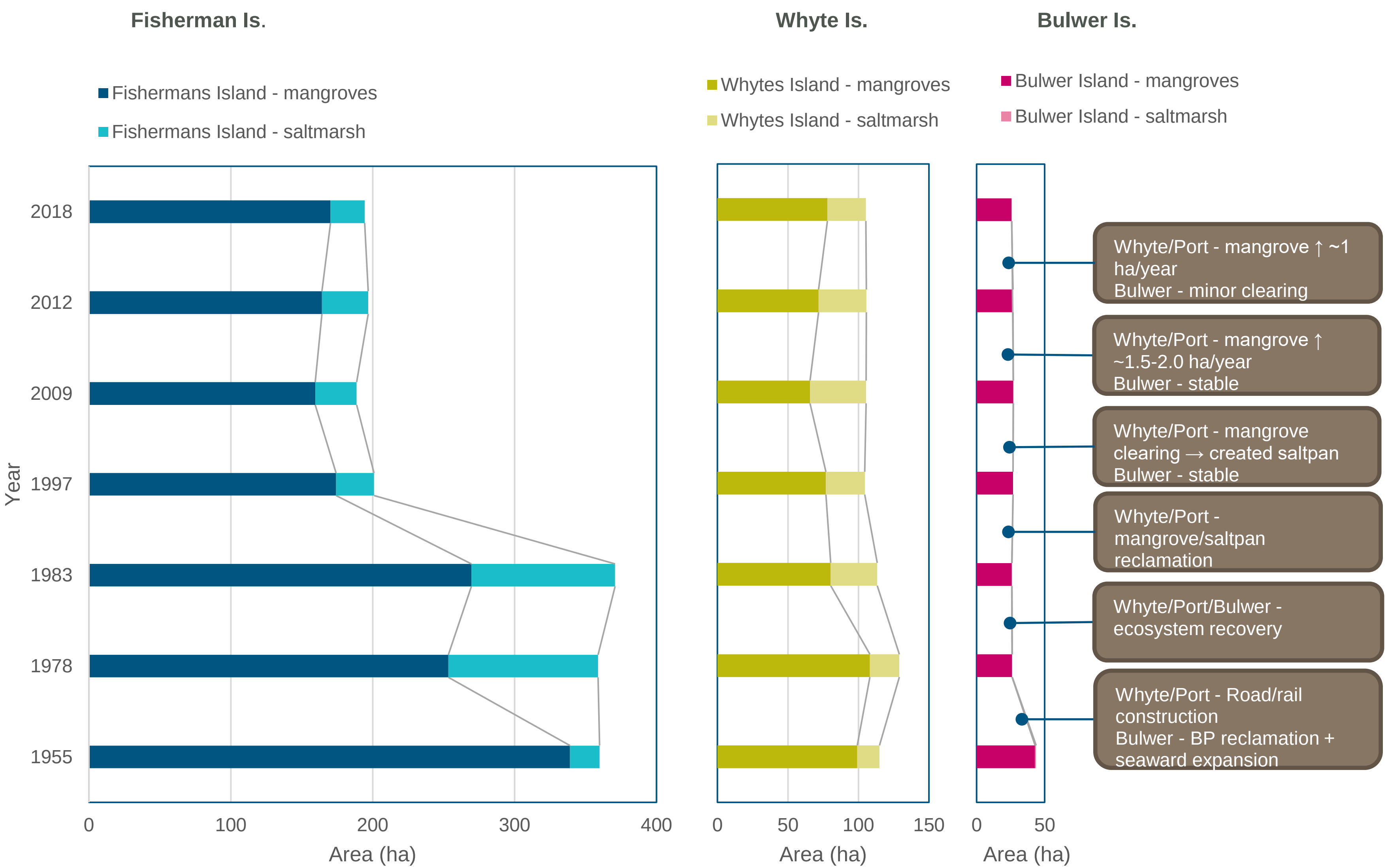

Figure 4-1 Timeline of changes in mangrove and saltmarsh communities at Fisherman and Whyte and Bulwer Islands

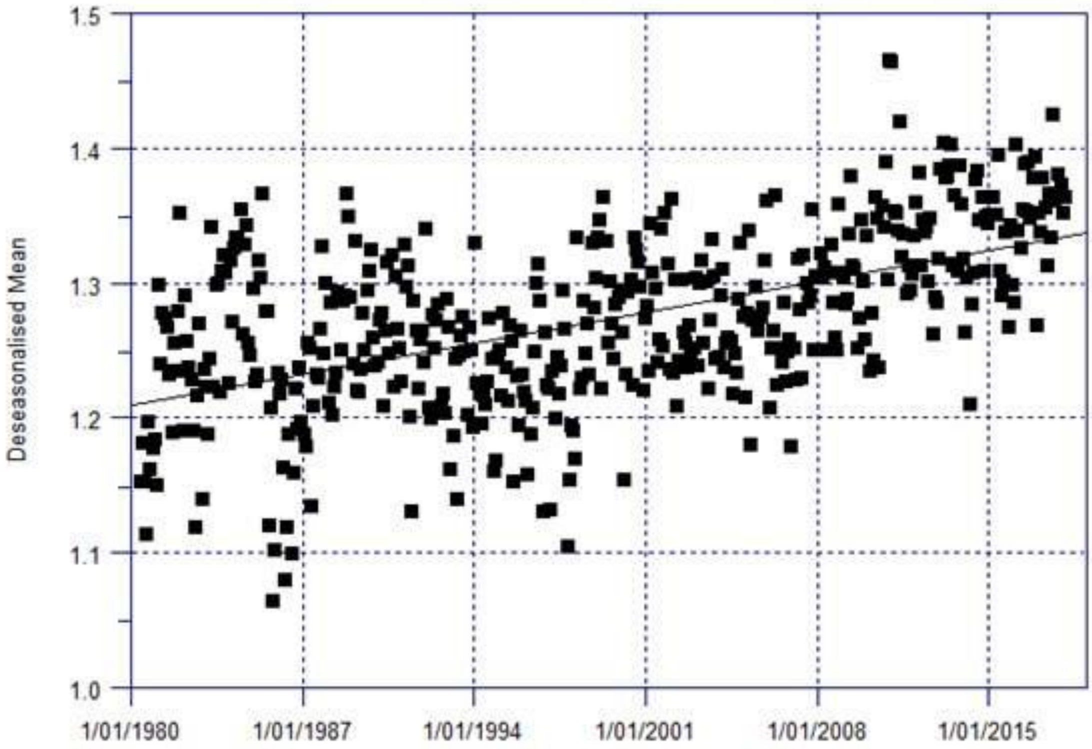

Figure 4-2 De-seasonalised mean monthly sea level at Brisbane Bar – 1980-2018 (DTMR unpublished data)

Mangrove expansion also occurred at the seaward fringe at several places:

- Whyte Island - A delta formed at the mouth of a small creek on the southern seaward fringe of Whyte Island between 1955 and 1978. It is likely that deltaic sediments were derived from road construction runoff. Mangroves colonisation on the delta created approximately 6 ha of mangrove forest.
- Bulwer Island – between 1955 and 1978, reclamation works for the BP terminal resulted major losses in mangrove forest on the western and northern sectors of the island, but also broad-scale mangrove forest expansion on the eastern fringe behind the rock wall. This newly created mangrove forest comprises a large proportion of the present-day mangrove forest at Bulwer Island. Possible drivers for this seaward expansion include sediment deposition associated with runoff from the reclamation works area and/or localised changes in hydrology.
- Fisherman Islands – between 1983 and 1997 mangroves colonised the area between Fisherman Island and Bishop Island. Since this time there has been a gradual seaward expansion of this mangrove forest. It is likely that reclamation works in the 1980's created habitat conditions (changes to local hydrodynamics, sediment deposition) suitable for mangrove colonisation.

In all three cases it appears that the seaward expansion of mangroves was mainly a response to sediment deposition resulting from construction works and localised changes to hydrodynamics. This does not preclude sea level rise as a potential driver for mangrove expansion in the port area.

Whilst estuarine habitats have been impacted by construction works, overall these communities adapt to changes in environmental conditions and as a result have remained broadly stable since port construction works in the 1990s. Superimposed on these broad scale changes in spatial extents are changes in mangrove health due to regional climate conditions, particularly the effects of drought which has been associated with mangrove dieback (see BMT WBM 2016 and below).

4.1.2 Conservation Status of Saltmarsh/Saltpan

The port is not a significant stronghold for conservation significant saltmarsh which is listed as a Vulnerable community under the EPBC Act. The port typically supports 30-80 ha of saltmarsh under stable conditions. However, these communities are highly sensitive to hydrological changes and sea level rise and aerial photography indicates more than 2-4 ha of saltmarsh has been converted to mangroves each year since 2009.

Re-profiling highly disturbed landward habitats adjacent to tidal lands could assist saltmarsh migration due to sea level rise and may increase this community's resilience to climate change.

4.2 Contemporary Temporal Changes in Mangrove Health

NDVI is a spectral index that estimates the amount of green biomass, with high NDVI values indicating higher green biomass. The present study identified cyclic changes in NDVI over the 2017-18 monitoring period, as follows:

- July 2017 – January 2018. There was a reduction in NDVI values from July 2017, to August 17, to September 2017, to October 2017 and to January 2018. This was observed at all test and control sites.
- January 2018 represented a low point in NDVI at all sites. This coincided with the lowest period of 12-month cumulative rainfall.
- January 2018 – March 2018. NDVI increased at all sites coincident with a peak in 12-month cumulative rainfall and monthly recorded rainfall in 2018.
- March 2018 – July 2018. NDVI plateaued off at Bulwer Island, the Coal Loader, and Whyte Island, reached a peak in May for Fisherman Islands and Luggage point, and steadily rose to a peak in July at St Helena, Green Island and Nudgee.
- July 2018 – August 2018v. NDVI declined at all sites following a period of low long-term and monthly rainfall.

These results are consistent with the long-term analysis of Landsat imagery (BMT WBM 2016), which identified higher NDVI during winter than summer periods, and that long-term NDVI patterns tracked rainfall. BMT WBM (2016) found that correlations between NDVI were highest when a lag of six to 12 months was applied, and only weak correlations with shorter lag periods. In the present study, NDVI tightly followed 12-month cumulative rainfall.

As discussed by BMT WBM (2016), ground water recharge and possibly nutrient delivery by surface water runoff are expected to drive these temporal patterns in mangrove health. Water table recharge times in mangrove forest vary in space and time, but tend to occur at timescales measured in months, depending on soil type, vegetation community structure, rainfall and groundwater levels (Alongi

2009). Spatial differences in groundwater regimes are likely to explain different temporal patterns among sites.

BMT WBM (2016) found that inter-annual patterns in NDVI tracked El Niño–Southern Oscillation (ENSO) cycle. The period 2015-16 represented very strong El Niño conditions (Figure 4-3), and NDVI values in 2016 were low relative to La Niña periods (BMT WBM 2016). The high rainfall associated with ex-Cyclone Debbie provided drought breaking rainfall in February 2017, and NDVI in July 2017 was much higher than it had been in July 2016. From this high-point, NDVI scores have undergone the typical seasonal fluctuations previously observed, but returned to a lower peak in NDVI in July 2018, with scores falling away rapidly in August 2018. The August 2017 to August 2018 spatial comparison is particularly revealing of this down-trend occurring late in the 2018 winter.

4.3 Local Scale Spatial and Temporal Patterns in Mangrove Health

NDVI values provide a basis for discriminating areas where mangrove canopy chlorophyll levels were low. BMT WBM (2016) suggested that differences in NDVI reflected either poor mangrove health and/or changes in community composition. Ground-truthing undertaken in the present study indicated that low NDVI values were mostly a response to poor mangrove health rather than vegetation community changes. In all community types, low NDVI values corresponded to areas where trees had low canopy cover, and partial or complete tree-falls were evident. The July 2017-July 2018 period was characterised by a general reduction in NDVI, resulting from a thinning canopy, and partial and complete tree falls, particularly in along some areas of mangrove fringe. The following describes patterns in mangrove health at the three investigation areas of interest to Port management: Fisherman Islands, Whyte Island and Bulwer Islands.

4.3.1 Fisherman Islands

Consistent with 2016 and 2017 survey results, the highest NDVI values at Fisherman Islands were recorded along the northern seaward fringe, far western section near the bridge over Boat Passage, and drainages within the well flushed tall *Avicennia* dominated closed and partially-closed forest. Areas where NDVI values declined between 2016 and 2018 at Fisherman Islands mangroves were as follows (see Figure 3-11):

- Area 1 – north-east Fisherman Islands fringing open *Avicennia*. General canopy thinning throughout the forest and large tree-falls along the seaward fringe.
- Area 2 - south-eastern fringe of Fisherman Islands east of Lucinda Drain. This area contained general canopy thinning throughout the forest and large tree-falls along the seaward fringe.
- Area 3 – *Avicennia* forest south-west section of Fisherman Islands, south-west of the Lucinda Drain entrance. Fringing mangrove dieback and evidence of erosion and sediment remobilisation.
- Area 4 – western fringe of the coal loader area. There is significant sand accretion along the shoreline of this area, resulting in mangrove burial and most likely alterations to tidal flushing processes. Consequently, mangroves here were in poor health, as evidenced by areas of fallen trees and canopy thinning. Mangrove burial (direct effects) and changes to hydrology (indirect effects) also lead to water/salinity stress. Continued dieback eastwards of the seaward fringe.

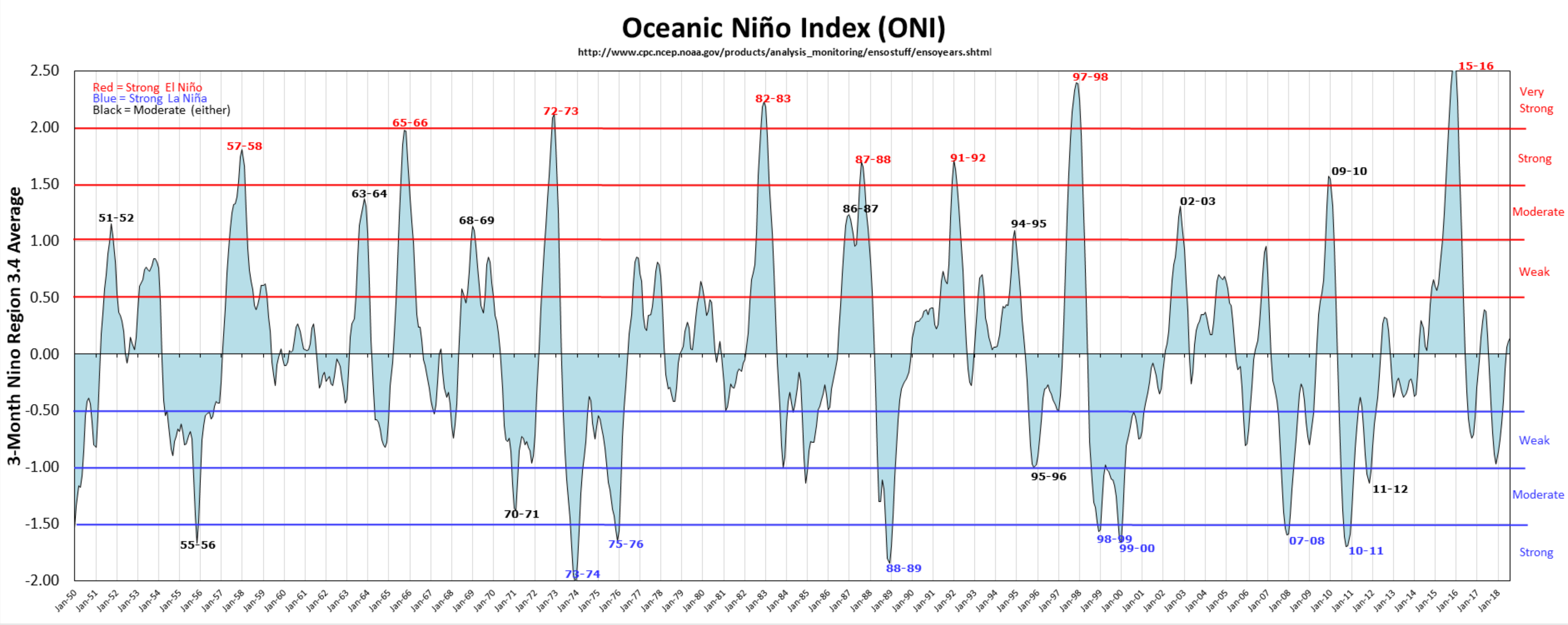

Figure 4-3 Oceanic Nino Index 1955-2017 (NOAA)

In addition to the above areas where declines in mangrove condition were observed between 2016 and 2017, there were additional areas where mangroves remained in a stable poor condition or improved during the 2017-18 period:

- Low closed *Ceriops* mangroves south-west of the western claypan area. The *Ceriops* forest remained in fair condition with relatively low canopy cover, with prominent leaf yellowing and some recent loss of foliage.
- The western claypan area at Fisherman Islands appeared to remain steady or show slight improvement. This area contains low closed *Avicennia* forest and open *Avicennia* forest, and represents an ecotone between mangroves and saltmarsh. Davie (1984) suggested that while the boundary between closed and open forest would vary over time in response to rainfall patterns, the position appears to coincide with a tidal level of >2.4 m LAT (Davie 1983). Such areas represent a marginal environment for mangroves due to high water/salinity stress, and therefore prone to cyclic changes in response to rainfall-drought conditions (Davie 1984).
- Southern tip of Fisherman Islands. The seaward fringe along south-eastern margin of Fisherman Island had lower NDVI values than the northern margin. BMT WBM (2016) suggested that this could in part be a result of differences in vegetation structure, however ground-truthing in 2017 indicated that both the northern and south-eastern margins of Fisherman Islands were dominated by *Avicennia* and differences in NDVI reflected differences in mangrove health. Mangroves here are presently in fair condition and there is no evidence of complete mangrove die-back, but numerous recently dropped branches were observed. The drivers for mangrove degradation in this area are unresolved.
- The central mangroves surrounding the mangrove die-back area on the eastern tip of Fisherman Islands (low-closed *Avicennia*) appeared to remain steady or show slight improvement. The drivers for past mangrove degradation in this area are unresolved, but likely linked to inadequate flushing resulting in ponding.

4.3.2 Whyte Island

Similar to Fisherman Islands, the tall mangrove forest on the seaward fringe of Whyte Island had high NDVI values. However highest NDVI values were recorded directly adjacent to freshwater inputs: the mouth of a small unnamed creek and a point directly adjacent to the Wynnum Wastewater Treatment Plant discharge point on Crab Creek. It is likely that the freshwater, nutrient enriched wastewater discharges enhanced chlorophyll and mangrove vegetation in this area.

The lowest NDVI values at Whyte Island typically occurred in landward areas on and adjacent to claypan and saltmarsh, and along the northern outer fringe of mangroves. NDVI change mapping between July 2017 and July 2018 showed that the southern part of Whyte Island experienced a greater reduction in NDVI scores than the northern section, which remained relatively neutral or slightly increased in NDVI score. While these environments are prone to natural fluctuations in groundwater levels, the southern section experiences more surface water input. Under reduced rainfall conditions, the southern area may have experienced greater reductions in NDVI score than the northern area, if it is more reliant on surface water.

Mangroves adjacent to the mangrove boardwalk and viewing platform were also in poorer condition along the fringe (near Area 6), while low-set communities next to the gravel walkway had improved in condition since 2017. No changes to flow across the gravel walkway had been made since last surveyed.

4.3.3 Bulwer Island

Mangroves set back at least 30 m from the seaward fringe had the highest NDVI values, lowest values were recorded 200 m back from the sea on the landward fringe. This spatial pattern likely reflects differences in groundwater-surface water regimes at different elevations, as described in BMT WBM (2016).

Mangrove clearing occurred in the southern portion of the mangrove forest in 2016 (shown as a red area in Figure 3-32. Analysis of NDVI suggested that there were patchy reductions in the central area between July 2017 and July 2018, with improvements in NDVI along the landward fringe ("I:\B20259_I_BRH Port of Brisbane DLR\JPG\Mangrove health 2018\181203\Figure 3-27.JPG"

Figure 3-27). Between 2016 and 2018, the canopy basically improved across the site with the exception of five clear pockets representing tree-falls near the central bund-wall opening (Figure 3-32). During ground-truthing, these appeared to be related to bed-level changes, where cable roots were exposed.

As discussed in Section 1.1, habitat enhancement works involving the partial removal of the seawall were undertaken to enhance aquatic fauna connectivity between the Brisbane River and Bulwer Island mangroves. The changes resulting from the works appear to be an overall improvement in NDVI scores across the site, with smaller isolated areas of impact where mangroves have been lost, possibly due to scour associated with altered hydrology. Ongoing monitoring is required to assess effects (either positive or negative) to mangrove forests resulting from further changes to hydrology.

While the DEEDI health scoring methodology showed an increase in average health between baseline surveys and 2018, the ability to detect changes depended on the placement of sites overlapping with small patches of impact. While photo-monitoring and ground-truthing are essential to understand processes occurring beneath the canopy, we would suggest that remote sensing is more advantageous than quadrat-based methods in terms of value for money, completeness of cover, the ability to assess multiple time periods, and explore recent historical changes.

4.4 Recommendations

BMT WBM (2016) provided generic recommendations regarding further work required to inform any future management actions, such as re-instatement of tidal hydrology to rehabilitate degraded areas. Surface-groundwater hydrology patterns and processes in mangrove die-back areas remains a knowledge gap.

In addition to targeted assessments of mangrove hydrology, annual reconnaissance monitoring using the methods outlined in the present study is recommended. Ground-truthing should focus on areas of die-back/poor health identified by remote sensing, and provide a preliminary assessment of likely drivers of change.

Table 4-1 Recommendations for ongoing work

Recommendation	Location	Approach
Pilot level assessment of tidal and groundwater hydrology	Transect extending through the eastern tip of Fisherman Islands Transect extending through the Coal Loader site (Area 5) Transect extending from Brisbane River through die-back areas at Bulwer Island (Area 8)	Conductivity-Temperature-Depth (CTD) loggers installed over tidal cycle Time lapse photography
Ongoing annual monitoring	All	As per present study Ground-truthing focussed on areas identified in Section 4.3 and any other additional die-back areas

5 Conclusions

The present study found that:

- There has been a net loss of approximately 207 ha of mangrove forest at Fisherman Islands, Whyte Island and Bulwer Island since 1955. Most losses were associated with reclamation and clearing works prior to the 2000's.
- Since the 2000s there has a trend of mangrove expansion, both landward (typically 1-2 ha/year at Fisherman and Whyte Islands, but stable at Bulwer) and to a far lesser extent seaward (~0.2 ha/year at Fisherman and Whyte Islands, but stable at Bulwer). The 2018 mangrove forest extent at the three locations was approximately 274 ha.
- Historical patterns in saltmarsh/saltpan habitat are more complex. The 2018 extent of saltmarsh/saltpan habitat is 55.7 ha compared to 37.5 ha in 1955, representing a net increase of 18.2 ha. The expansion in saltmarsh/saltpan habitat was mostly a result of reclamation works and mangrove die-back. Since the 2000s, there has been a long-term reduction in this habitat type, mostly due to mangrove re-colonisation.
- The historical seaward expansion in mangrove forest appear to be driven by sedimentation associated with construction works.
- Encroachment of mangroves into saltmarsh/saltpan has been a long-term process, possibly associated with changes to bed levels associated with sediment compaction, and/or sea level rise.
- NDVI values derived from satellite imagery identified areas where mangrove canopy chlorophyll levels were low due to poor mangrove health.
- The highest NDVI values were recorded along the seaward fringe within the well flushed tall *Avicennia* dominated closed and partially open forest.
- Key locations of mangrove die-back or poor health were identified by remote sensing, which were validated by aerial photograph and field observations.

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Appendix A Photographic Monitoring at Bulwer Island


Site 1
Site 2
Site 3


Site 4

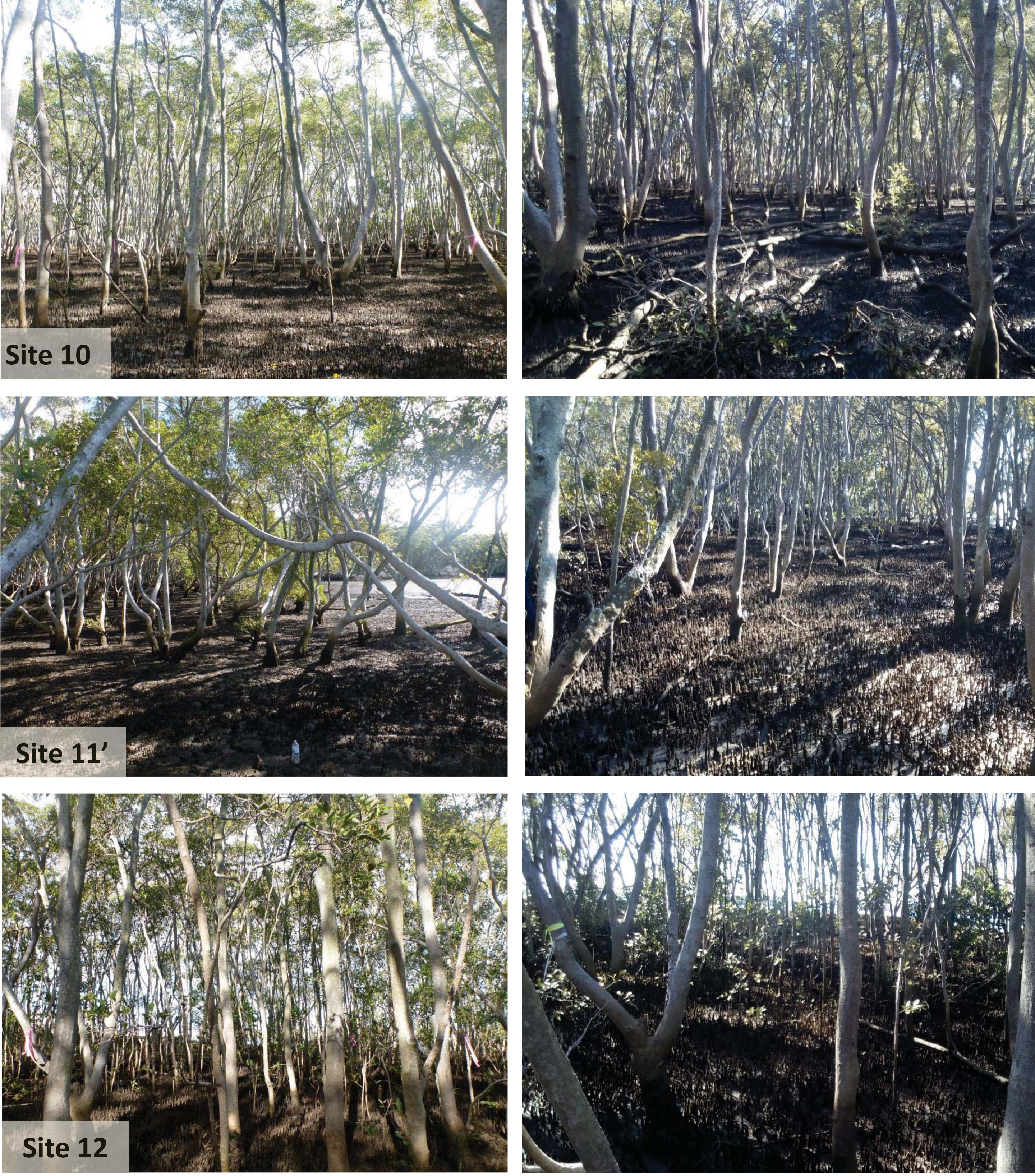

Site 5


Site 6


Site 7


Site 8


Site 9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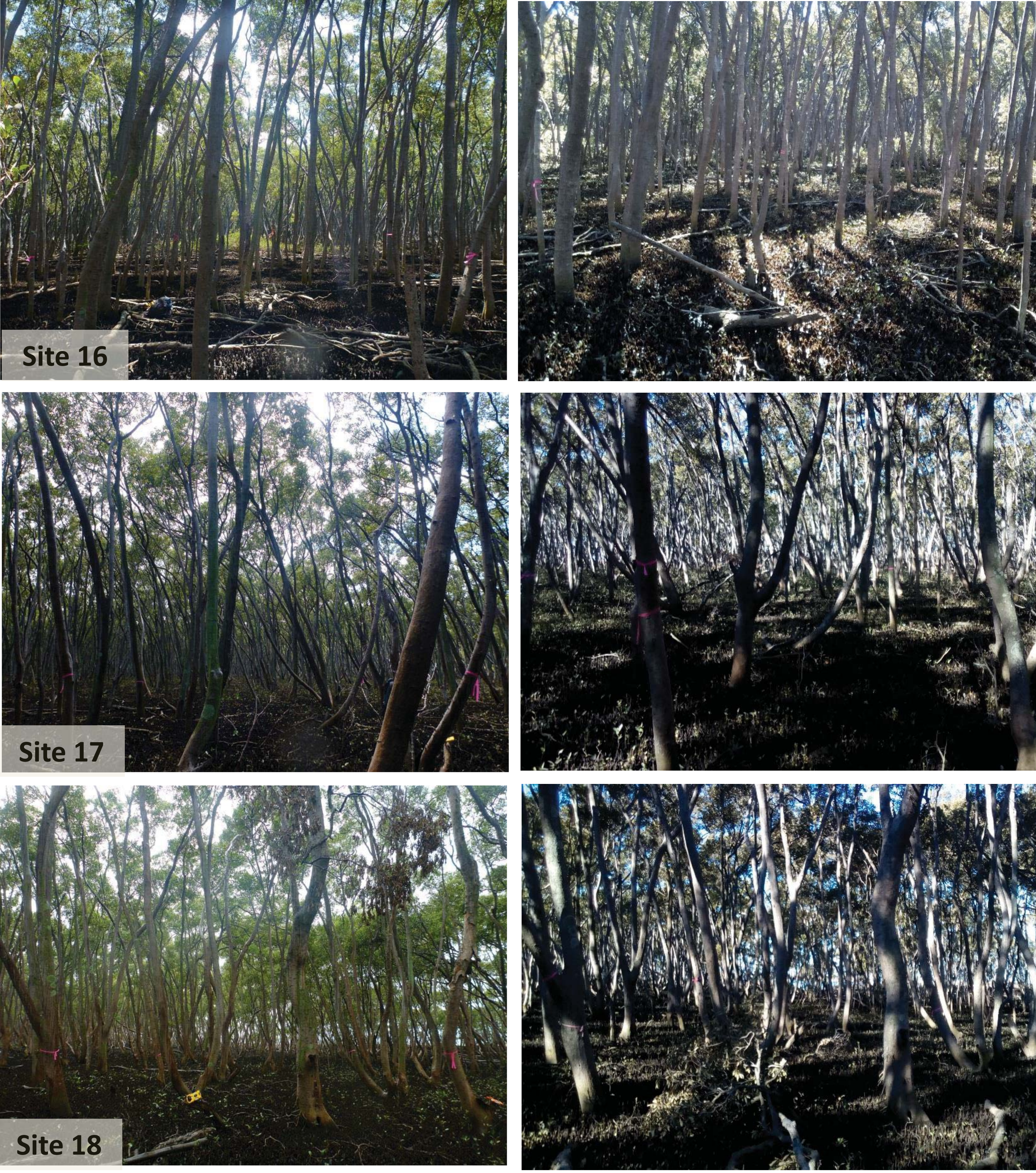
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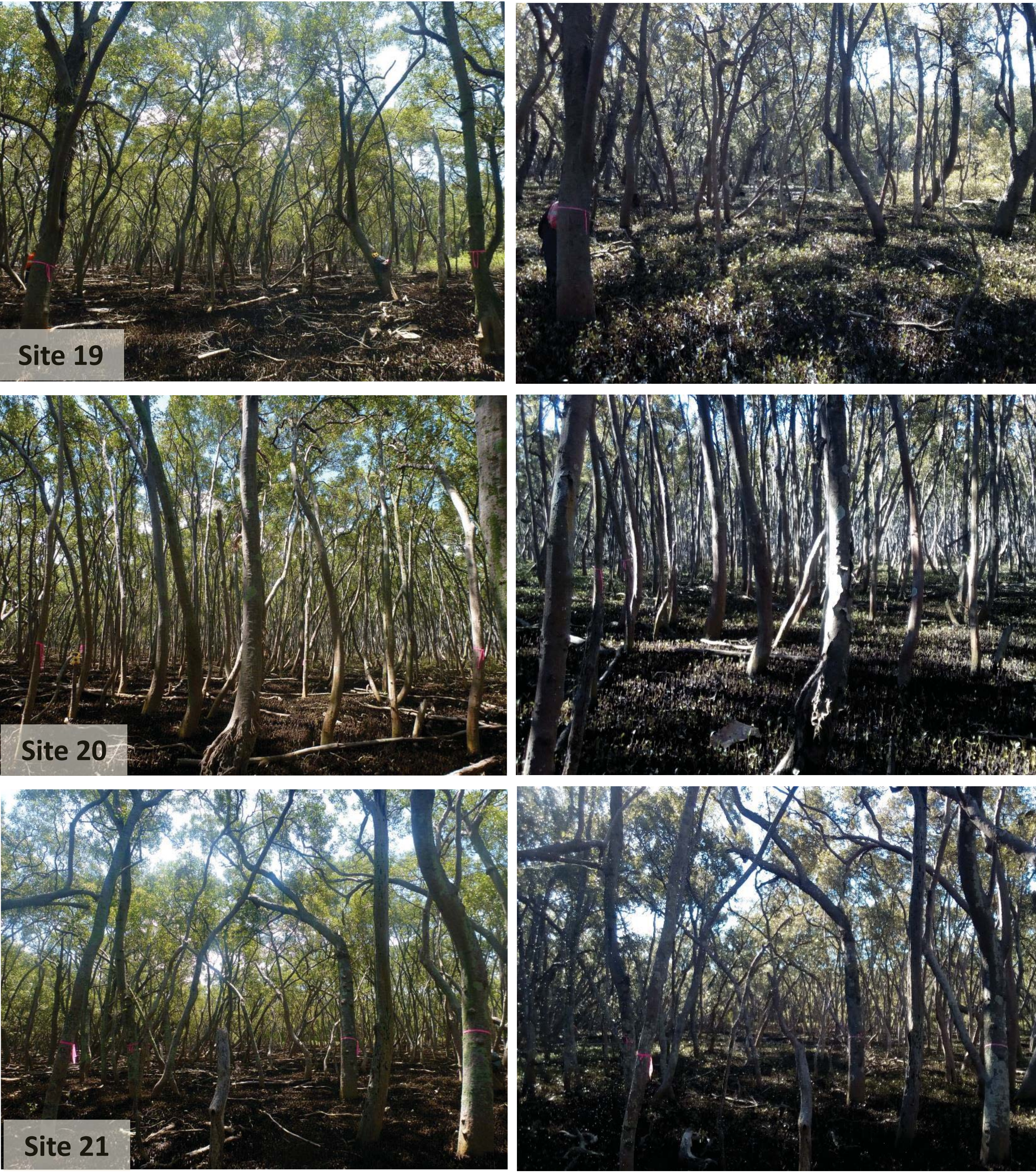
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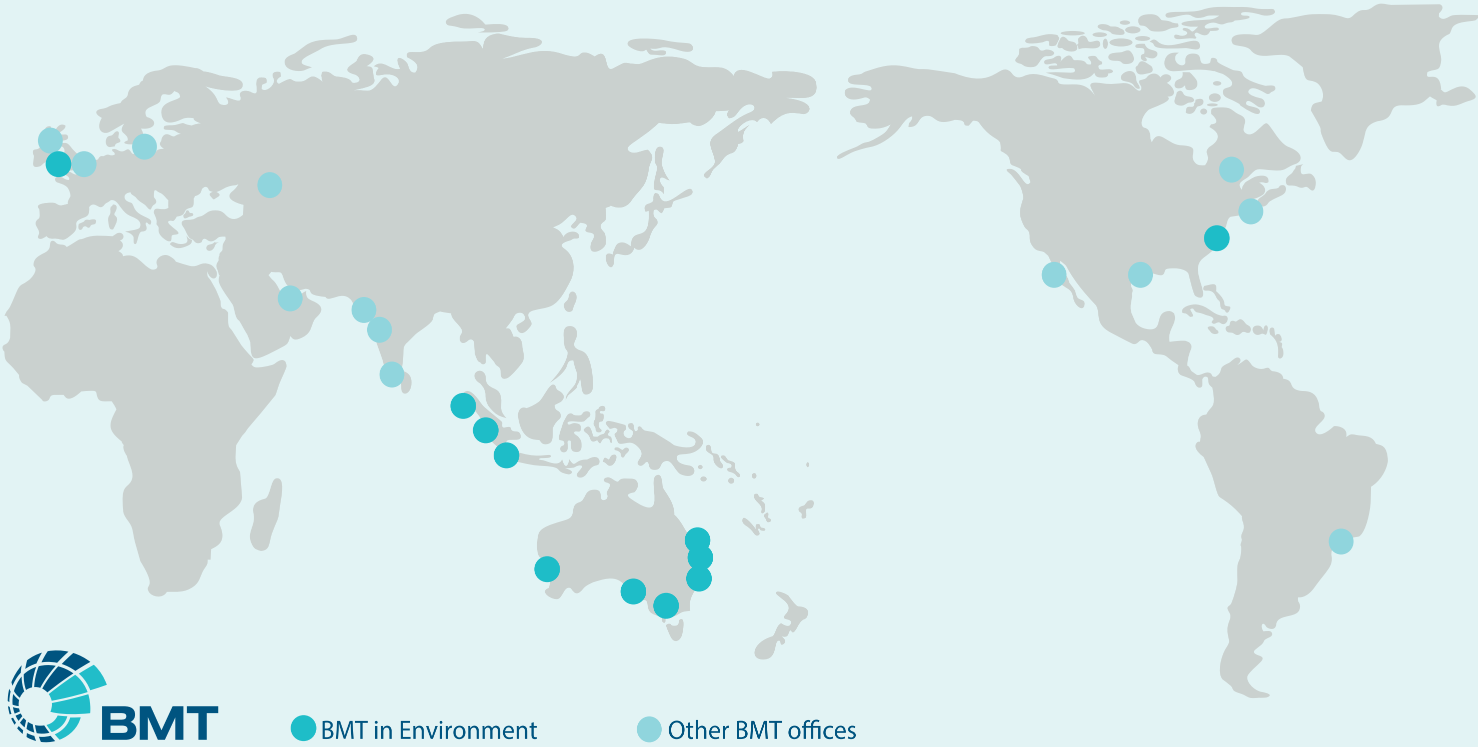

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