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Port of Brisbane Mangrove Health Monitoring Program - 2017 Survey

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Date: December 2017
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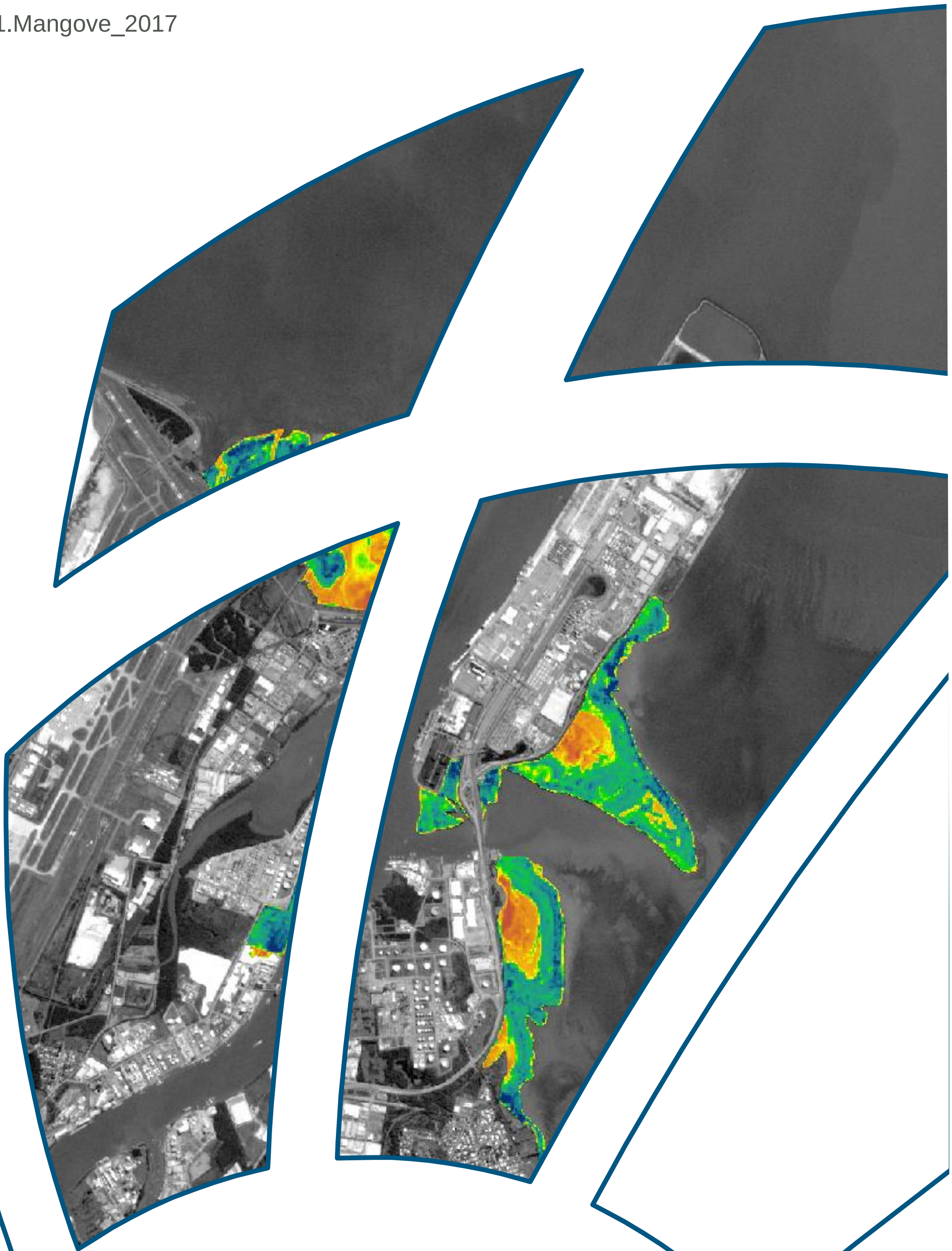

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Synopsis: **This report describes current trends in mangrove health based on remote sensing data and field surveys from July 2016 to August 2017.**

REVISION/CHECKING HISTORY

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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. The Port of Brisbane Mangrove Monitoring Program was revised in 2016 to provide a more robust objective means for characterising patterns in mangrove condition. This report outlines the methodology and findings of the 2017 survey.

The specific objectives of this study were to:

- Refine the preliminary (2016) vegetation community map.
- 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.

Refined Vegetation Community Map

Figure 1 shows that mangrove forests on the seaward fringe were generally comprised of a tall *Avicennia marina* (grey mangroves) dominated closed and open forest, whereas mangals further landward were comprised of low closed to open *Avicennia marina* forest, eventually grading to claypan with or without saltmarsh. *Ceriops australis* dominated or co-dominated in places. This spatial pattern in community structure is largely controlled by salinity stress, which is a function of decreasing water availability from either tidal inundation or fresh-water seepage with elevation.

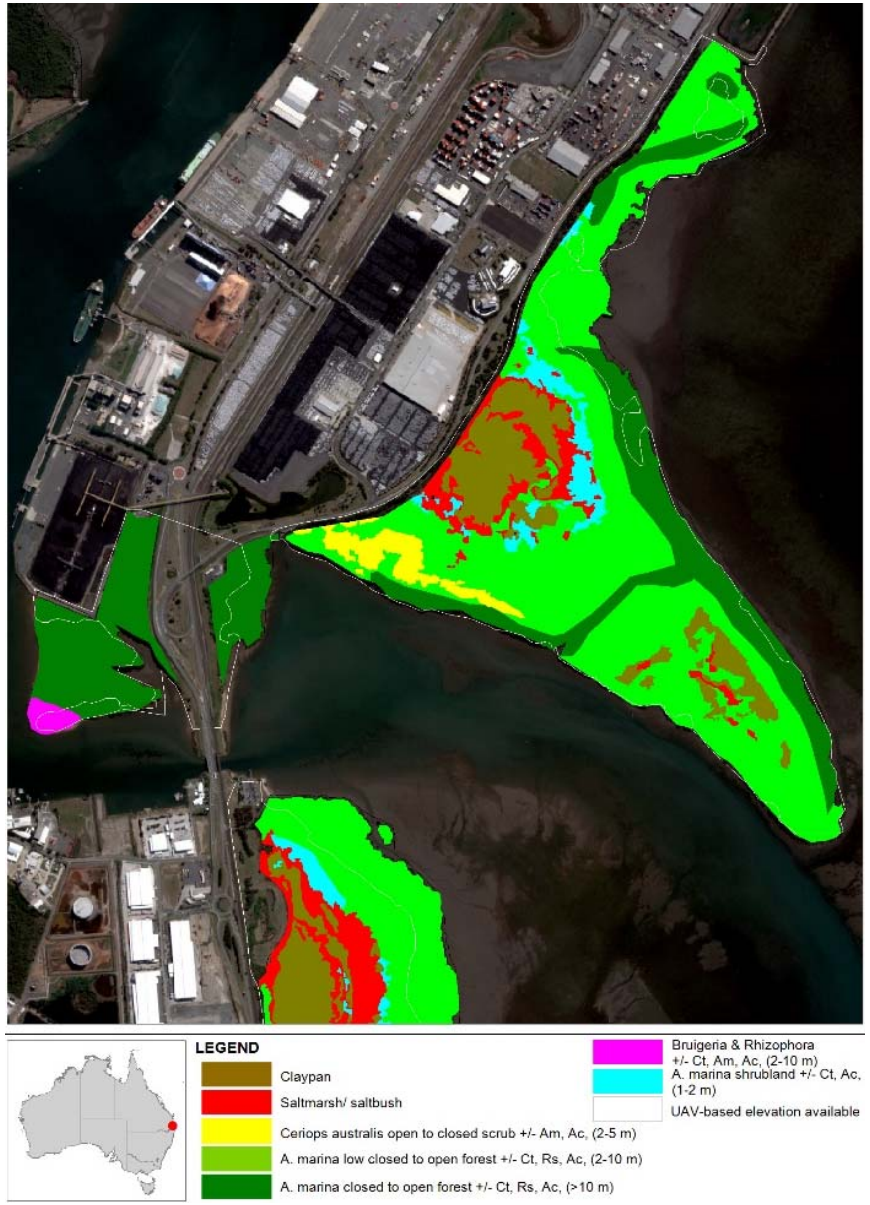

Figure 1 Mangrove Community Map – Fisherman Islands

Broad-scale Temporal Patterns

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 2016-17 monitoring period, varying in intensity and timing across sites. 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 (Figure 2).

Long-term NDVI patterns also tracked rainfall (with a lag of 2-3 months). NDVI in July 2017 was higher than the July 2016 period. 2015-16 was a drought period, whereas high rainfall associated with ex-Tropical Cyclone Debbie provided drought breaking rainfall in February 2017. Ground water recharge and possibly nutrient delivery by surface water runoff likely drive these temporal patterns in mangrove health.

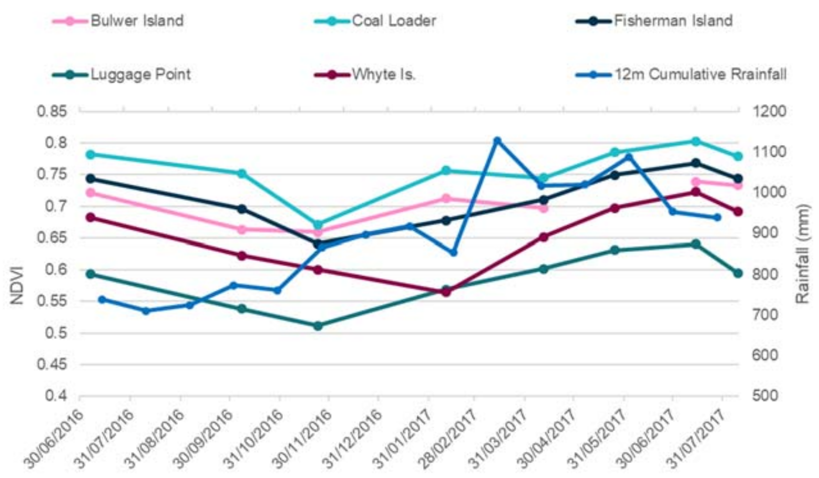

Figure 2 Temporal changes in NDVI with respect to 12-month cumulative rainfall at Test sites, from July 2016 to August 2017

Mangrove Condition

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:

- mangroves located adjacent to claypan areas where water/salinity stress would be greatest. Such areas are likely to experience water stress due to cyclic changers in groundwater levels.
- mangrove patches in the interior of mangrove forests on the eastern tip of Fisherman Islands and Bulwer Island.
- mangroves affected by sand burial at the coal loader site.
- mangroves affected by the board walk at Whyte Island.

While rainfall/drought cycles strongly influence long-term patterns in mangrove condition, local scale stressors (particularly hydrological barriers) reduce the resilience of assemblages, ultimately leading to mangrove stress and mortality.

Recommendations

It is recommended that a small field study be implemented to assess the roles of tidal amplitude, surface water, and ground water salinity in healthy and dieback areas at Fisherman Islands. It is also 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.

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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).

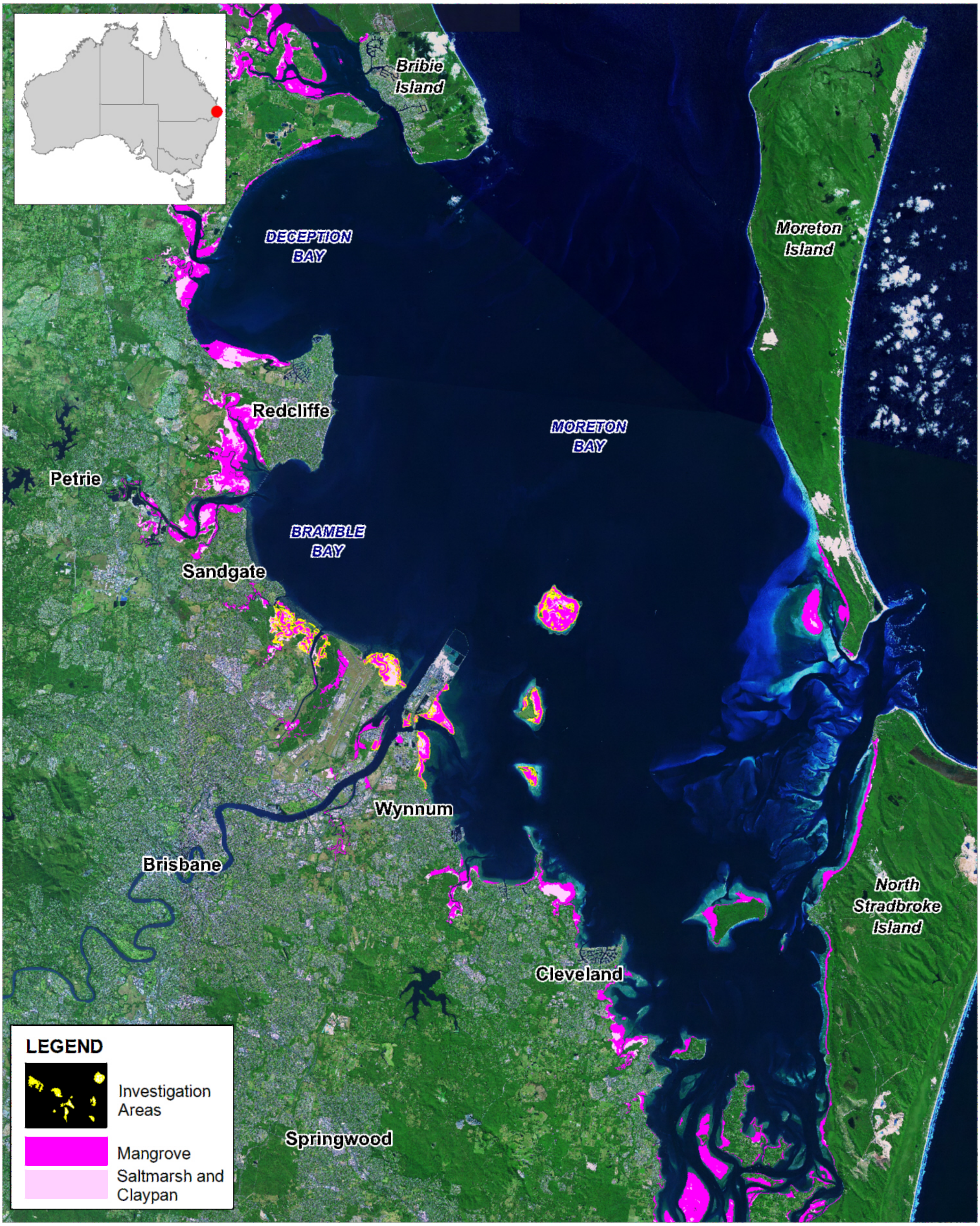
BMT WBM (2016) found a strong association between 12-month cumulative rainfall and normalized difference vegetation index (NDVI), producing quasi-cyclical patterns in health and rainfall. In the longer term, patterns in health were associated with SOI and the El Niño–Southern Oscillation (ENSO) cycle. 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 2017 assessment report was prepared to update the mangrove and saltmarsh/saltpan health assessment to cover the period between the winters of 2016 and 2017.

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:

- Refine and validate the marine vegetation community map prepared by BMT WBM (2016) for Fisherman Islands and Whyte Island, and develop a preliminary marine vegetation community map for Bulwer Island.
- 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.



Title:

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

Figure: **1-1**

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Approx. Scale

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2 Methodology

2.1 Approach

BMT WBM (2016) determined boundaries of marine vegetation communities based on the present-day representation of 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. Two different spatial scales of satellite imagery were used to monitor mangrove communities:

- 2 m, four-band imagery from Worldview 2 (August 2017) and Pleiades (August 2016) over Whyte Island and Fisherman Islands only.
- 10 m, 12-band Sentinel-2 imagery for the whole of study area over the following capture dates:
  - 6th of July 2016
  - 7th of October 2016
  - 23rd of November 2016
  - 10th February 2017
  - 4th of April 2017
  - 25th May 2017
  - 14th of July 2017
  - 9th of August 2017.

The high-resolution imagery was used to investigate small-scale changes in canopy health at Whyte and Fisherman Islands between August 2016 and August 2017, whereas the 10 m resolution Sentinel-2 imagery was used to examine changes in health over a greater range of dates throughout the investigation period.

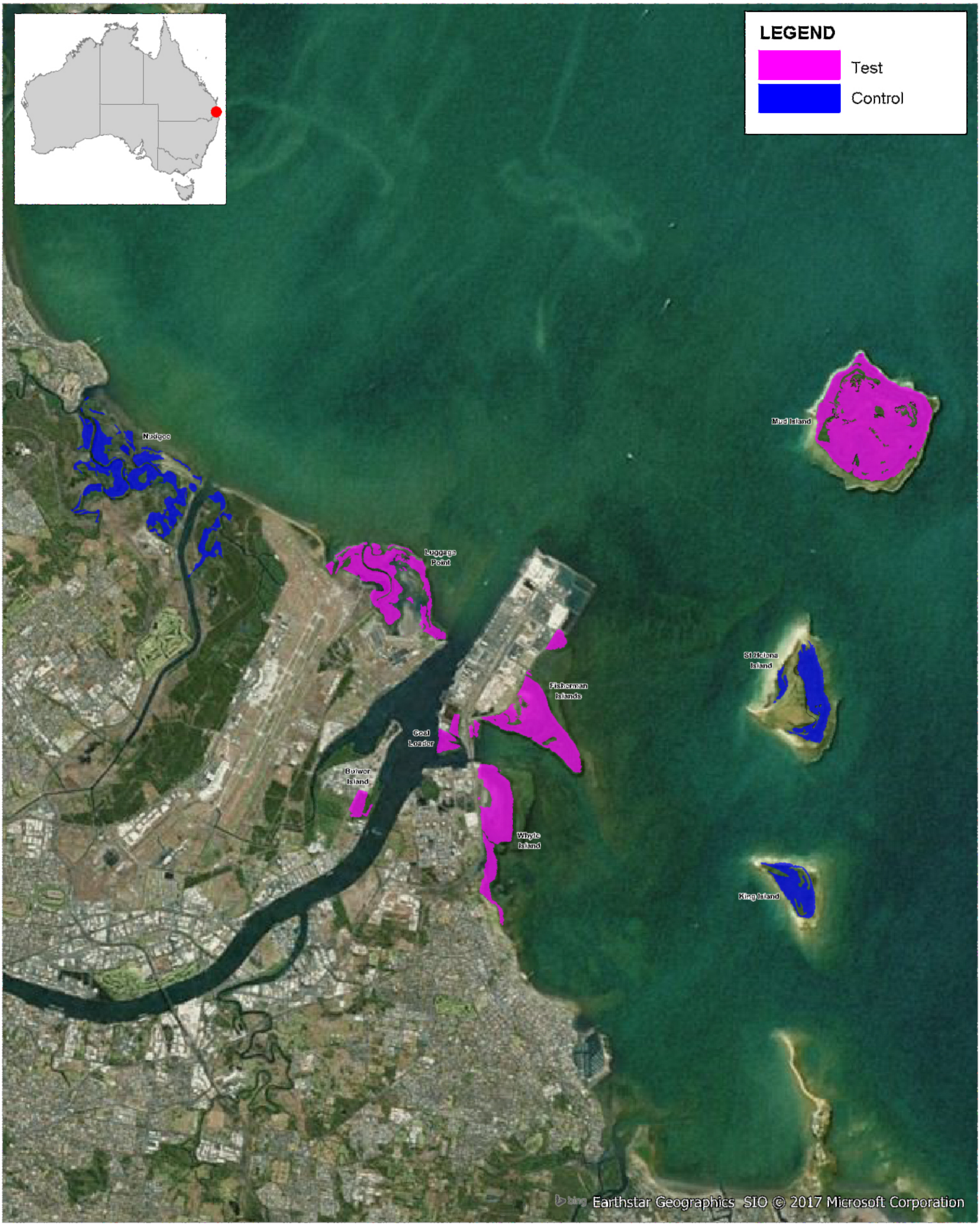
While BMT WBM (2016) used Landsat imagery to compile a long-term assessment of mangrove health, the objectives of the present study were to assess changes that had occurred in the past 12 months. Therefore, Sentinel-2 imagery was used in preference to Landsat due to its higher resolution. NDVI was calculated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

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 and LAI).

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**



Title:

Test and Control Investigation Areas

Figure: **2-1**

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Approx. Scale

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2.3 Remote Sensing Data Processing

2.3.1.1 Sentinel-2 Imagery

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.

2.3.1.2 WorldView2 and Pleiades Imagery

The Pleiades-1A satellite features four spectral bands (blue, green, red, and IR), as well as image location accuracy of 3 meters (CE90) without ground control points. These spectral bands allow high-resolution vegetation mapping and the calculation of NDVI.

A multispectral Pleiades satellite image bundle (2 m spatial resolution) was acquired for the study area (10 August 2016). The image was delivered geometrically corrected and ortho-rectified to UTM 56J WGS84. Radiometric calibration was also applied for the Pleiades 1A image using the ATCOR model, which implements the MODTRAN4+ radiative transfer code (Geosystems, 2013).

No Pleiades captures were available for the study area over the winter of 2017. Therefore, a WorldView2 image from August 2017 with 1.8m pixel resolution was used. High-resolution NDVI comparisons are shown in Appendix A.

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 2015 to August 2017, 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 appears in March 2017. Discussion on temporal trends in rainfall are discussed in Section 4.2.

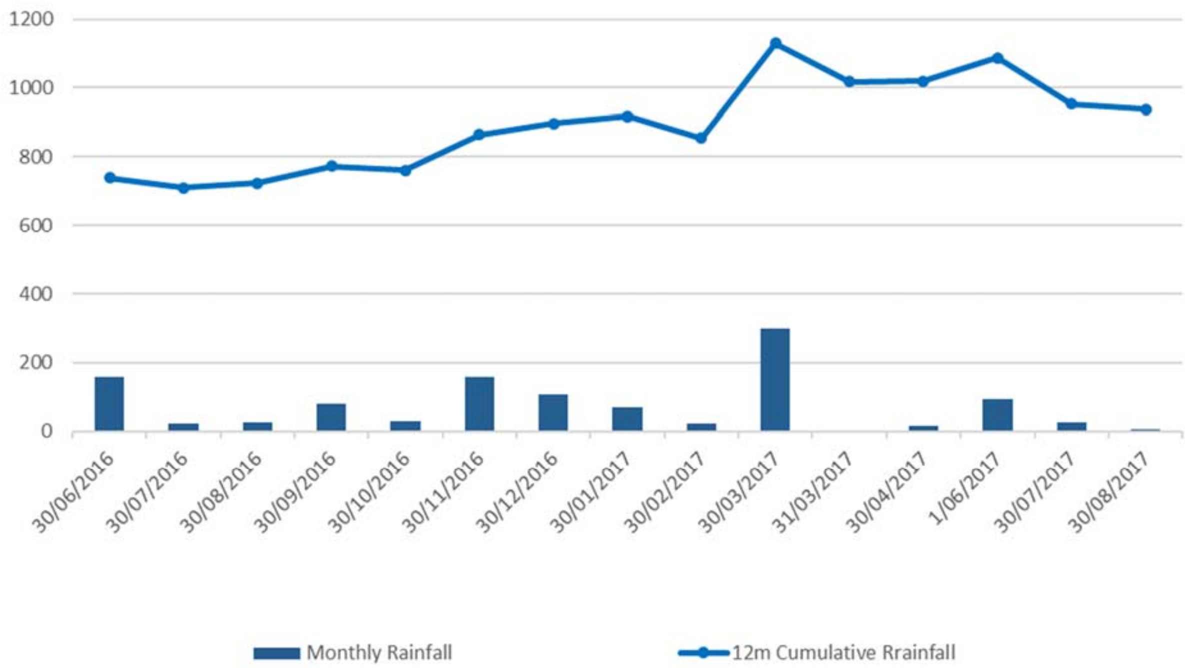

Figure 2-2 Monthly total rainfall and 12-monthly rainfall for the Brisbane Airport (station 040842 and 040320)

2.5 Contemporary Patterns in Wetland Communities

Community maps generated in 2016 (using a combination of unmanned aerial vehicle (UAV) derived canopy heights and high-resolution Pleiades 1A imagery) were updated with ground-truthing and interrogation of Nearmap imagery from November 2016. Nearmap imagery from this point in time allowed better investigation of sub-canopy constituents, given the very thin nature of canopy.

Vegetation communities were originally classified using pixel statistics from known community types based on past ground-truthing events. Classifications were made in the investigation areas using supervised classification and maximum likelihood methods. Maximum likelihood classification was used in ArcMap 10.3.1 under default parameters, based on training polygons of known vegetation classes (based on BMT WBM 2014). The vegetation community map was smoothed firstly using the boundary clean algorithm in ArcGIS, then using the nibble function to keep polygons with a minimum size of 100 pixels. Because areas of poor mangrove health could not be discerned from yellow mangrove (*C. australis*) using pixel-based classification, yellow mangrove polygons were accepted or rejected based on prior vegetation community mapping. Variations to these polygons were hand-digitised after specific ground-truthing conducted on the 31st of August 2017.

Ground- truthing, canopy heights, NDVI, and Nearmap imagery were used to derive a map of the following vegetation community classes:

- *Avicennia marina* closed to open forest, >10 m canopy height +/- *Aegiceras corniculatum, Ceriops australis*, and *Rhizophora stylosa.*
- *A. marina* low closed to low open forest, 2-10 m canopy height +/- *A. corniculatum, C. australis*, and *R. stylosa.*
- *Rhizophora stylosa* and *Bruguiera gymnorhiza* low closed to low open forest, 2-10 m canopy height +/- *A. marina, A. corniculatum,* and *C. australis.*
- *A. marina* shrubland, 1-2 m canopy height +/- *A. corniculatum* and *C. australis.*
- *C. australis* open to closed to open forest, 2-5 m canopy height +/- *A. corniculatum* and *A. marina.*
- Claypan (including ponded waters).
- Saltmarsh assemblage.

2.6 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 different sensors were used for the comparison between high-resolution satellite images (WorldView 2 vs Pleiades). Despite these differences, the overall pattern of change between 2016 and 2017 was similar between the high-resolution images and the Sentinel-2 images, which maintained the same sensor.

3 Results

3.1 Existing Community

3.1.1 Updated Vegetation Community Mapping

The following mangrove species have been recorded in the investigation areas during rapid site inspections in 2016 (coincident with UAV flights), during 2017 ground-truthing and in previous studies (WBM 2002; BMT WBM 2014):

- Grey mangroves *Avicennia marina* var *australasica.*
- Yellow mangroves *Ceriops australis.*
- Red mangroves *Rhizophora stylosa.*
- Orange mangrove *Bruguiera gymnorhiza.*
- River mangrove *Aegiceras corniculatum*.

Milky mangrove *Excoecaria agallocha* and black mangrove *Lumnitzera racemosa* are known to occur in Moreton Bay (Dowling 1979), and may occur in the investigation areas in small numbers.

Vegetation community data, past and present ground truthing, and canopy elevation data were used to interpret preliminary vegetation maps, and the resulting marine vegetation community map is shown in Figure 3-1 for Fisherman Islands, Whyte Island and Bulwer Island.

Avicennia marina (grey mangrove) dominated assemblages were the main vegetation class in all investigation areas. The *Ceriops*-dominated mixed assemblage was mapped directly south of the saltpan near the Port Office, at Fisherman Islands. *Ceripos australis* was recorded elsewhere throughout the study area as occasional canopy or sub-canopy components, but was not dominant in these areas. The only other region where *A. marina* was not a dominant part of the canopy was along the southern tip of the Coal Loader mangroves, where *Bruguiera gymnorhiza* and *Rhizophora stylosa* were co-dominant, with *Aegiceras corniculatum* in the understory and occasional *A. marina* trees.

The central interior portions of Fisherman Islands and Whyte Island contain a mosaic of saltmarsh and claypan vegetation classes. The claypan class also includes ponded waters containing benthic microalgae mats. Saltmarsh and claypan were not present at Bulwer Island.

LEGEND

- Claypan
- Saltmarsh/ saltbush
- Ceriops australis open to closed scrub +/- Am, Ac, (2-5 m)
- A. marina low closed to open forest +/- Ct, Rs, Ac, (2-10 m)
- A. marina closed to open forest +/- Ct, Rs, Ac, (>10 m)
- Bruigeria & Rhizophora +/- Ct, Am, Ac, (2-10 m)
- A. marina shrubland +/- Ct, Ac, (1-2 m)
- UAV-based elevation available

Title:

Updated habitat classes and adopted boundaries at Fisherman Islands, Coal Loader, Whyte and Bulwer Islands

Figure: 3-1

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Approx. Scale

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3.2 Temporal Changes in NDVI

NDVI time series are shown in Figure 3-2 and Figure 3-3, and as spatial representations in Figure 3-4. At inter-annual time scales, NDVI scores were higher in July 2017 than July 2016. 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 dip in NDVI through the summer months with the lowest values occurring in November. There were exceptions to this November minima; Whyte Island, St Helena Island and Nudgee had their lowest NDVI values in February 2017. The highest NDVI values were observed in July 2017 at all investigation sites. NDVI scores had declined at all investigation sites between July 2017 and August 2017.

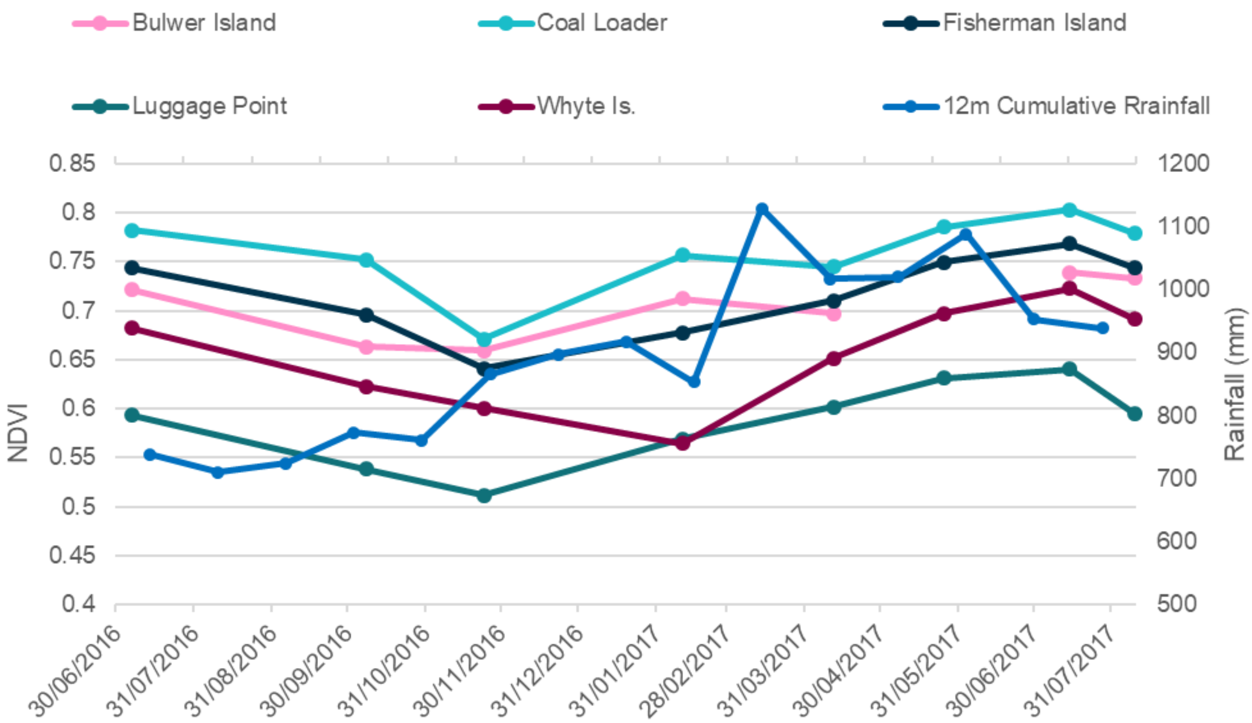


Figure 3-2 Temporal changes in NDVI with respect to 12-month cumulative rainfall at Test sites, from July 2016 to August 2017

Control and test sites exhibited a similar temporal pattern in NDVI. Temporal trajectories were not consistent among island or mainland sites, nor was it consistent between test and control sites. The highest NDVI values occurring in July 2017 was consistent across all sites. Data were missing (due to cloud shadowing) from Nudgee in November 2016 and from Bulwer Island in May 2017.

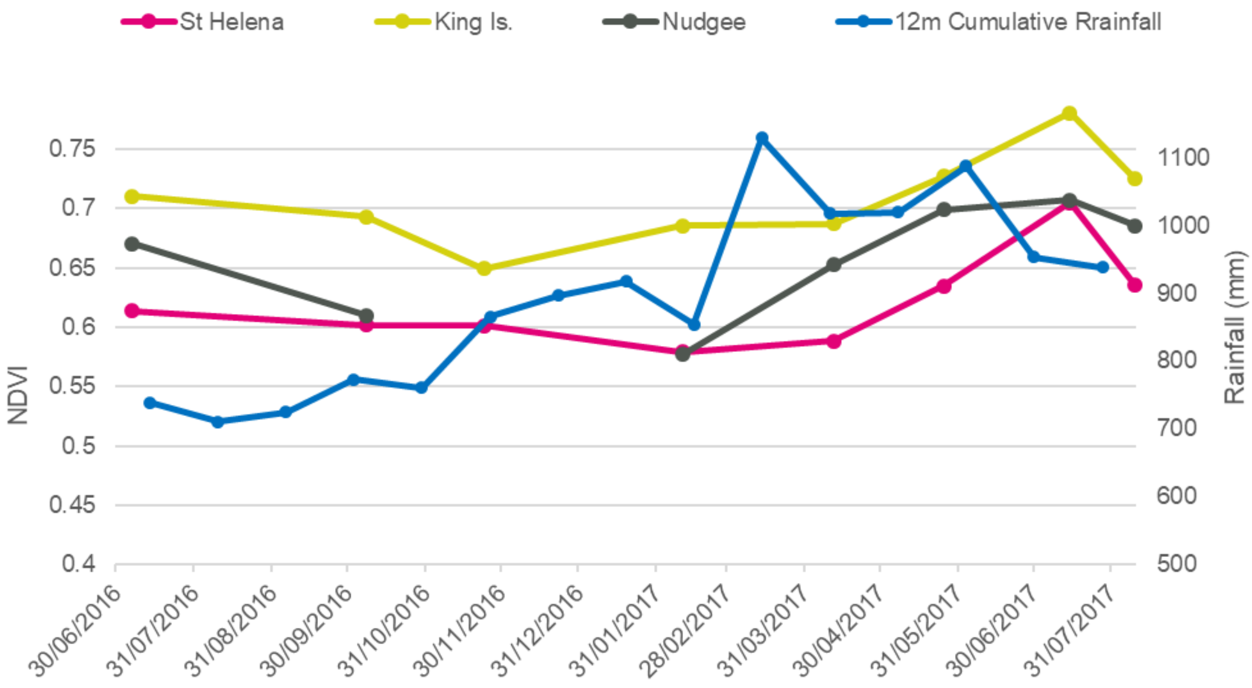
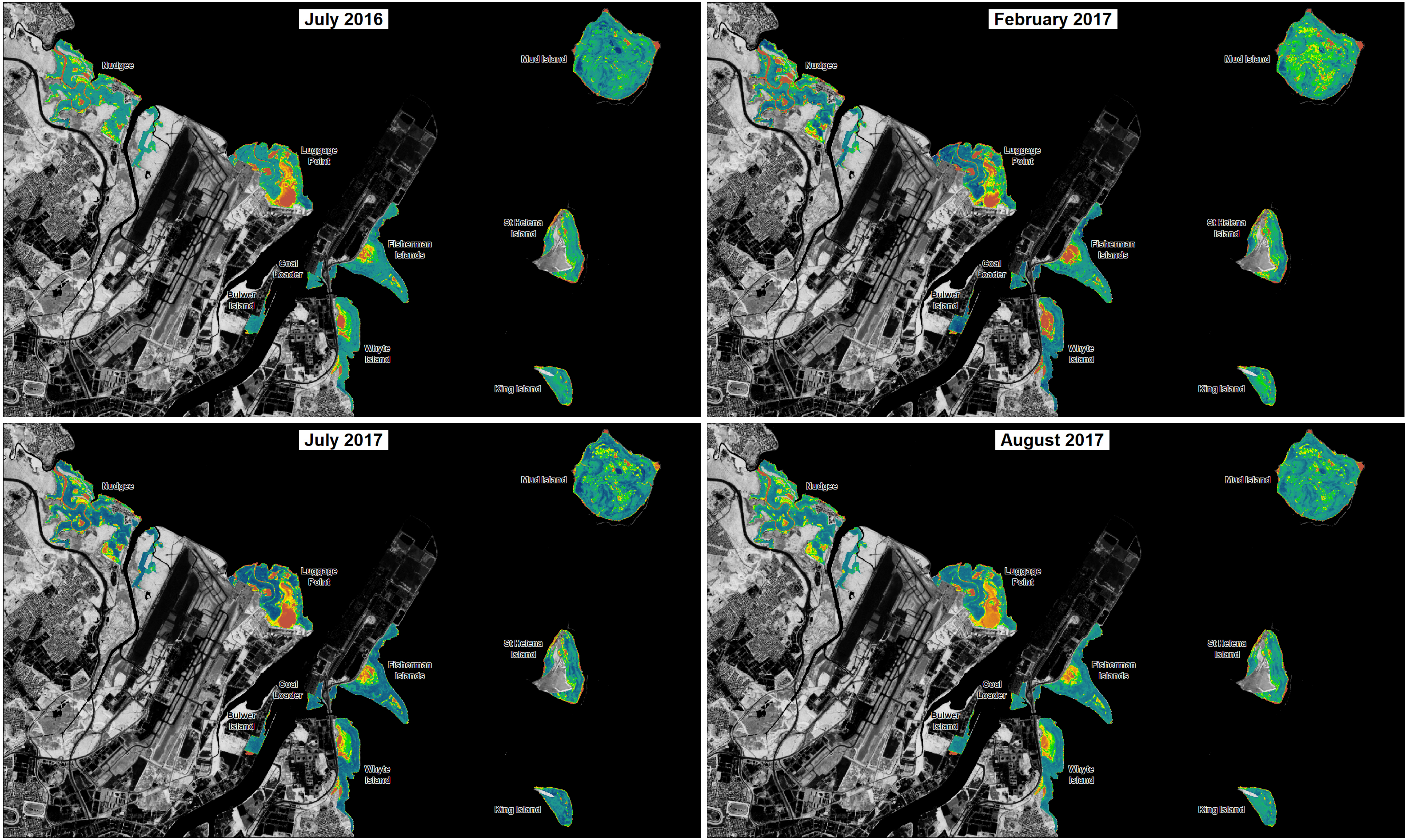
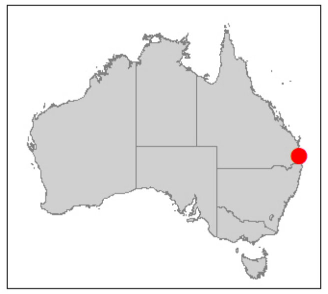


Figure 3-3 Temporal changes in NDVI with respect to 12-month cumulative rainfall at Control sites, from July 2016 to August 2017

The differences in NDVI between July 2016 and February 2017 (Figure 3-5) and between July 2016 and July 2017 (Figure 3-6) highlight points where wetland vegetation NDVI values changed between these two periods. Blue areas depict increasing NDVI values through time, while red areas signal reductions in NDVI. The period between July 2016 and February 2017 shows major reductions in NDVI, largely within saltmarsh areas, but also within mangrove canopies at Fisherman Islands, Mud Island, St Helena Island, and King Island (Figure 3-5). Conversely, the 12-month period between July 2016 and July 2017 shows some reductions in NDVI in saltmarsh areas, but widespread improvements in mangrove canopy NDVI across all investigation sites. This change in NDVI across the 12-month period was used to identify dieback ‘hot-spots’, as areas of reduced NDVI provided strong contrasting signal against the broad-scale increases in NDVI.





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NDVI Score

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NDVI at investigation sites in July 2016, February 2017, July 2017, and August 2017

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Approx. Scale

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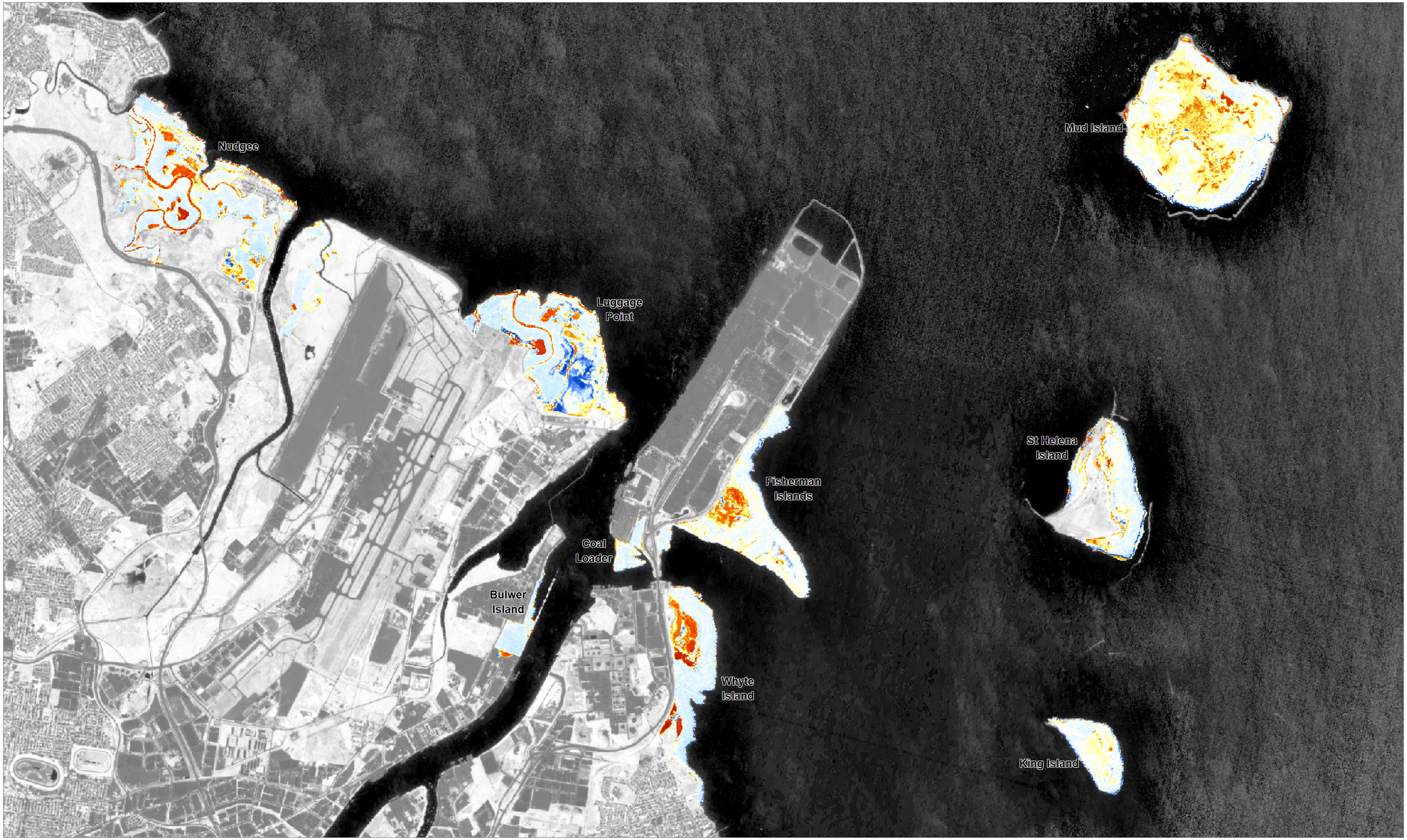

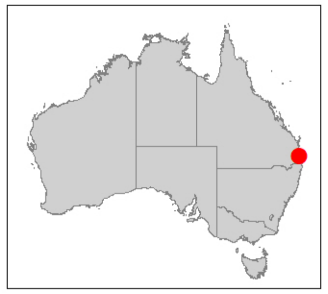

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NDVI Change Score

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Changes in NDVI between July 2016 and February 2017

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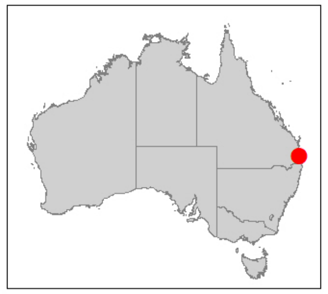

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NDVI Change Score

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Changes in NDVI between July 2016 and July 2017

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3.3 Ground-truthing of NDVI Changes

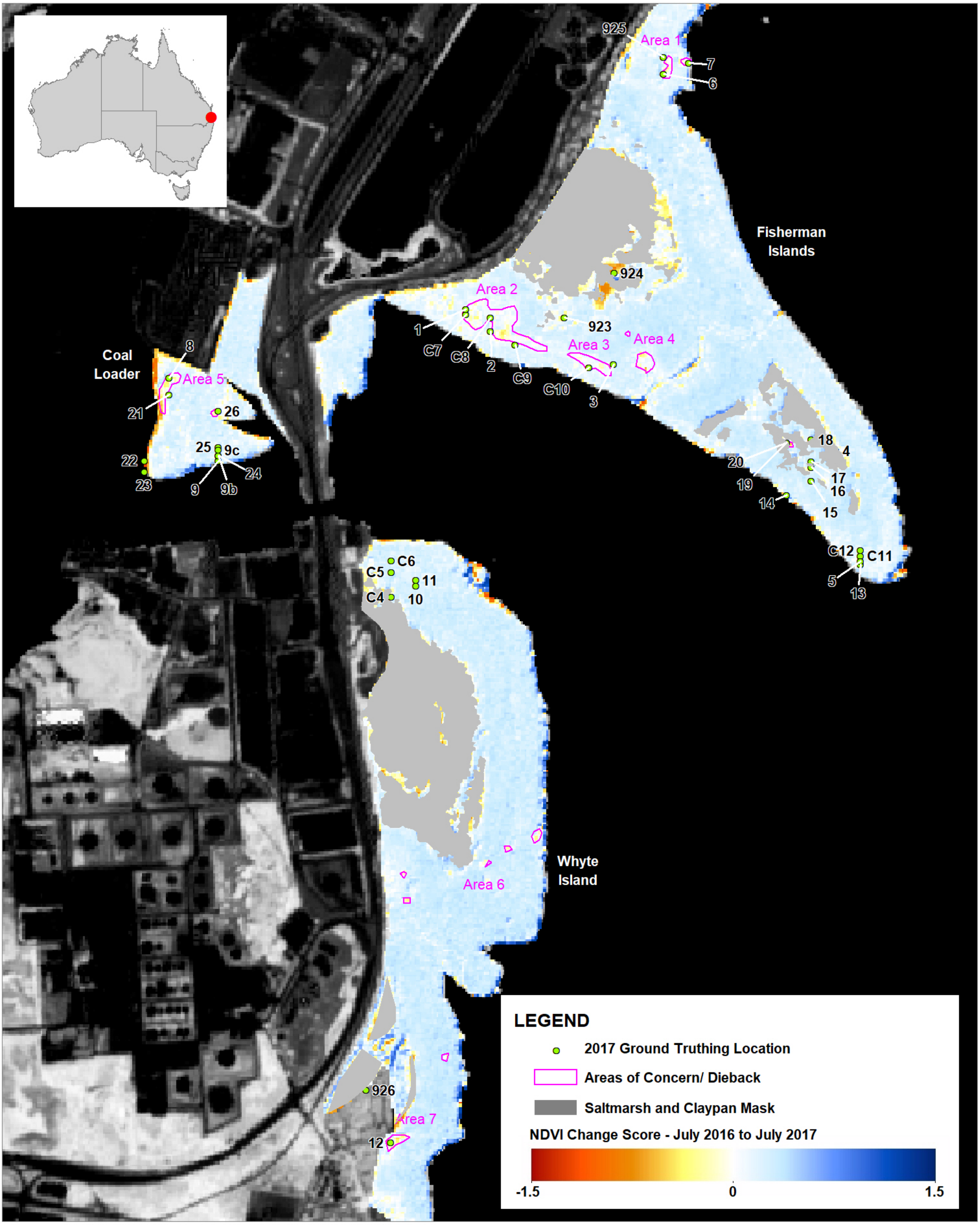
Ground-truthing conducted on the 31st of August confirmed the presence of active dieback areas, recent tree-falls and canopy thinning that reduced NDVI scores between July 2016 and July 2017. Areas where mangrove condition declined over the 12 month period are depicted in Figure 3-8, with points indicating ground-truthing effort used to check NDVI change maps and adjust community mapping[1]. Eight areas were identified where, against broad-scale trends, mangrove condition had declined during 2016-17, as described below.

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

Area 1 at the northern most section of Fisherman Islands included a mixture of mangrove regrowth and dieback (Figure 3-7). Although this is an area of longer-term dieback, recent dieback (within the last 12 months) occurred to the east of the older dieback area, and around the margins of some of the older dieback areas. There was also extensive recruitment and regrowth occurring inside the older areas of regrowth (Figure 3-11).

Figure 3-7 Area 1: Recent dieback around the margins of older dieback (left), and strong regrowth within the centre of older dieback (right)

[1] NDVI in saltmarsh/claypan varies markedly over time in response to variability in soil moisture, standing water, benthic microalgae abundance, and the vegetative signal of the saltmarsh plants. These influences confound assessments of vegetation health, and saltmarsh/claypan were therefore not included in this analysis.



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Changes in NDVI, Ground-truthing and Areas of Concern

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Area 2 – South-west Fisherman Islands (*Ceriops* dominated community)

Area 2 is located within the *Ceriops* dominated community south of the Port Office, and is one of the largest areas of NDVI decline in the 2016-17 period. Site inspections indicate that (Figure 3-9) that several emergent *Avicennia* had recently dropped large branches, resulting in canopy thinning. Furthermore, many *Ceriops* trees had sparse foliage with numerous small twigs, suggesting recent defoliation amongst longer-term defoliation (branches lacking leaves or twigs). Although few trees were completely defoliated, apparent canopy thinning was widespread (Figure 3-12).

Figure 3-9 Area 2: defoliated *Ceriops* (upper), and large recently dropped branches from emergent *Avicennia* with branchlets and some leaves still attached (lower)

Area 3 – South-west Fisherman Islands (*Avicennia* dominated community)

Mangrove condition at this area was similar to neighbouring Area 2, consisting of broad-scale canopy thinning and occasional dropped branches (Figure 3-10). Many emergent *Avicennia* also had abundant epicormic growth (lateral shoots), a sign off poor tree health (Duke et al. 2010), particularly on trees with recently dropped branches. There were also some trees without branchlets, suggesting that defoliation had also occurred here in the past . Individual tree falls were observed in aerial imagery over the past 12 months (Figure 3-13).

Figure 3-10 Area 3: defoliated *Avicennia* showing browned leaves (left), and longer-term dieback – the green in the foreground is missing bark suggesting this has been occurring over a longer time period (right)

Area 4 – South-west (central) Fisherman Islands (*Avicennia* dominated community)

Area 4 was not inspected in the field, but individual tree falls were discerned from aerial imagery over the 12 month period (Figure 3-14). There was also a small pocket of defoliation visible on the NDVI change image (Figure 3-8). When comparing the canopy texture between the two July aerial images, the 2017 image also has more canopy gaps than the July 2016 image. The January 2017 image does not show these canopy gaps, but the sun angle during January is much higher, making a visual comparison of canopy evenness less meaningful at this time.

Area 5 – Coal Loader at Fisherman Islands (*Avicennia* dominated community)

Several large *Avicennia* had partially or completely defoliated canopies, and several large branches had fallen (Figure 3-15). 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 (Figure 3-15). The position of the sand ridge can be seen on Figure 3-16, with the largest changes in canopy cover occurring on and surrounding this feature.

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

Area 6 was not inspected in the field, but canopy dieback was visible at five locations running in an approximately ENE to WSW direction across Whyte Island over the last 12 months (Figure 3-8). These changes are visible on the NDVI change map (Figure 3-8), as well as aerial imagery (Figure 3-16).

Area 7 – Whyte Island boardwalk (*Avicennia* dominated community)

Area 7 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) mangroves as well as smaller trees and regrowth (Figure 3-18). The changes in canopy cover can be seen in (Figure 3-19).

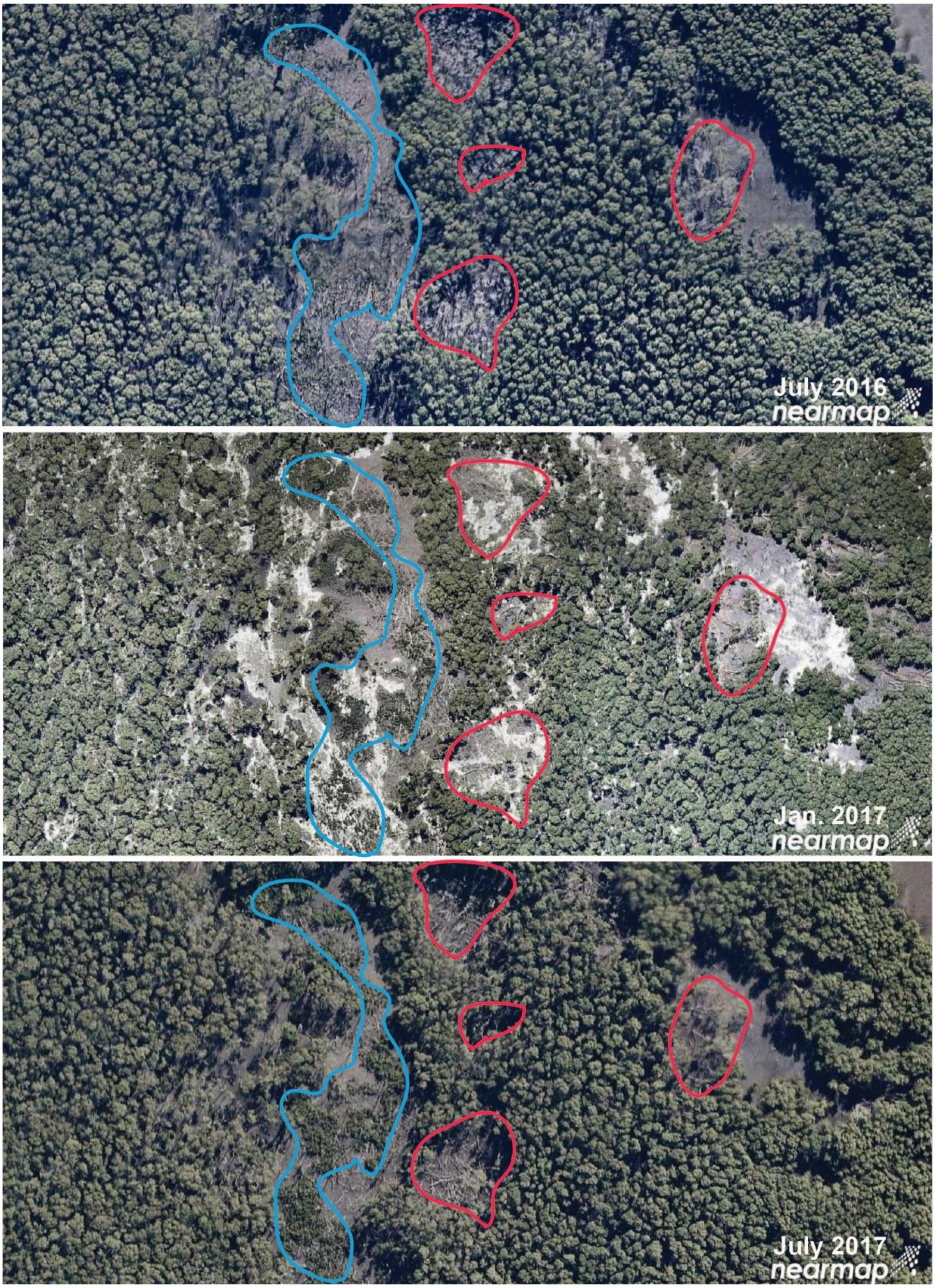


Figure 3-11 High-resolution aerial imagery of canopy conditions at Area 1 in the north of Fisherman Islands in July 2016 (top), January 2017 (middle) and July 2017 (bottom). Blue polygons represent regrowth, red shows recent dieback

Figure 3-12 High-resolution aerial imagery of canopy conditions at Area 2 in the eastern section of Fisherman Islands in July 2016 (top), January 2017 (middle) and July 2017 (bottom)

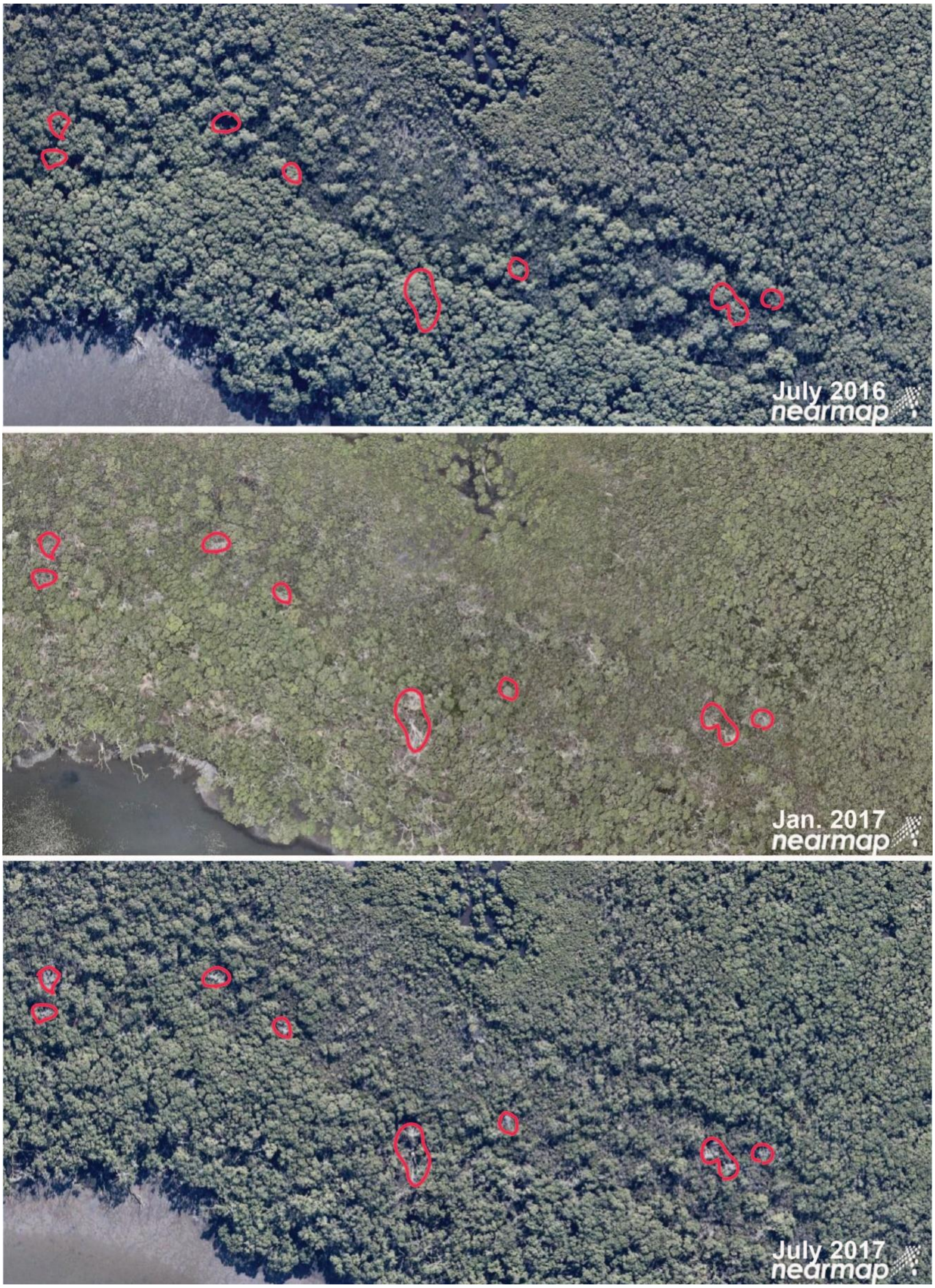


Figure 3-13 High-resolution aerial imagery of canopy conditions at Area 3 in the eastern section of Fisherman Islands in July 2016 (top), January 2017 (middle) and July 2017 (bottom). Red polygons show recent dieback

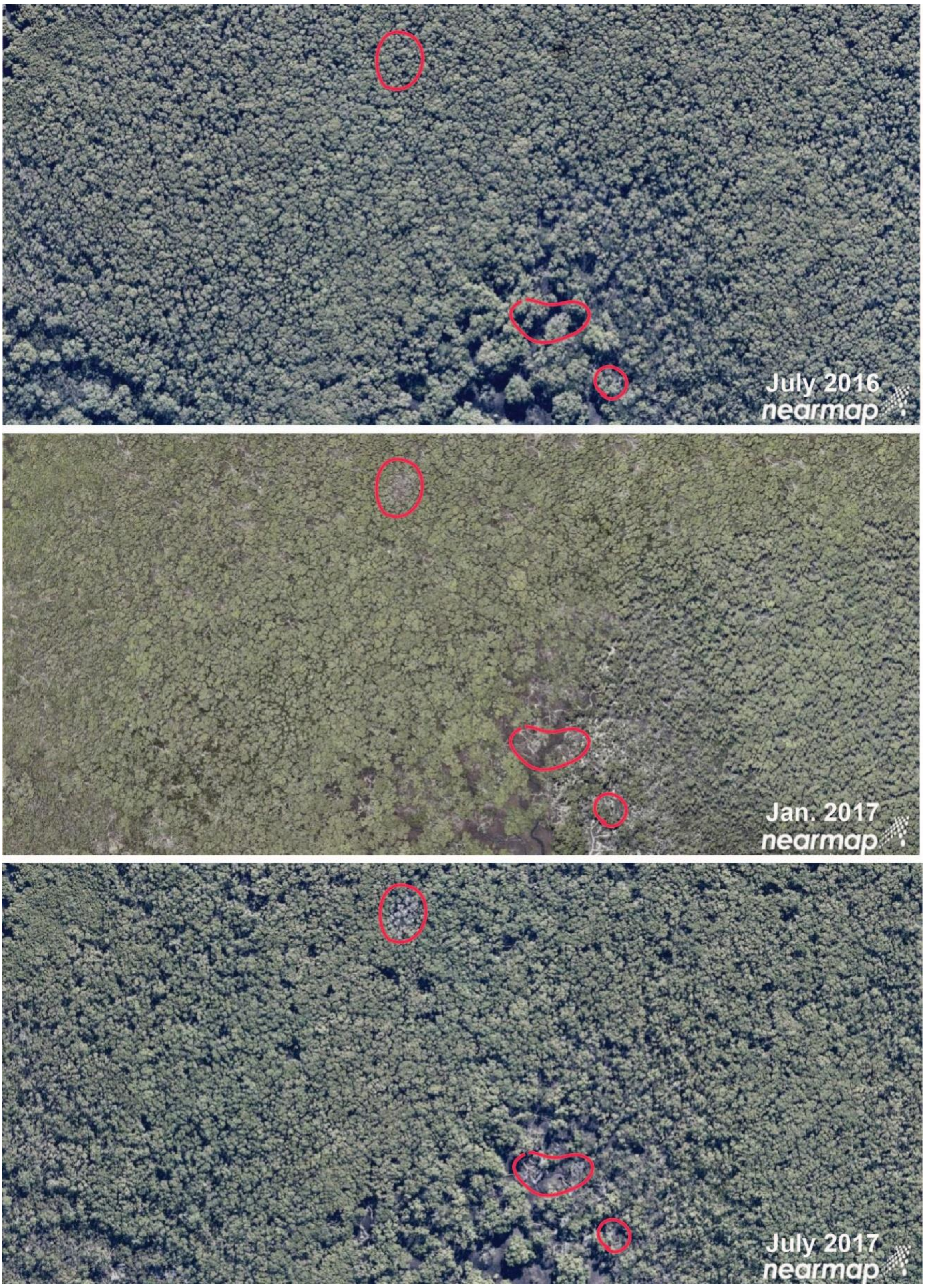


Figure 3-14 High-resolution aerial imagery of canopy conditions at Area 4 in the central section of Fisherman Islands in July 2016 (top), January 2017 (middle) and July 2017 (bottom). Red polygons show recent dieback

Figure 3-15 Area 5: defoliated *Avicennia* (top left), numerous large fallen branches with branchlets (top right), mangroves covered in sand near at the sand-ridge (lower left), and exposed lateral roots in mangroves fronting the Brisbane River (lower right)

Figure 3-16 High-resolution aerial imagery of canopy conditions at Area 5 at the Coal Loader in July 2016 (top), January 2017 (middle) and July 2017 (bottom)

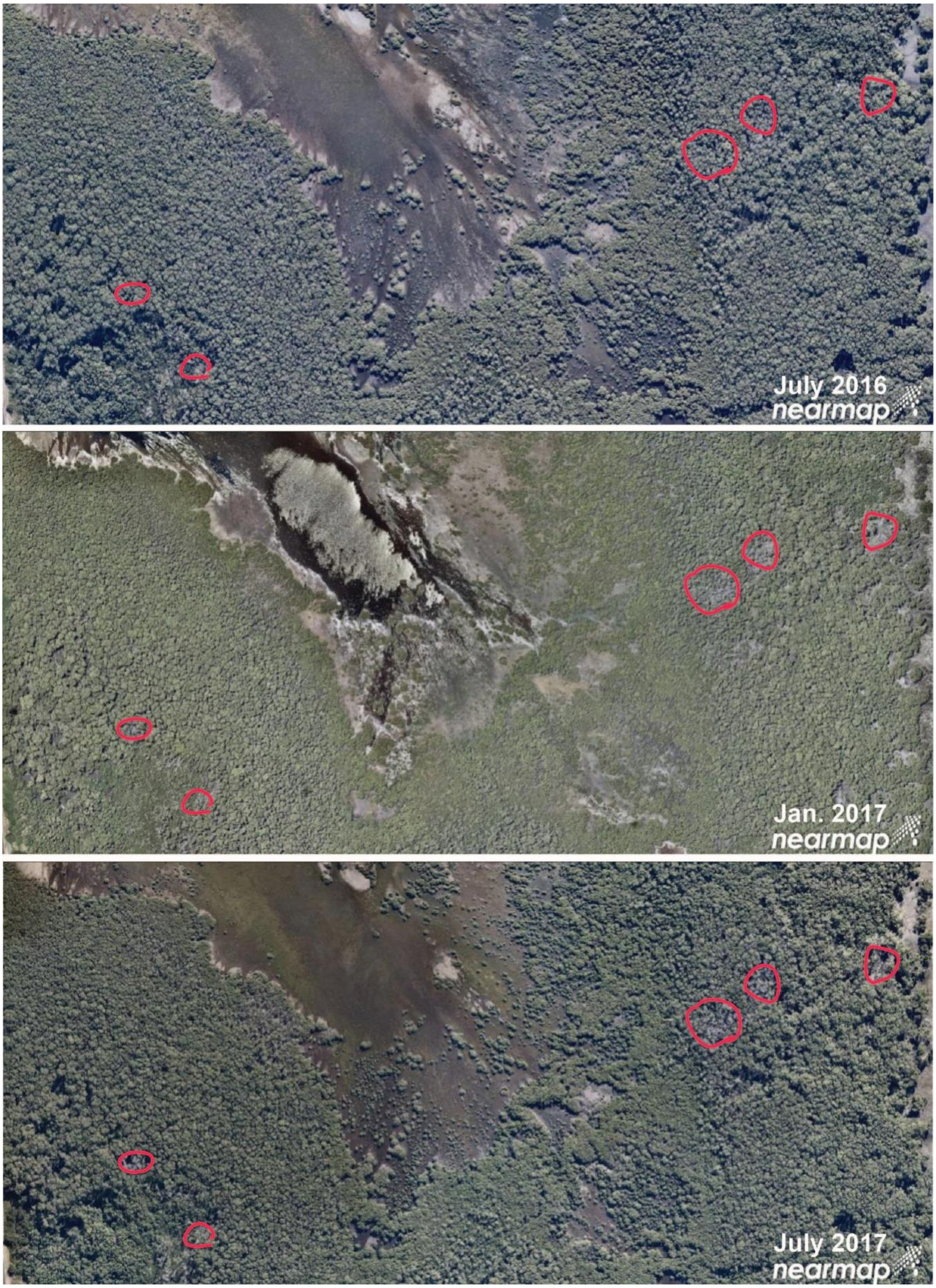


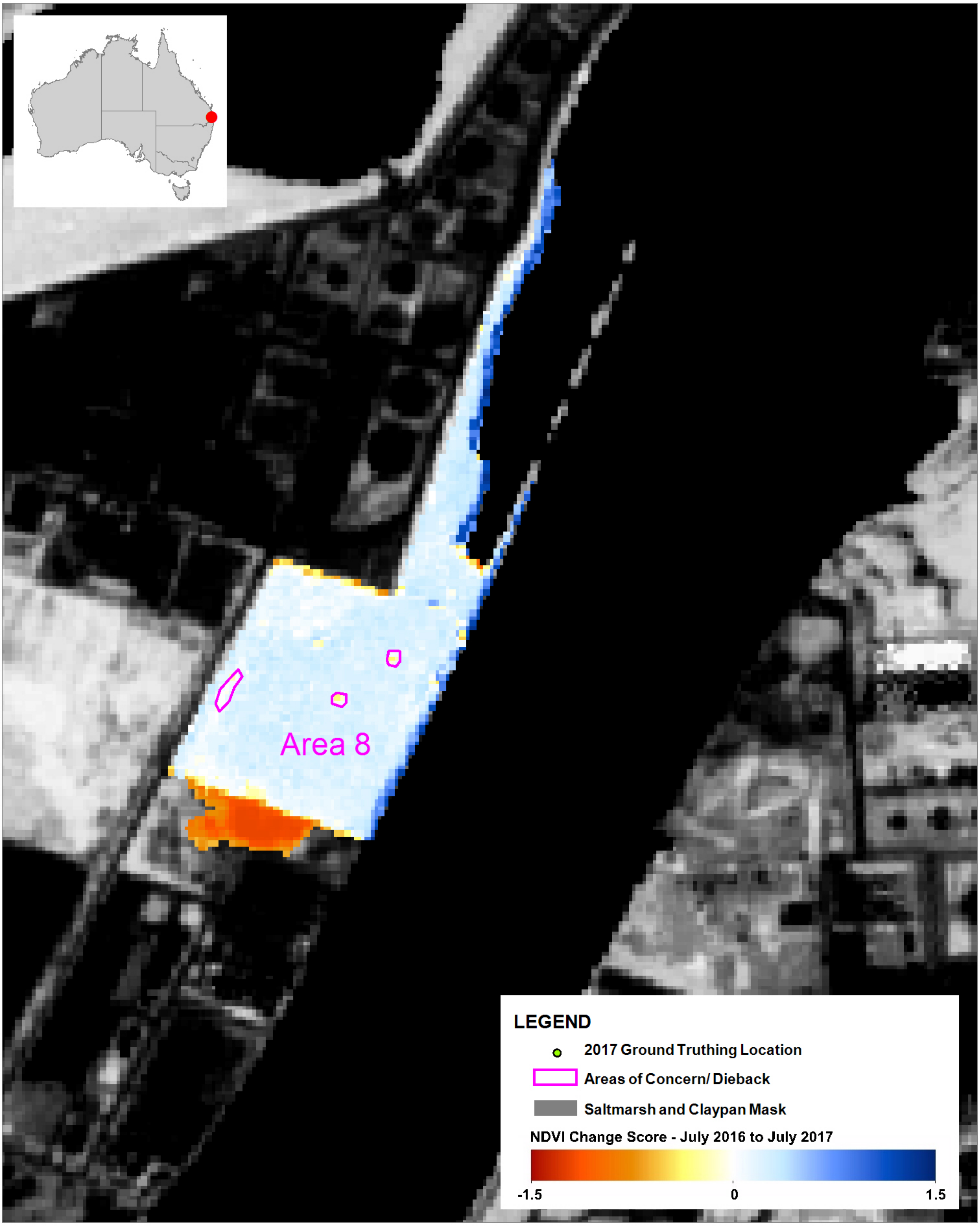
Figure 3-17 High-resolution aerial imagery of canopy conditions at Area 6 at the White Island in July 2016 (top), January 2017 (middle) and July 2017 (bottom)

Figure 3-18 Area 7: defoliated large *Avicennia* trees (left) and small shrubs and regrowth (right)

Area 8 – Bulwer Island (*Avicennia* dominated community)

Area 8 was located at Bulwer Island near the BP products wharf, which was not visited during ground-truthing. NDVI change mapping showed both declines and one improvement in NDVI in that area (Figure 3-20). The increase in NDVI occurred near the culvert works conducted in 2016, and may relate to better tidal connectivity in this area. Small reductions in canopy NDVI appear to be the result of pockets of canopy defoliation, as opposed to tree falls (Figure 3-21). The large change in NDVI at the southern end of the investigation site was due to a land-form change from mangrove to developed land.

Figure 3-19 High-resolution aerial imagery of canopy conditions at Area 7 at the Whyte Island in July 2016 (top), January 2017 (middle) and July 2017 (bottom)



Title:

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

Figure: 3-20

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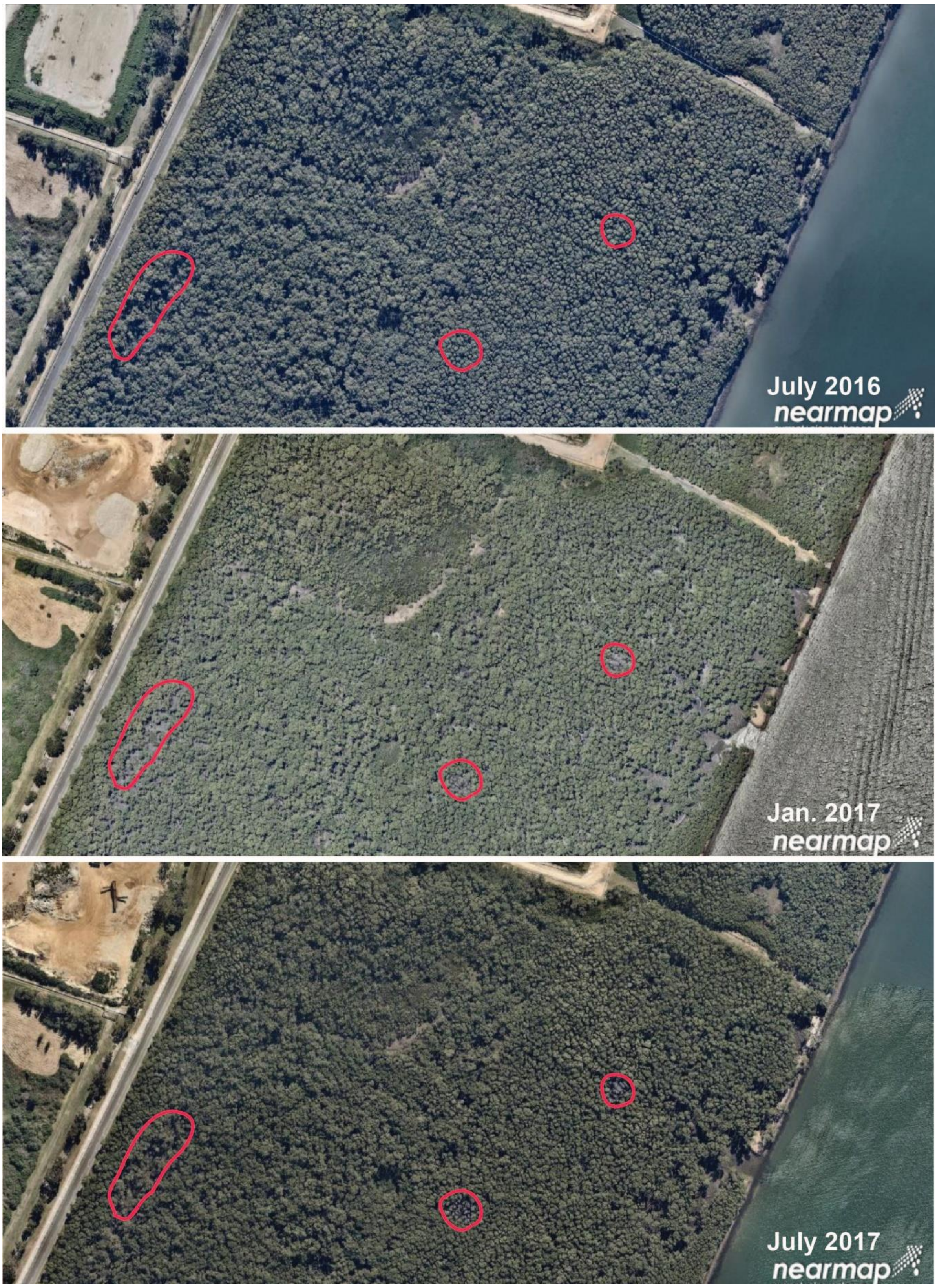

Figure 3-21 High-resolution aerial imagery of canopy conditions at Area 8 at Bulwer Island in July 2016 (top), January 2017 (middle) and July 2017 (bottom). Red polygons indicate reductions in canopy NDVI scores.

4 Discussion

4.1 Vegetation Community Mapping

BMT WBM (2016) developed a preliminary vegetation community map based on remotely sensed data (elevation, multi-spectral data analysis) and a review of past studies. The marine vegetation community map was refined in the present study based on further remote sensing data analysis and ground surveys.

Mangals at both Fisherman Islands and Whyte Island were dominated by grey mangrove *Avicennia marina,* with other species sub-dominant except in small patches. *Ceriops australis and Rhizophora stylosa* dominated or co-dominated with *Avicennia marina* in places. There was a trend of decreasing mangrove canopy height upslope from the mean high water tide level, as described by Davie (1984) and BMT WBM (2016). The updated vegetation community map was consistent with previous mapping studies in the study area, but refined the boundaries of several vegetation classes most notably the *Ceriops*-dominated community along the south-western margin of Fisherman Islands, mixed mangrove community at the coal loader site, and on the northern shoreline of Whyte Island.

Saltmarsh and saltpan vegetation of Fisherman Islands and Whyte Island can show great variability over time a variety of time-scales. Ponded waters in mangrove die-back areas at the eastern tip of Fisherman Islands can contain dense mats of micro-phytobenthos (microalgae) and high NDVI values, but upon drying NDVI was low. Saltmarsh communities dominated by *Suaeda australis* and *Sarcocornia quinqueflora* can also change seasonally in response to rainfall patterns, as described in the following sections.

The mangals at Bulwer Island were comprised of *Avicennia*-dominated forest, and no significant areas of saltmarsh or saltpan were recorded. This pattern suggests that the marine vegetation assemblage at Bulwer Island was mostly located below mean high water. Marine vegetation assemblages at Bulwer Island have been subject to a range of disturbances and stressors including:

- ongoing and historical clearing and reclamation (Mackey 1992; Accad *et al.* 2016) resulting in direct loss and likely indirect changes to hydrology and associated flushing.
- discharge of sewage from Luggage Point WWTP. Mackey (1992) reports that nutrients in sewage discharges have resulted in enhanced growth rates in Bulwer Island mangals. Nutrient enrichment can also reduce mangrove resilience to environmental stresses, including water stress (Lovelock *et al.* 2009).
- seawalls. A seawall is located along the seaward fringe of mangrove forests at Bulwer Island. The effects of the seawall on hydrology are unresolved, but are known to create a barrier to aquatic fauna movements (BMT WBM 2015). Recent habitat restoration works undertaken by PBPL aim to create fish passage between the Brisbane River and Bulwer Island mangals through the partial removal of the seawall. Further monitoring will be required to assess any effects (positive or negative) to hydrology and mangrove condition. Refer to Section 4.3.3 for a discussion on trends in mangrove condition at Bulwer Island.

4.2 Broad-scale Temporal Patterns 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 2016-17 monitoring period, as follows:

- July 2016 - November 2016. There was a reduction in NDVI values between July 2016, September 2016 and November 2016, which was observed at all test and control sites.
- November 2016 – January 2017. There was an increase in NDVI values at most sites except Whyte Island, and control sites at St Helena Island and Nudgee. This was a period of higher rainfall than the previous period.
- January 2017 – March 2017. NDVI declined or remained static between January and March at Bulwer Island, the Coal Loader, King Island and St Helena Island, but increased over this period at Nudgee, Whyte Island and Luggage Point.
- March 2017 – June 2017. NDVI increased over time at all sites. This followed a period of significant rainfall in February 2017 associated with Cyclone Debbie.
- June 2017 – July 2017. NDVI declined at all sites, following a two to three-month period of low 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 lagged rainfall by two to three months, varying among sites.

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 2015-2016 represented very strong El Niño conditions (Figure 4-1), 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 higher than the July 2016 period.

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 changes in NDVI highlighted where community health had declined in the 2016-17 period. 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 survey results, the highest NDVI values at Fisherman Islands were recorded along the northern seaward fringe and drainages within the well flushed tall *Avicennia* dominated closed and partially-closed forest. Areas where NDVI values declined between 2016 and 2017 at Fisherman Islands mangals were as follows (see Figure 3-4):

- Area 1 – north-east Fisherman Islands (University of Queensland monitoring location). The factor/s driving changes in mangrove condition at this area are currently under investigation.
- Area 2 - south-western corner of Fisherman Islands east of Lucinda Drain. This area contained Ceriops australis (yellow mangrove), low closed *Avicennia* forest and open *Avicennia* forest. The leaves of Ceriops have high densities of yellow pigments (see Basak *et al*. 1996), but were also observed to have large canopy gaps. The presence of low closed *Avicennia* forest and open *Avicennia* forest also suggests that this area also suggests that this area is prone to water/salinity stress.
- Area 3 – the *Ceriops* and *Avicennia* forest south-east of Area 2 where there was a general reduction in NDVI score and numerous isolated fallen trees.
- Area 4 – the area of declining *Avicennia* health in the central southern section of Fisherman Islands where there was a general reduction in NDVI score and numerous isolated fallen trees were observed.
- Area 5 – 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.

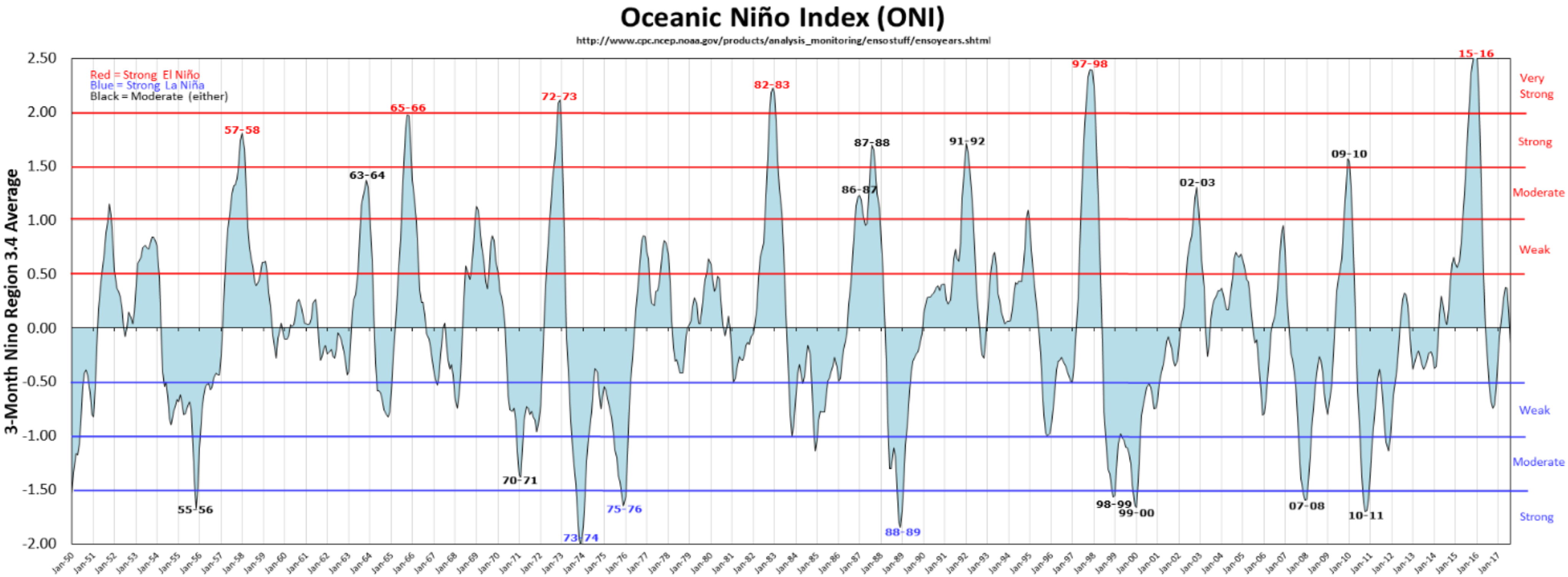

Figure 4-1 Oceanic Nino Index 1955-2017 (NOAA)

In addition to the above areas where declines in mangrove condition were observed between 2016 and 2017, there were additional areas where mangroves were in poor condition but remained stable during the 2016-17 period:

- Mangroves adjacent to the western claypan area at Fisherman Islands. 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).
- South eastern fringe 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 indicates 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 recent mangrove die-back. The drivers for mangrove degradation in this area are unresolved.
- Central mangroves surrounding the mangrove die-back area on the eastern tip of Fisherman Islands. Mangrove assemblages are highly dynamic, as evidenced by significant mangrove recruitment in 'die-back' areas observed in July 2017. The drivers for 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 (Area 6). These environments are prone to natural fluctuations in groundwater levels in response to rainfall-drought cycles, as described in Section 4.3.1. Mangroves adjacent to the mangrove boardwalk and viewing platform were also in poor condition and showed a decline over time (Area 7), likely due to disruptions to flow paths caused by the placement of fill (gravel) material.

4.3.3 Bulwer Island

Mangroves on the seaward fringe had the highest NDVI values, lowest values were recorded 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. Analysis of NDVI suggested that there was little change to mangrove health outside the clearing footprint between July

2016 and July 2017 (Area 8). Thus, impacts to mangroves appear to be largely restricted to the clearing footprint during the 12 month period. Further monitoring is required to assess any longer-term changes to mangroves due to edge effects or indirect changes (e.g. hydrology).

The most notable changes to mangroves during 2016-17 were three isolated patches of mangrove die-back in the central portion of the mangal. Both patches were approximately 15-20 m in diameter and involved the loss of multiple trees, and the die-back occurred sometime between September 2016 and January 2017. No recovery has been recorded here to date. These die-back areas were remote from clearing, and therefore the die-back is unlikely to be affected by construction activities.

As discussed in Section 4.1, habitat enhancement works involving the partial removal of the seawall were recently undertaken to enhance aquatic fauna connectivity between the Brisbane River and Bulwer Island mangroves. Results to date do not suggest that broad-scale adverse effects to mangrove condition occurred. Ongoing monitoring is required to assess effects (either positive or negative) to mangrove forests resulting from any changes to hydrology.

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. Ground-truthing is also required to validate the preliminary marine vegetation community map for Bulwer Island.

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:

- Vegetation community mapping undertaken by BMT WBM (2016) were broadly consistent with field observations undertaken in the present study. Some adjustments to the vegetation community map were undertaken to reflect field observations.
- The seaward margin of mangrove forests was generally comprised of a tall *Avicennia marina* (grey mangroves) dominated closed and open forest, whereas mangals further landward were comprised of low closed to open *Avicennia* marina forest, eventually grading to claypan with or without saltmarsh. *Ceriops* and *Rhizophora* dominated or co-dominated with Avicennia marina in places, consistent with previous field surveys.
- 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 carried out in 2016. Areas of poor health included:
  - mangroves adjacent to claypan areas where water/salinity stress would be greatest. Such areas are likely to experience water stress due to cyclic changers in groundwater levels.
  - mangrove patches in the interior of mangrove forest on the eastern tip of Fisherman Islands and Bulwer Island.
  - mangroves affected by sand burial at the coal loader site.
  - mangroves affected by the board walk at Whyte Island.

The results of the present study indicate that rainfall/drought cycles strongly influence long-term patterns in mangrove green biomass, but that local scale stressors (particularly hydrological barriers) may reduce the resilience of assemblages, ultimately leading to mangrove stress and mortality. To further understand the drivers of mangrove health and the practicality of mangrove rehabilitation it is recommended that:

- a small field study (using conductivity, temperature, depth loggers and time-lapse cameras) be undertaken to assess tidal healthy, degraded and dieback areas. This will provide important information regarding the modes of inundation and help understand whether there are tidal restrictions to overland flow.
- future monitoring assessments continue to use high-resolution satellite imagery as a basis for assessing broad-scale trends in mangrove health and rapid ground inspections to assess sub-canopy environmental conditions on an annual basis.

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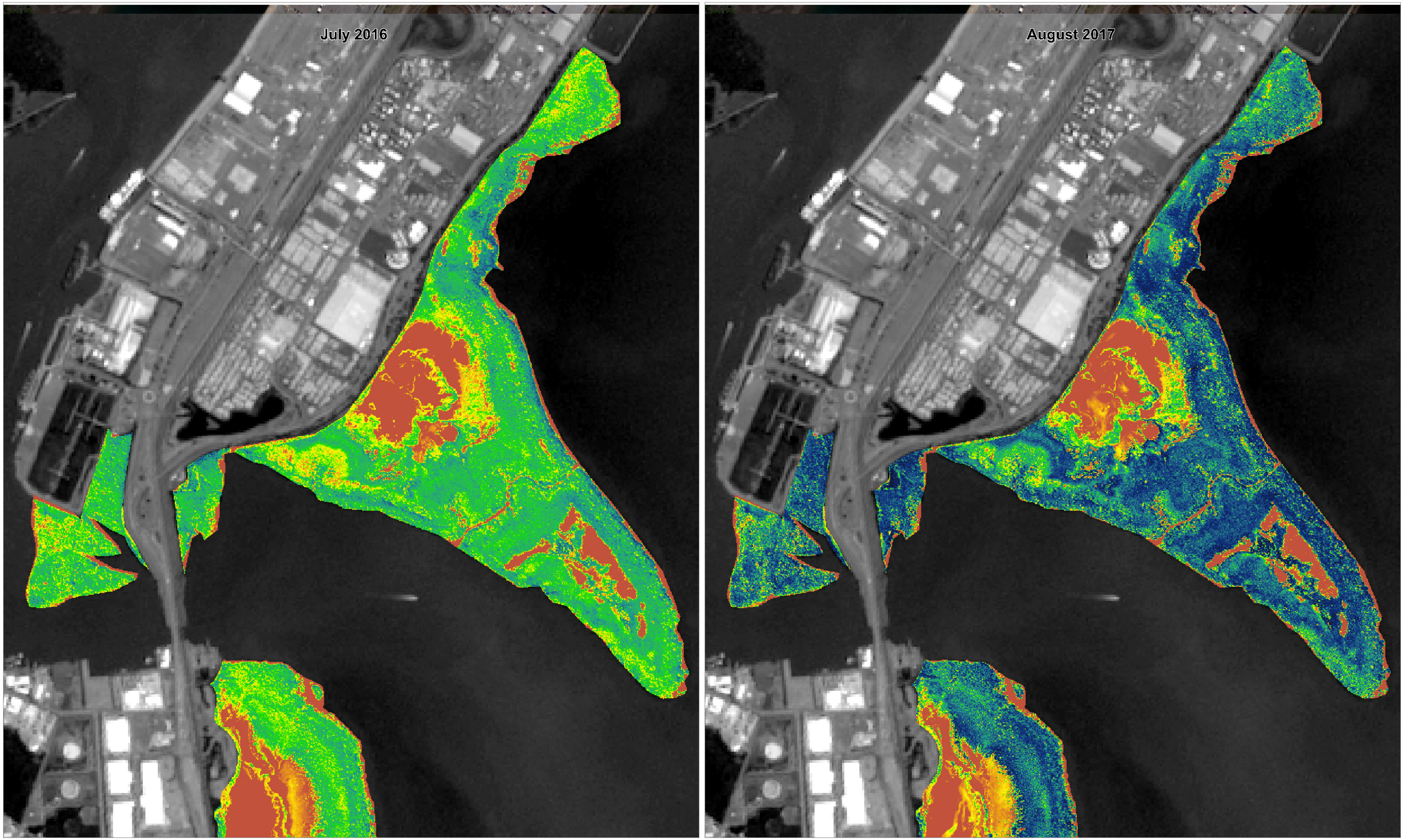
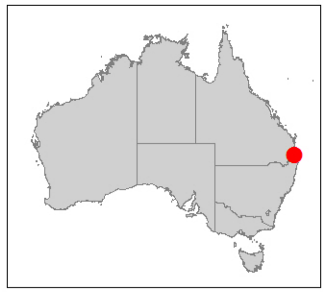
Appendix A High-Resolution NDVI Comparisons





NDVI

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■	0.7
■	0.6
■	0.5
■	0.4
■	0.3
■	0.2

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NDVI of high-resolution satellite imagery at Fisherman Islands in July 2016 and August 2017

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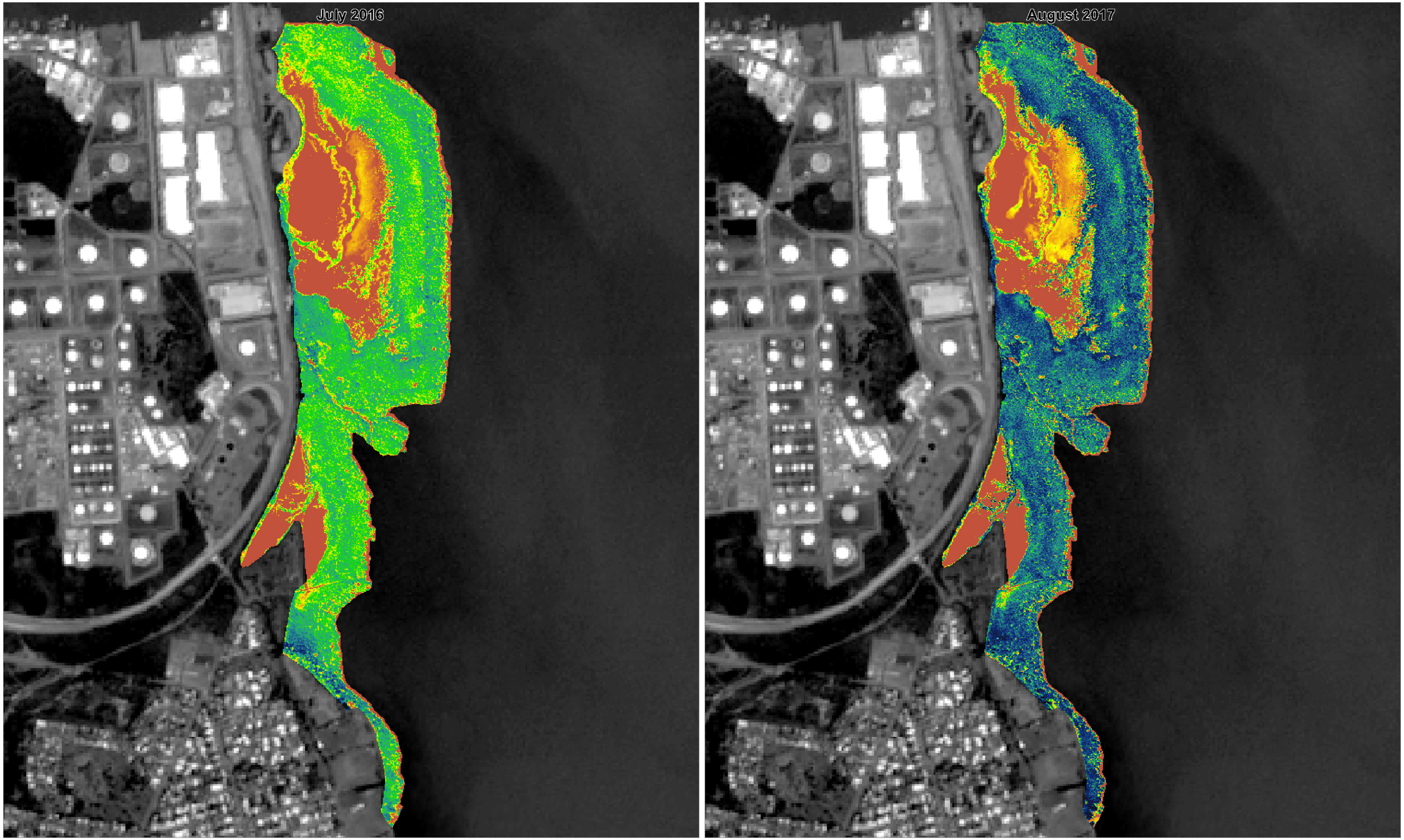

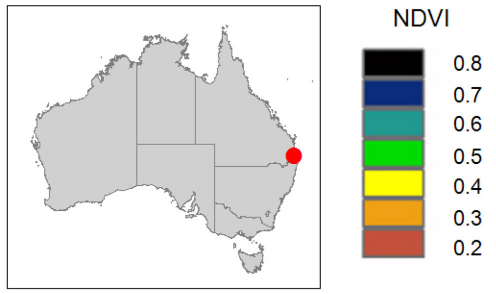

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NDVI of high-resolution satellite imagery at Whyte Island in July 2016 and August 2017

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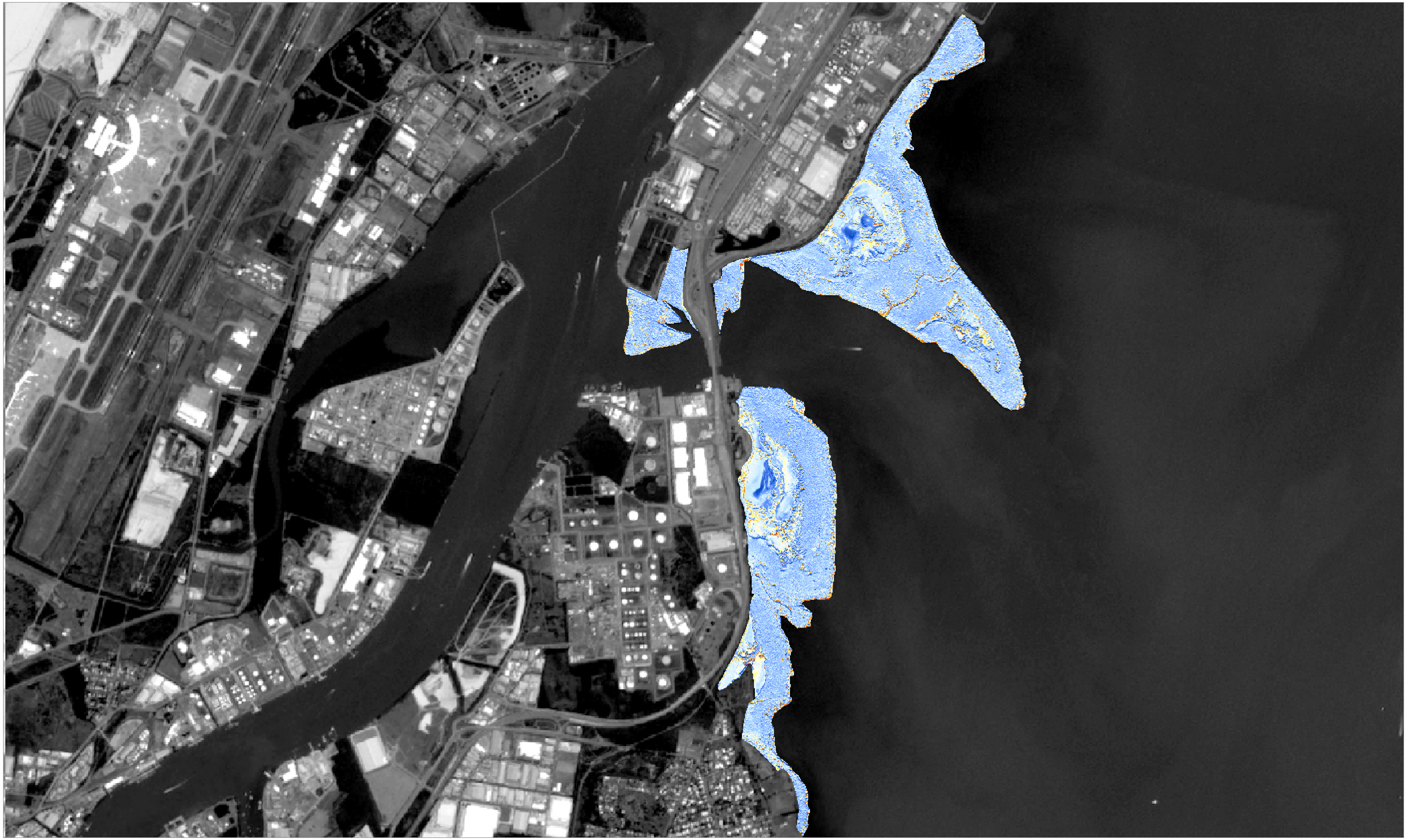

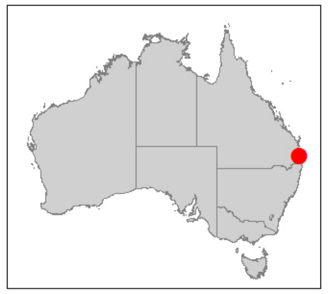

LEGEND

NDVI Change Score

-1.5 0 1.5

Title:

Changes in NDVI between July 2016 and August 2017

Figure: **A-3**

Rev: **A**

N

0km 0.5 1

Approx. Scale

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