Port of Brisbane Mangrove Monitoring Program - 2023

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Authors	Julian Manning
Reviewed By	Darren Richardson
Project Manager	Darren Richardson and Mackenzie Stacey

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Executive Summary

Background

Extensive mangrove forests and saltmarsh communities occur at and near the Port of Brisbane at Fisherman and Whyte Island, and on the northern side of the Brisbane River mouth. Port of Brisbane Pty Ltd (PBPL) has implemented a mangrove monitoring program (MMP) to measure trends in the condition and extent of mangroves at and around the Port. This report outlines the findings of the 2023 MMP assessment.

The major element of the MMP was to quantify of patterns in mangrove canopy conditions using medium-resolution (Landsat) and high resolution (Sentinel -2) satellite data. Four mangrove condition indices (NDVI, EVI, SAVI and LAI) were mapped for the periods of 1988-2023 (Landsat) and 2015-2023 (Sentinel-2) using analysis-ready data. Potential relationships between vegetation indices and environmental data (rainfall, Southern Oscillation Index, and temperature) were examined. Aerial imagery inspections and field surveys were undertaken to investigate and validate areas where changes in mangrove condition were observed over the twelve-month period.

Findings

Long-term patterns in mangrove condition (NDVI) were positively correlated with rainfall, with declines in mangrove condition during drought years and improved mangrove condition during wet periods. The 2022-23 monitoring period showed a decrease in average annual rainfall (i.e., the rainfall in July 2022 and July 2023 were 71 mm and 38 mm, respectively) however the 12-month rolling average NDVI value remained greater than the long-term average across all the sites.

The temporal analysis of individual sites showed a marginal increase in the average health condition among the test sites including Bulwer Island, Luggage Point, and Whyte Island, whereas Fisherman Islands and Coal Loader test sites remained almost stable. Amongst the control sites Green Island showed a decrease in overall health condition while Mud Island, St Helena Island and Nudgee Wetland remained stable.

The spatial analysis of individual sites did not show a broad-scale improvement in mangrove conditions between July 2022 to July 2023 (Figure 1). The direction (i.e., improvement, stability, decline) and magnitude of change varied among and within locations. At broad scales, mangrove conditions across all the sites either showed a stable condition or marginal decrease in NDVI value (≤ -0.1), while some patches particularly at Fisherman Islands and Bulwer Island showed a marginal increase in NDVI value (≤ 0.1). Although, there was no major NDVI declines overall, there were small patches of mangrove canopy loss at Mud Island, Bulwer Island, Coal Loader, and Whyte Island.

There was both mangrove canopy expansion and retraction at Bulwer Island, with a net increase between 2022 and 2023 surveys (1.4 ha). The narrow mangrove fringe on the northern tip of Bulwer Island showed the greatest change (both expansion and retraction), probably reflecting differences in canopy extension and condition, mangrove loss due to bank erosion, weed invasion and possibly vegetation misclassification in structurally complex areas containing a mix of mangroves, saltmarsh, and terrestrial vegetation. The section of Bulwer Island that has been subject to rehabilitation works (i.e., removal; of tidal impediments) showed minor small-scale changes in mangrove extent, but condition has remained stable since 2022 (NDVI change <0.1).

These results are consistent with previous assessments which demonstrate: (i) significant positive correlations between mangrove condition and rainfall, and (ii) declines in mangrove condition typically operate at small spatial scales (measured in metres to 10s of metres), and most common in the mangrove-saltmarsh interface where water stress is highest.

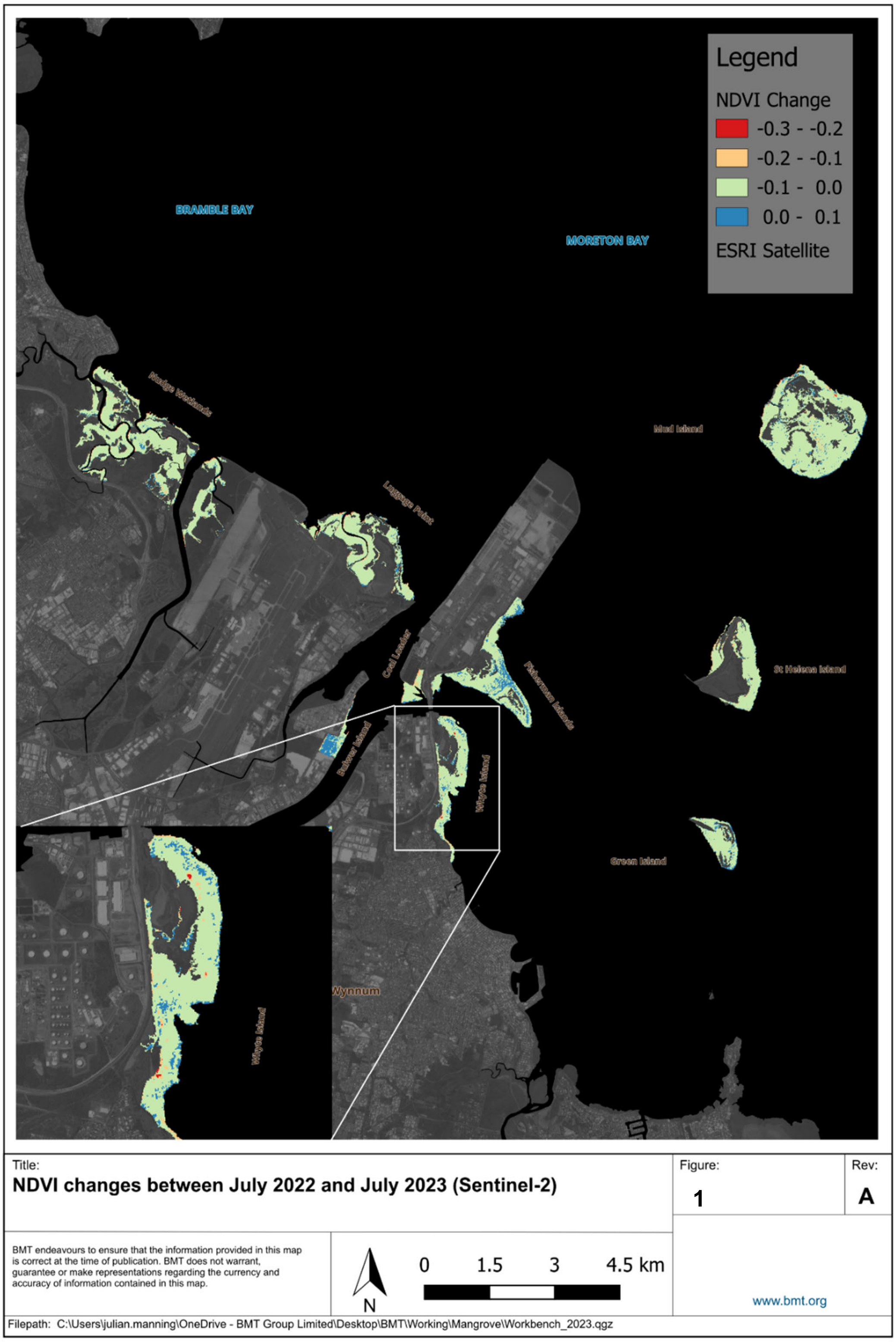

Figure 1. NDVI changes between July 2022 and July 2023

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1 Introduction

1.1 Background

Mangrove forests have high environmental values and are protected species under the *Fisheries Act 1994*. One of the most important areas that host a rich and unique diversity of mangrove communities is Moreton Bay which covers approximately 140 square kilometres (Davie *et al*., 2011; Lovelock *et al*., 2019). The Queensland Herbarium and Biodiversity Science (QHBS), Department of Environment and Science has developed an ongoing program to monitor the status of mangroves and associated communities within Moreton Bay. In 2016, the QHBC sponsored a landmark study Accad *et al*. (2016) to investigate the long-term mangrove coverage change from 1955 – 1997 – 2012 - 2016. Their findings indicated that the mangrove forests of Fisherman Islands and Whyte Island, located at the mouth of the Brisbane River, are among the largest in western Moreton Bay. Since then the QHBS has presented a new update in 2021 which shows (Figure 1.1) the locality of the most recent mangrove and associated communities (Queensland Herbarium and Biodiversity Science, 2022)[1].

The Port of Brisbane Pty Ltd (PBPL) operates adjacent to a number of mangrove forests (e.g., Fisherman Islands, Whyte Island, Bulwer Island) and associated wetland communities. To ensure port operations are not impacting these valued vegetation communities, the PBPL has developed an ongoing program, namely the Port of Brisbane Mangrove Monitoring Program, to monitor the health status of mangrove communities through time and space. A variety of methods were used between 1992 to 2016 (WBM, 1992, 1998, 2000, 2002a, 2002b, 2003), which prevented meaningful assessment of long term trends and drivers. The Port of Brisbane Mangrove Monitoring Program was revised in 2016 to provide a robust, systematic methodology for mapping and characterising patterns in mangrove health conditions over a multiple timescales (BMT WBM, 2016). Since then, several reports have been produced using this methodology (BMT, 2017, 2018, 2019, 2020, 2021, 2022).

The outcome of previous studies has shown a strong association between climatic variations and changes in mangrove health. The short-term to long-term variation in rainfall have been found to be closely correlated with several vegetation health markers such as the Normalised Difference Vegetation Index (NDVI), Leafe Area Index (LAI), Enhanced Vegetation Index (EVI), and Soil Adjusted Vegetation Index (SAVI). The study of cumulative rainfall over a long-term period has shown there is a linkage between the amount of rainfall and the El Niño–Southern Oscillation (ENSO) cycles (BMT WBM, 2016). For instance, the medium trends show a decrease in mangrove health which coincided with strong La Niña conditions (1987-1989) and again during the Millennium Drought (2006-2008).

1.2 Aim and Objectives

The aim of the present study is to describe spatio-temporal variations in mangrove vegetation health condition and infer potential environmental drivers of change.

The specific objectives of this study are as follows:

- Map the long-term temporal patterns in mangrove green biomass (e.g., NDVI) using remote sensing imagery with the following steps:

[1] An interactive map viewer that visualises changes in the extent of mangroves and associated communities in Moreton Bay can be seen here.

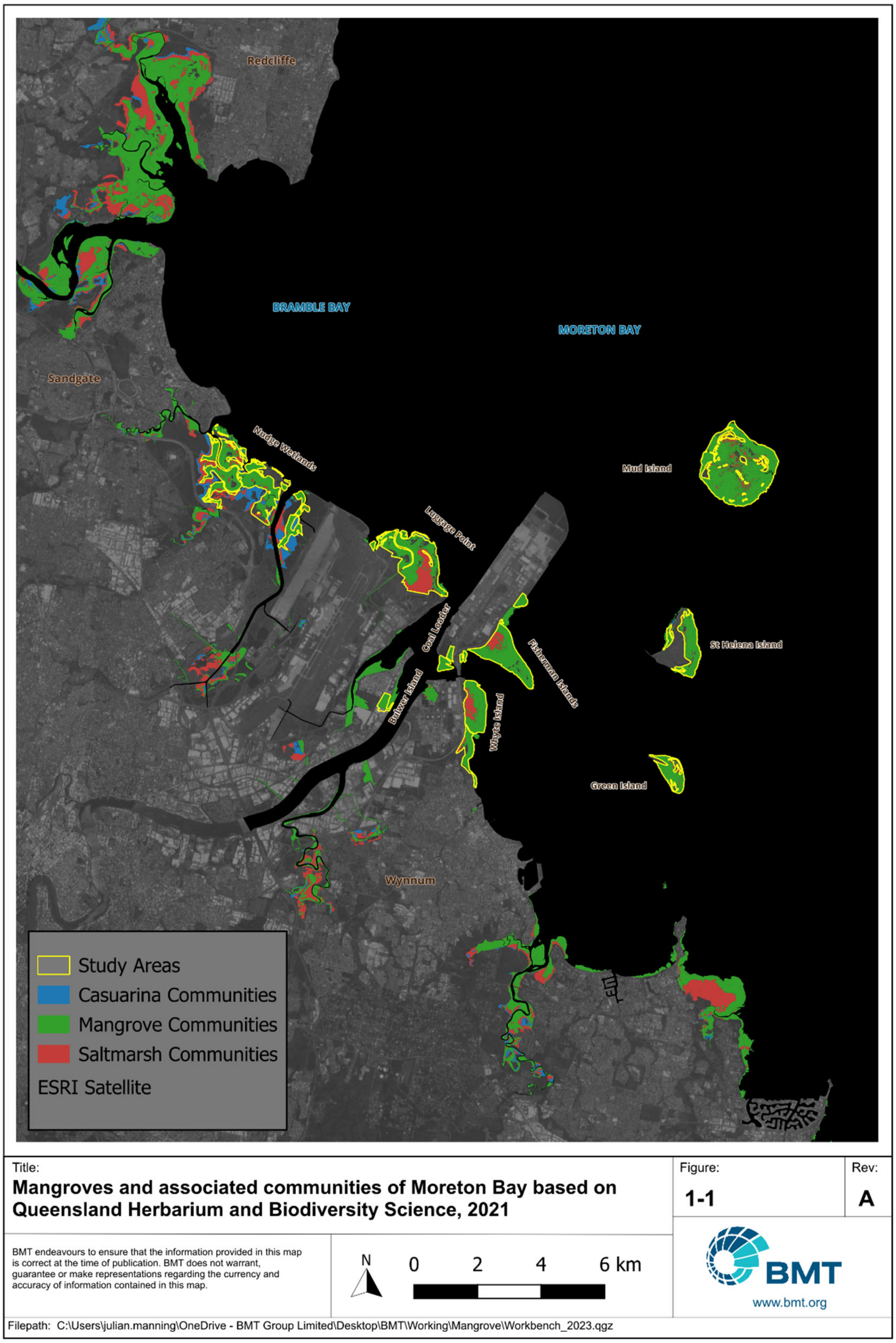


Figure 1.1 Locality plan showing mangrove and associated communities based on Queensland Herbarium and Biodiversity Science, 2021

  - Step one: short-term (2022 to 2023) seasonal changes in mangrove health status using high spatial resolution multispectral satellite imagery.
  - Step two: validating the outcome, derived from the previous step, using very high-resolution aerial imagery.
  - Step three: long-term (1988 and 2023) changes in mangrove health status using medium-range spatial resolution multispectral satellite imagery.

- Quantify short-term changes in the spatial extent of mangrove and saltmarsh/claypan between 2018 and 2023 using available aerial imagery.

- Identify potential drivers of mangrove change at key investigation areas (Fisherman Islands, Whyte Island and Bulwer Island).

2 Methodology

2.1 Remote Sensing

2.1.1 Digital Earth Australia (DEA) Data Cube

Analysis was performed on the Digital Earth Australia (DEA) Data Cube platform where Sentinel, Landsat and some other freely available remote sensing data are available for the Australian continent. The data cube contains analysis-ready datasets (ARD) for Sentinel 2A, 2B and Landsat 5, 7 and 8 sensors. The ARD datasets are geometrically corrected and stacked consistently which allows sequential observations for tracking changes over time. These datasets are also adjusted for various radiometric and atmospheric corrections including Bidirectional Reflectance Distribution Function (BRDF), Adjusted Reflectance with Terrain illumination (NBART[2]), sensor viewing angle with respect to the pixel position on the surface, as well as sensor/instrument gains, biases, and offsets.

2.1.2 Data Sources

Sentinel-2 high spatial resolution imagery (i.e., 10 m) and Landsat 5, 7, and 8 medium spatial resolution imagery (i.e., 30 m) imagery were gathered for both individual study sites and the combined mangrove region as described in Table 2.1. The Sentinel-2 masking near port infrastructure reduced the number of available scenes at the Coal Loader and Bulwer Island, otherwise a large number of scenes were available for analysis. Consequently, the data quality filters for Sentinel imagery were relaxed to vary between 50% and 90% to increase temporal coverage, as opposed to a minimum of 98% that was used for Landsat imagery.

Table 2.1 Scene availability for different sensors and time periods

Site	Sentinel 2 (July 2017 – July 2023)		Landsat 5, 7, 8 (Aug 1988 – July 2023)	
	Quality Pixel	Time Steps	Quality Pixel	Time Steps
Pelican Banks / Coal Loader	50%	572	98%	372
Nudgee Wetlands	70%	515	98%	306
Luggage Point	90%	459	98%	380
Bulwer Island	50%	566	98%	440
Whyte Island	70%	498	98%	448
St Helena Island	98%	432	98%	573
Green Island	98%	418	98%	589
Mud Island	90%	436	98%	522
Fisherman Islands	50%	565	98%	404

[2] Adjusted Reflectance with Terrain illumination (NBART) has the same features of *Nadir-corrected BRDF Adjusted Reflectance* (NBAR) but includes an additional terrain illumination reflectance correction and as such considered to be actual surface reflectance as it considers the surface topography.

2.1.3 Investigating Areas

Two treatments were adopted:

- Test treatment – which are mangrove areas directly adjacent to Port operations (i.e., Fisherman Islands, Coal Loader, and Whyte Island/Wynnum foreshore) or occur in the vicinity of operational works undertaken by PBPL (i.e., habitat restoration works at Bulwer Island, cruise ship construction works at Luggage Point).
- Control treatment – these are mangrove areas outside the direct influence of PBPL activities and provide contextual information on background variability. These sites encompass minimally disturbed environments (e.g., St Helena Island), and areas subject to historical (e.g., coral dredging at Mud Island) and/or ongoing human disturbance.

The extent of these areas is shown in Figure 2.1.

2.1.4 Spatial Data Processing

Vegetation Indices

Atmospherically-corrected Bottom-of-Atmosphere (BoA) analysis-ready products for Sentinel-2 and Landsat 5, 7, and 8 products were accessed and analysed using several modified codes from Krause *et al*. (2021) to derive the following four vegetation indices:

1. The Normalized Difference Vegetation Index (NDVI), which is the difference between near-infrared (which chlorophyll in vegetation strongly reflects) and red light (which chlorophyll absorbs), and essentially represents greens (i.e., chlorophyll found in leaves). NDVI for each of the pixels was calculated using the following formula:

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

   where NIR is the near-infrared BoA reflectance and Red is the BoA reflectance of the red band.

2. Enhanced Vegetation Index (EVI) is very similar to NDVI and can be used to quantify vegetation greenness. However, EVI corrects for some atmospheric conditions and canopy background noise and is more sensitive in areas with dense vegetation (Huete *et al*., 2002).

   $$EVI = G * ((NIR - Red)/(NIR + C_1 * Red - C_2 * Blue + K)$$

   where G is a gain factor, $Blue$ is the BoA reflectance of the blue band, C_1 and C_2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band, K is the canopy background adjustment that addresses non-linear (differential NIR and red radiant transfer through a canopy).

3. Like NDVI, the soil adjusted vegetation index (SAVI) is based on the difference between red and near infrared wavelengths, and therefore provides a measure of chlorophyll content in leaves. SAVI also compensates for the confounding effects of soil moisture and soil colour (i.e., changes in 'soil brightness'). SAVI was calculated for each pixel using the following formula:

   $$SAVI = (NIR - Red)/(NIR + Red + L) * (1 + L)$$

   where NIR is the near-infrared BOA reflectance, Red is the BoA reflectance of the red band and L is the vegetation correction factor.

4. Leaf area index (LAI) is a biophysical index that as the name suggests measures the area of leaves in the visible canopy. LAI was calculated for each pixel using the following formula from Boegh *et al*. (2002) utilising the Enhanced Vegetation index of Huete *et al*. (2002):

$$LAI = (3.618 * 2.5 * (Green * ((NIR - Red)/(NIR + SWIR * Red - 7.5 * Blue + 1))) - 0.118$$

Where $SWIR$ is the BoA reflectance of short-wave infrared and $Green$ is the BoA reflectance of the green band.

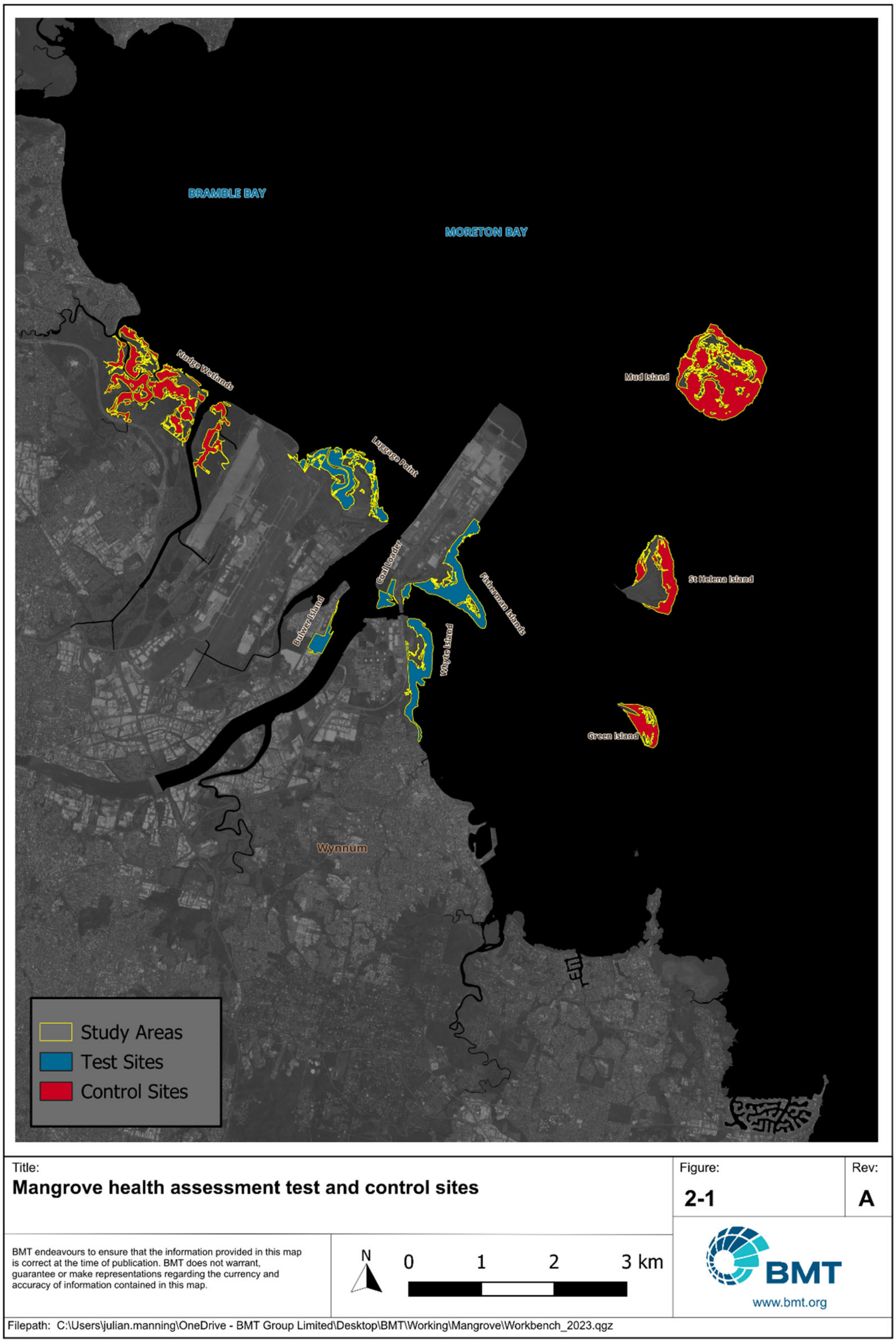


Figure 2.1 Mangrove health assessment test and control sites

Mangrove Community Mapping

A combination of known mangrove community locations from the previous field surveys, existing maps, and very high spatial resolution aerial imagery (i.e., Nearmap) were used to train several machine learning image classification algorithms (e.g., random forest and support vector machine) within ESRI ArcGIS Desktop (Version 10.8) to map out the mangrove and associated communities. In the absence of multispectral bands (e.g., near-infrared) the image was classified into two classes including mangrove communities and saltmarsh/claypan areas.

2.1.5 Rainfall Data

Rainfall data were accessed from the Bureau of Meteorology from January 1988 to July 2022. The weather station closest to the study area was Brisbane Airport (040842) station. However, the data from this station does not cover the entire timespan of this study. As a result, the missing rainfall records were filled using the nearby Fort Lytton (040320) station. Figure 2.2 shows the monthly average and twelve-monthly cumulative rainfall data.

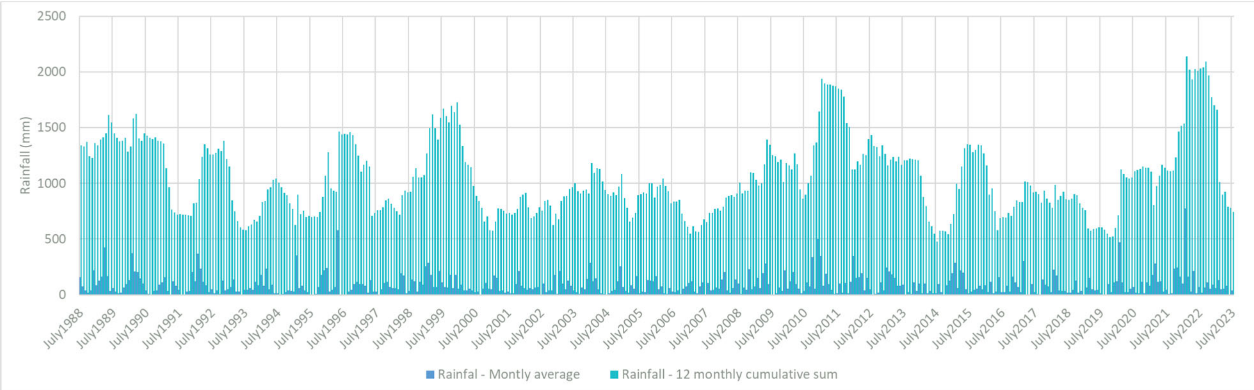


Figure 2.2 Monthly average rainfall (dark blue) and 12-monthly cumulative sum rainfall (light blue) for the study area in millimetres (based on Brisbane Airport station 040842 and Fort Lytton station 040320).

2.1.6 Assumptions and Limitations

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

Various minimum-good data thresholds (based on cloud filtering) between 50% to 98% were applied to each analysis based on the availability of data (Table 2.1). For long-term Landsat analysis, scene counts were always relatively high and the minimum good data thresholds were maintained at 98%. Some of the Landsat ARD scenes included heavy clouds that had not been effectively filtered. These were removed by filtering out mean NDVI scene values less than 0.40 units. For Sentinel-2, ARD pixel masking tended to be adversely affected by nearby infrastructure, particularly near the Coal Loader and Bulwer Island. At these locations, where scene counts were low, the thresholds of minimum good data were lowered from 50% to 98%.

NDVI represents an extremely robust vegetation index for long-term comparisons in the vegetation community due to its relative simplicity and similarities in central wavelengths for the red and NIR bands among sensors. Inter-sensor comparisons (AVHRR, SPOT, MODIS SeaWiFS, Landsat) typically differ by less than 0.05 NDVI units over most of the non-polar regions of the world (Brown *et al.*, 2006).

Comparisons of NDVI among various Landsat sensors since 1988 are potentially prone to small changes in sensors, orbit, and sensor drift. Orbit changes in Landsat 5 over the 27-year record resulted in 0.0006 NDVI / year, equivalent to about a 0.016 NDVI change over the entire Landsat 5 TM data record (Zhang & Roy, 2016). These issues for long-term assessments have been resolved by the introduction of analysis-ready data where atmospheric correction, spatial alignment and radiometric calibration allow estimation of the remotely sensed surfaces without sensor, atmospheric, or geolocation artefacts (Dwyer *et al*., 2018).

Image classification of aerial imagery within the visible range of electromagnetic spectrum and without having auxiliary bands such as infrared band, is subject to some level of inevitable misclassification. These are often due to the presence of atmospheric conditions (e.g., haze) as well as some visual artifacts that are the results of mosaicking a large number of high-resolution imageries (i.e., 2 m spatial resolution) captured at slightly different sun elevation angle. However, to minimise these errors the blue, green, and red bands could be aided with submeter accuracy digital elevation model (DEM).

3 Findings

3.1 Mangrove and Associated Community Extents

The overall extent of mangrove community over the period of 2018 to 2023 remained relatively consistent (Figure 3.1Area of Mangrove and Saltmarsh/Claypan at Fisherman Islands, Bulwer Island and Whyte Island through time). However, over the shorter period over the past year (July 2022 to July 2023) the following changes were observed:

- A small reduction in mangrove spatial extent was observed in Fisherman Islands (Figure 3.2). Most of these areas of mangrove decline were located adjacent to the claypan areas. The upper intertidal area is a marginal habitat for mangroves due to high levels of water stress. which are subject to water upper limit of this phenomenon could be related to the amount of rainfall (i.e., the rainfall in July 2022 and July 2023 were 71 mm and 38 mm, respectively) which shows a decline by half in point-to-point comparison. The same trend was also observed in Whyte Island which also have large areas of claypan and therefore susceptible to the level of available water for healthy vegetation growth.

- A net increase in mangrove spatial extent was observed in Bulwer Island (Figure 3.3) with the narrow mangrove fringe on the northern tip of Bulwer Island showing the greatest change (both expansion and retraction in mangroves). This could be due to possible vegetation misclassification in structurally complex areas that contain the mixture of mangroves, saltmarsh, and terrestrial species, weed invasion or mangrove change due to bank erosion.

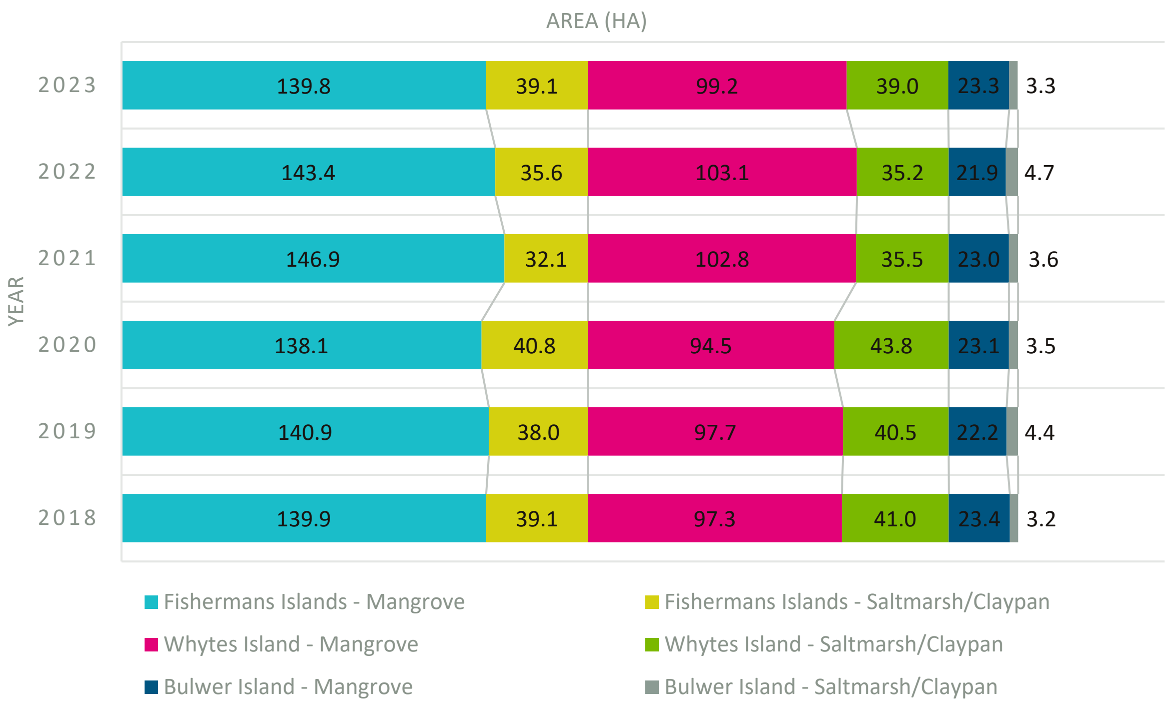
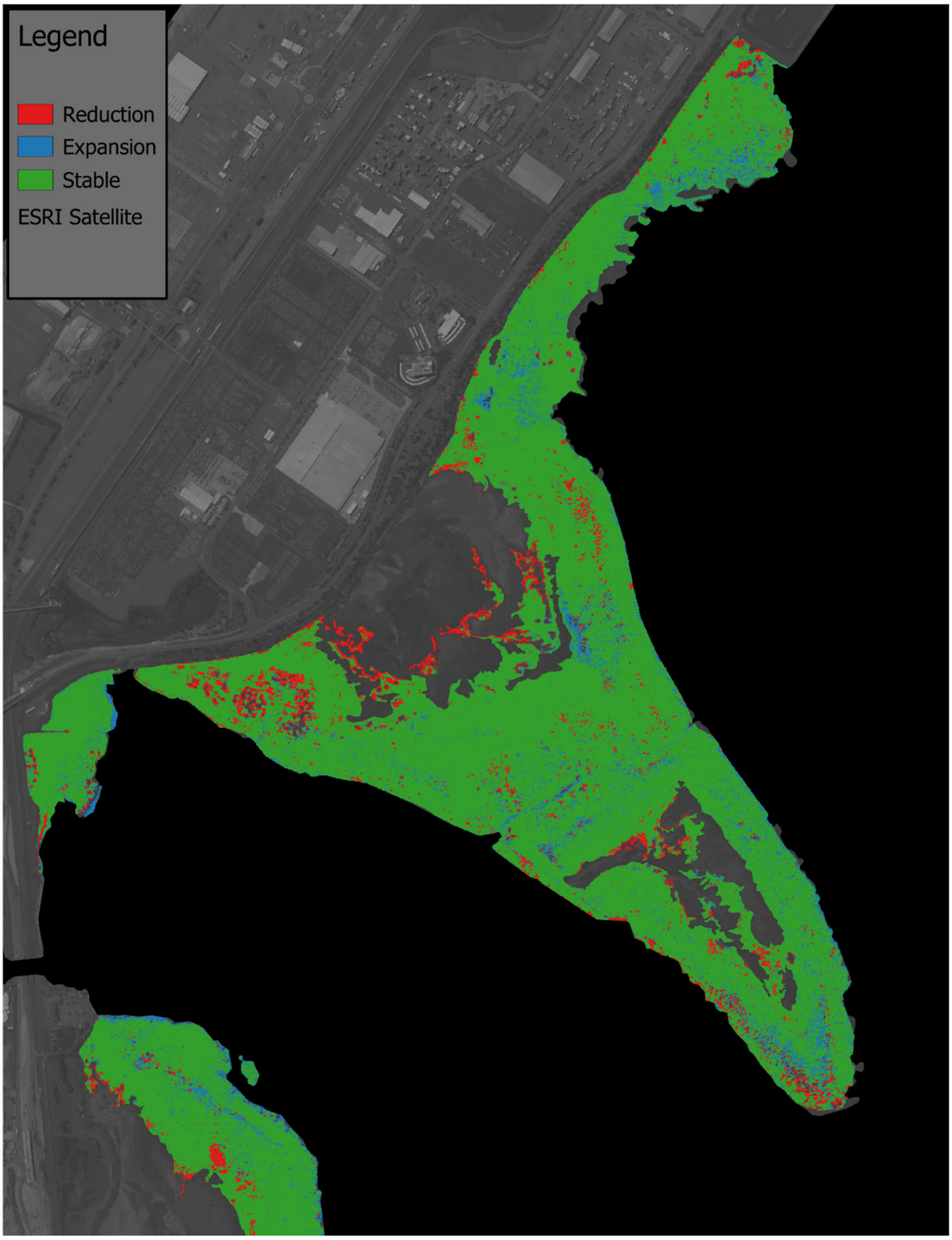


Figure 3.1 Area of Mangrove and Saltmarsh/Claypan at Fisherman Islands, Bulwer Island and Whyte Island through time



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Change in mangrove extent between July 2022 to July 2023

Figure: 3.2

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Figure 3.2 Change in mangrove spatial extent between July 2022 to July 2023

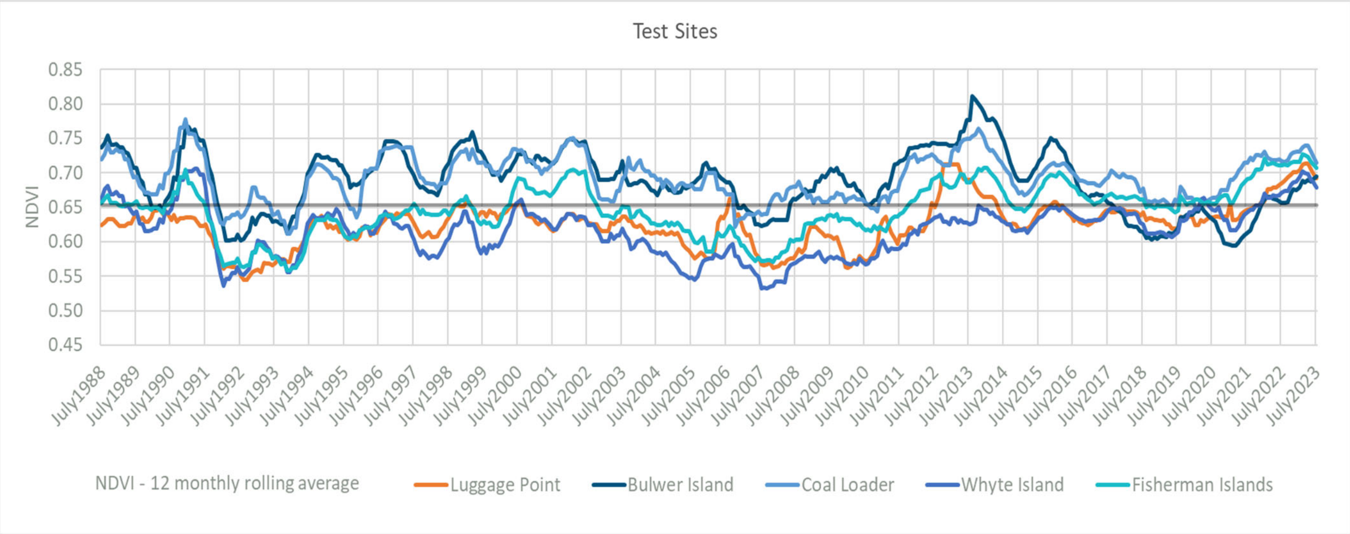
Figure 3.3 Change in mangrove spatial extent between July 2022 to July 2023

3.2 Mangrove Condition

3.2.1 Temporal Trends

The long-term (July 1988 and July 2023) analysis of 12 monthly rolling averages of NDVI scores at both the test and control sites showed variations both above and below the overall long-term NDVI average (Figure 3.4).

The overall condition of all the test and control sites between July 2022 and July 2023 remained above the overall long-term NDVI average. Among the test sites Bulwer Island, Luggage Point, and Whyte Island showed an increase in NDVI while the remaining sites including Fisherman Islands and Coal Loader remained almost stable. Among the control sites, Green Island showed a decrease in NDVI while the remaining sites including Mud Island, St Helena Island and Nudgee Wetland remained almost stable.



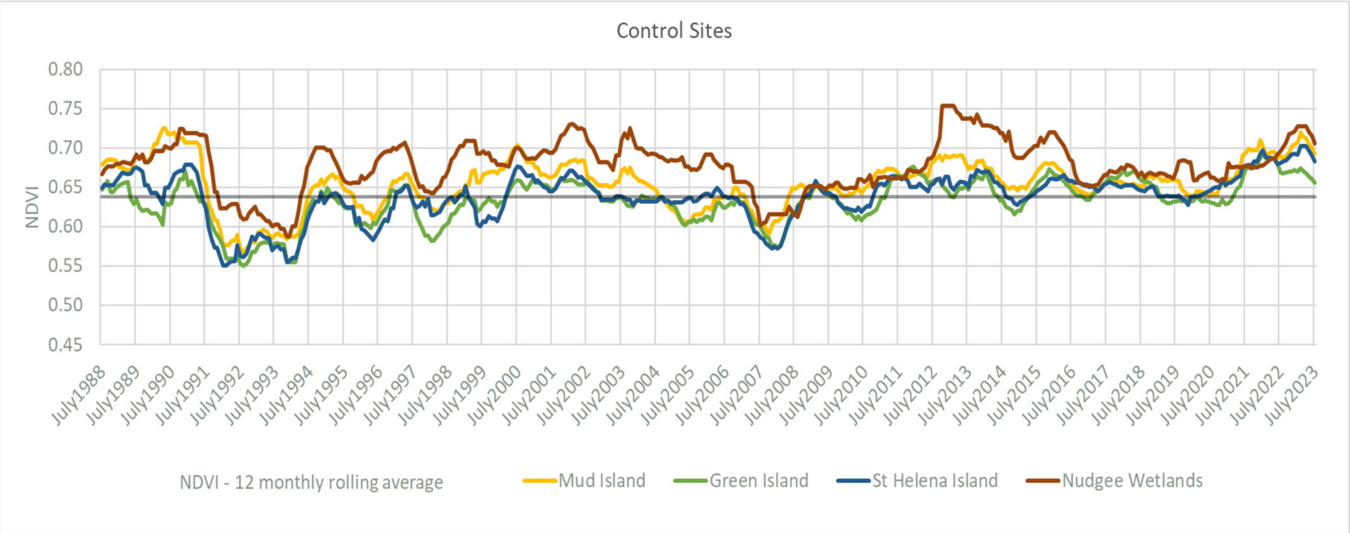


Figure 3.4 Shows 12-month rolling average of NDVI scores for both control and test sites from July 1988 to July 2023

There was a positive association between the 12-motnth rolling average of mangrove condition (i.e., NDVI) and rainfall (r = 0.31, p < 0.0001) over the period of July 1988 to July 2023 (Figure 3.5). This indicates that while there was a positive relationship between rainfall and mangrove conditions, it was not strongly linear, suggesting that other factors may interact with rainfall to control mangrove conditions.

Water availability is one of the key drivers of mangrove conditions and community structure (Hutchings, 1987), and rainfall is just one factor determining water availability. As discussed by BMT WBM (2016), water availability is a function of tidal inundation, groundwater recharge, surface water runoff, and the relationship between these processes varies in time and space. Groundwater tables are often recharged in the magnitude of months, depending on soil type, vegetation community structure, rainfall and ground water (Alongi, 2009). Consequently, there may be a lag between rainfall, groundwater recharge and mangrove response measured in months. Superimposed on this groundwater process are (i) regular tidal flushing (diurnal near sea level, less frequent higher in the profile); (and (ii) irregular surface water runoff. Both processes affect soil salinity and nutrient delivery and may influence mangrove conditions over shorter timescales. Refer to BMT WBM (2016) for a review of these processes.

The El Niño - Southern Oscillation (ENSO) is a key driver of rainfall in the region, therefore relationships between mangrove conditions and the Southern Oscillation Index (SOI) were explored. There was a positive correlation between the 12-motnth rolling average of mangrove condition (i.e., NDVI) and ENSO (r = 0.45, p < 0.0001) over the period of July 1988 to July 2023 (Figure 3.6). BMT WBM (2016) did not find a correlation between these variables, as only linear associations were examined, and sample sizes were smaller.

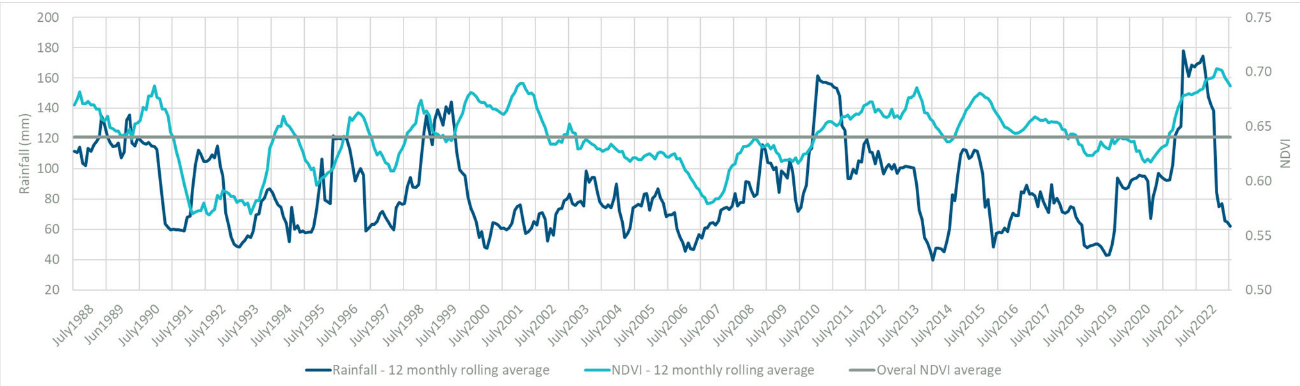


Figure 3.5 12-month rolling average of NDVI score and rainfall from July 1988 to July 2023

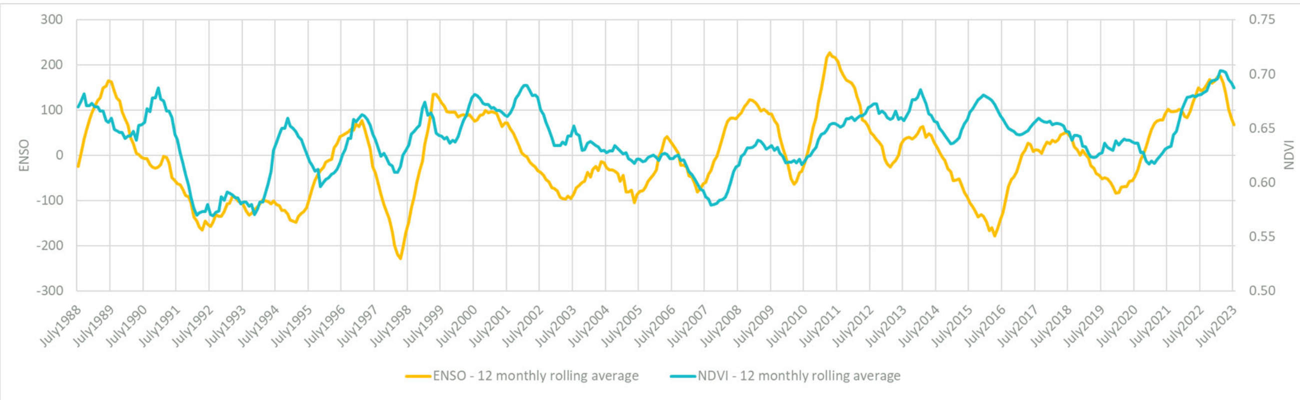


Figure 3.6 12-month rolling average of NDVI score and El Niño–Southern Oscillation (ENSO) from July 1988 to July 2023

ENSO is linked to both rainfall and temperature with periods of positive ENSO bringing higher than average rainfall and lower temperatures and conversely lower ENSO results in less rainfall and warmer higher temperatures. This linkage between the ENSO and rainfall over the period of July 1988 to July 2023 is shown in Figure 3.7. The relationship between the 12-month rolling average of maximum temperature (maximum daily temperatures averaged across each month) was inversely correlated ($r = -0.14$, $p < 0.005$) to the 12-month rolling average of NDVI across the study area NDVI (Figure 3.8).

Time series of NDVI, SAVI, EVI and LAI for the entire Sentinel-2 capture history (2015-2023) show the same annual patterns observed in recent Landsat data (Annex A). Each site shows a relatively consistent pattern with strong correlations among all four indices, a generally flat to slightly inclined trajectory, and the most recent overall minima occurring late in 2019 coinciding with very low rainfall and high temperatures.

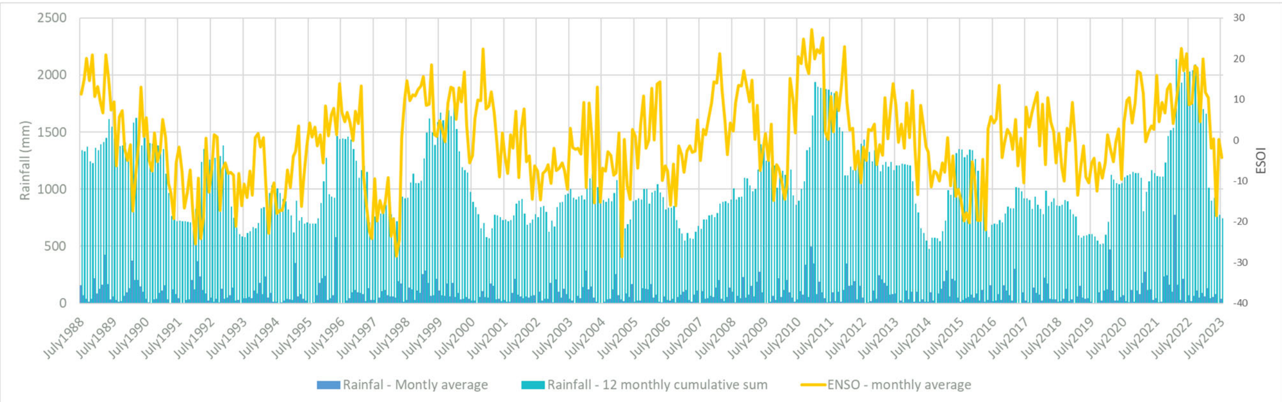


Figure 3.7 Monthly rainfall average, and cumulative rainfall average, and El Niño–Southern Oscillation (ENSO) from July 1988 to July 2023

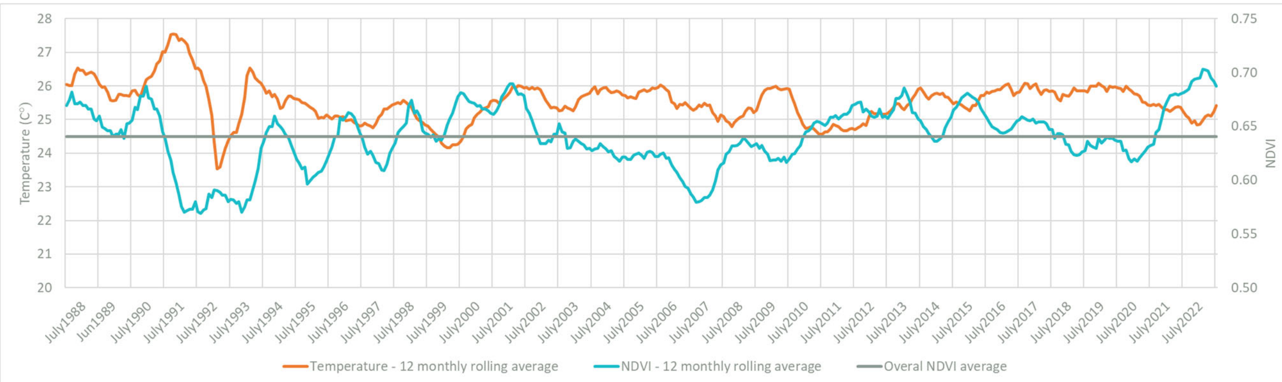
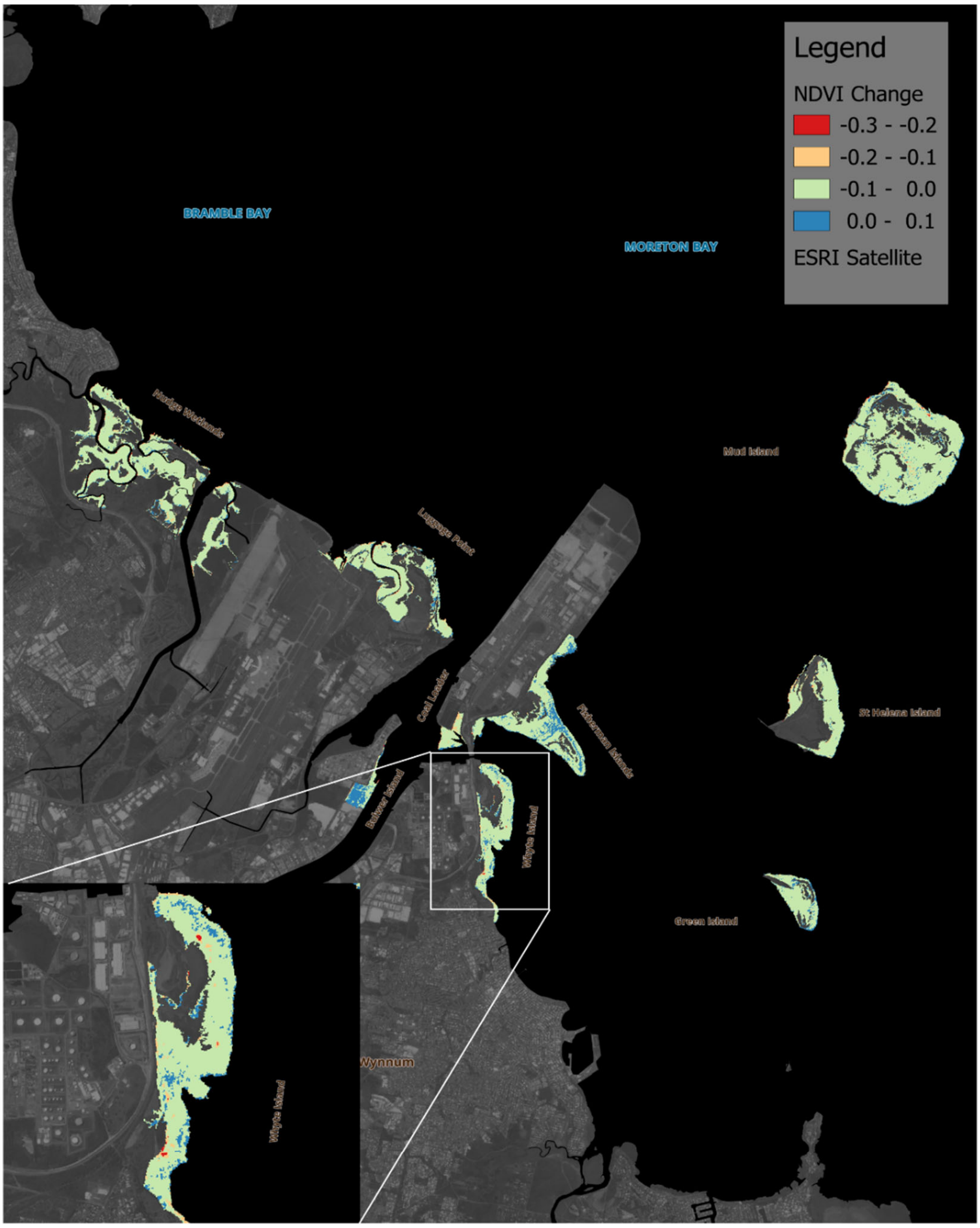


Figure 3.8 12-month rolling average of NDVI score and maximum daily temperature from July 1988 to July 2023

3.2.2 Spatial Trends

While mangrove condition in 2023 was higher than the long-term average, there was not a broad-scale improvement in mangrove condition between 2022-2023. Figure 3.9 is a map of NDVI changes between July 2021 and July 2022. The direction (i.e., improvement, stability, decline) and magnitude of change varied among and within locations. At broad scales, mangrove conditions across all the sites either showed a stable condition or marginal decrease in NDVI value (≤ -0.1), while some patches particularly at Fisherman Islands and Bulwer Island showed a marginal increase in NDVI value (≤ 0.1). Although there were no significant NDVI losses overall, some small patches with a major decrease in NDVI value (≤ -0.3) were observed in several sites including Mud Island, Coal Loader, and Whyte Island. The following subsections describe trends these test sites (Figure 3.10 to Figure 3.15) and confirm the observed data with ground control points (GCP) and aerial imagery. The photographs from the GCPs are presented in Annex B.



Title:
NDVI changes between July 2022 and July 2023 (Sentinel-2)

Figure: 3-9 Rev: A

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N 0 1.5 3 4.5 km

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Filepath: C:\Users\julian.manning\OneDrive - BMT Group Limited\Desktop\BMT\Working\Mangrove\Workbench_2023.qgz

Figure 3.9 NDVI changes between July 2022 and July 2023 (Sentinel-2)

Whyte Island

The vegetation health trend was mostly stable with both marginal increases and decreases overall (Figure 3.9). However, some sporadic small patches of significant NDVI loss were observed at Whyte Island. The calculated NDVI values were 100% confirmed through both GCPs (nine observations) and aerial imagery from July 2023.

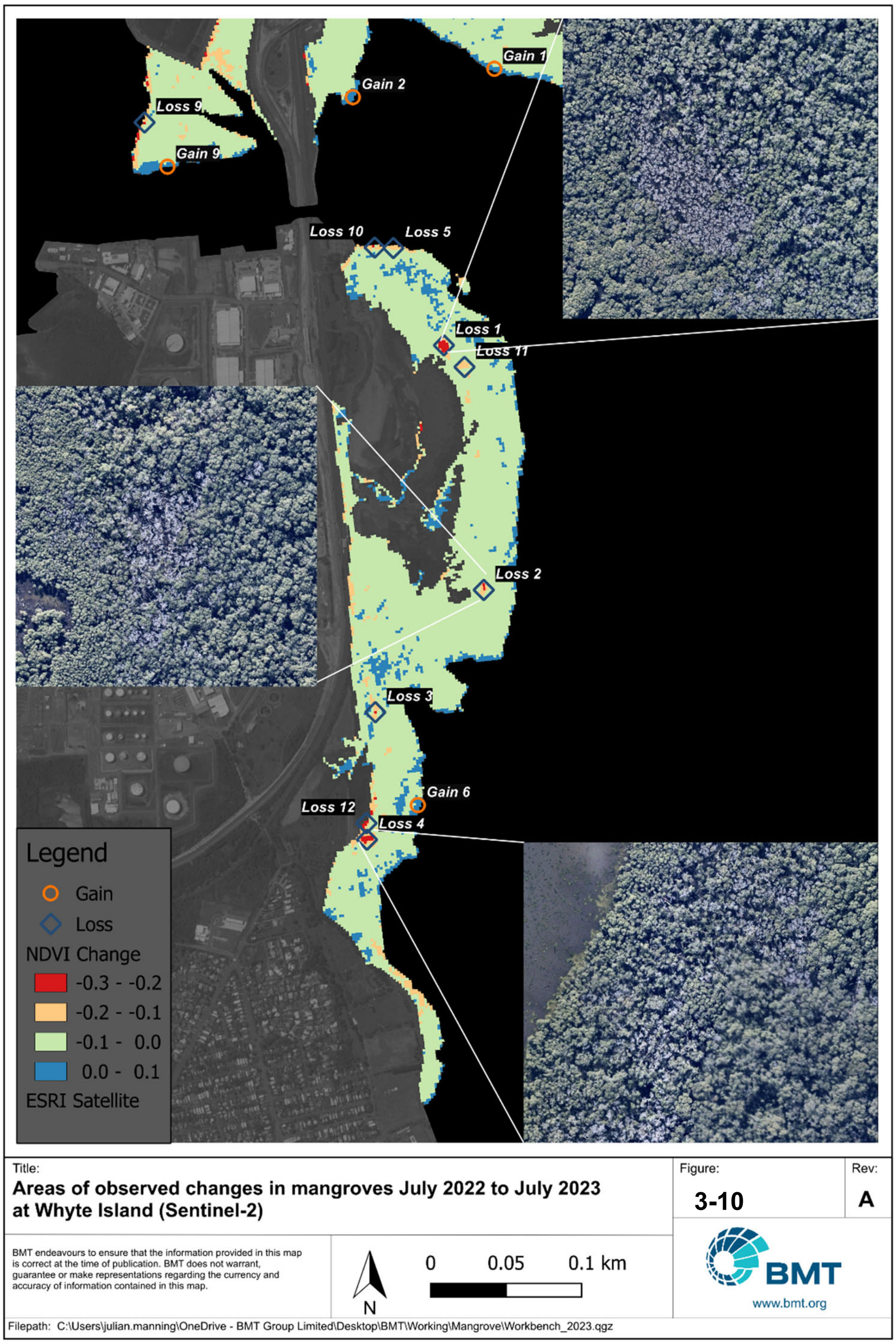


Figure 3.10 Areas of observed changes in mangroves July 2022 to July 2023 at Whyte Island

Bulwer Island

The vegetation health trend was mostly stable or increased marginally particularly at the south-west corner of the mangrove patch (Figure 3.10). The investigation of aerial imagery together with GCPs (four observations) showed the majority of the area is relatively consistent except for some canopy losses around the boundary which could be due to erosion, loss of individual trees or weedy species.

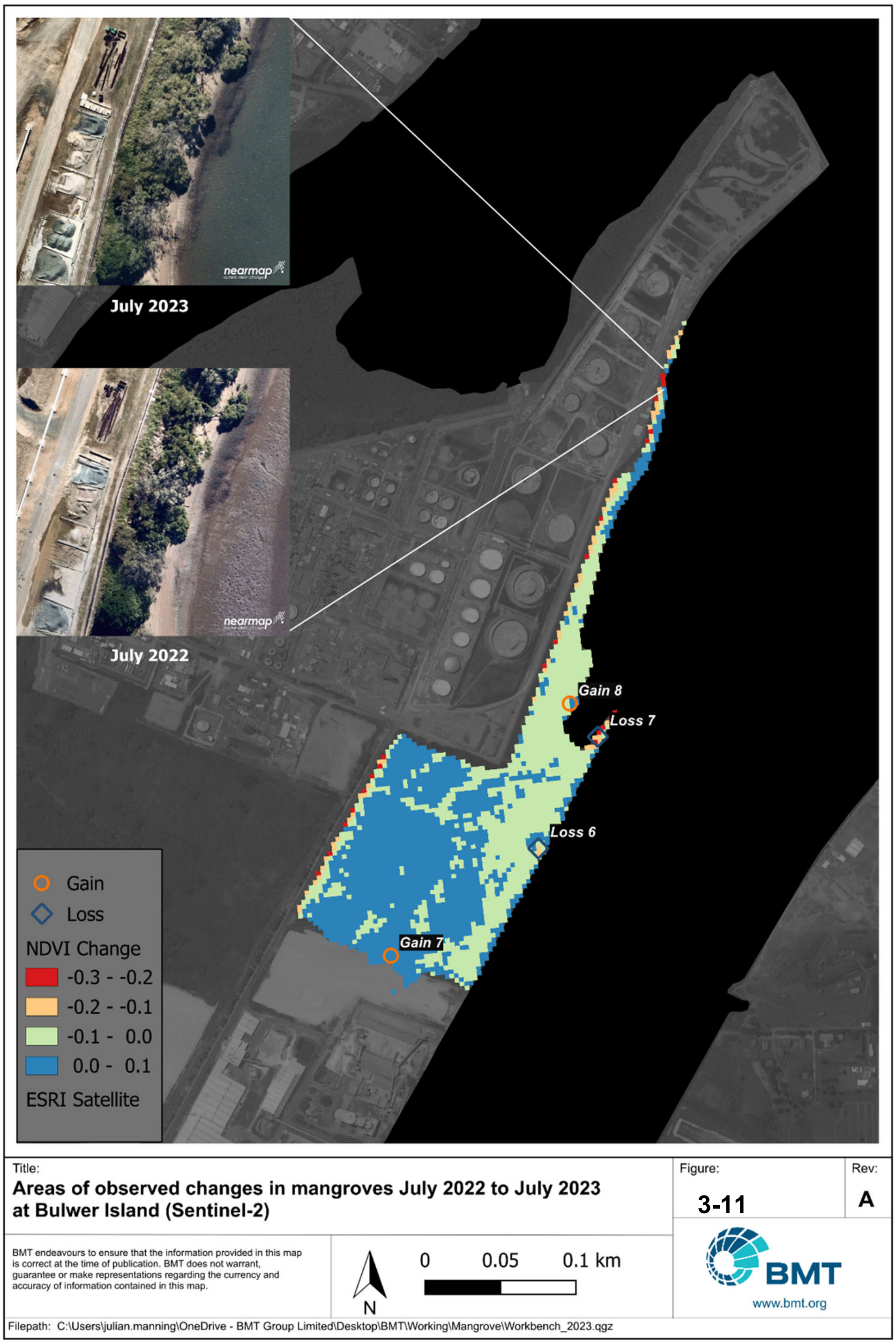


Figure 3.11 Areas of observed changes in mangroves July 2022 to July 2023 at Whyte Island

Coal Loader

The investigation of aerial imagery together with GCPs (two observations) showed that the majority of the area was relatively consistent in terms of mangrove condition (Figure 3.11). However, a moderate decrease in mangrove health was observed at the north and southwest of the site, which might be an early sign of stressed vegetation. The seaward fringe of the site in the south experienced a marginal improvement in vegetation health conditions.

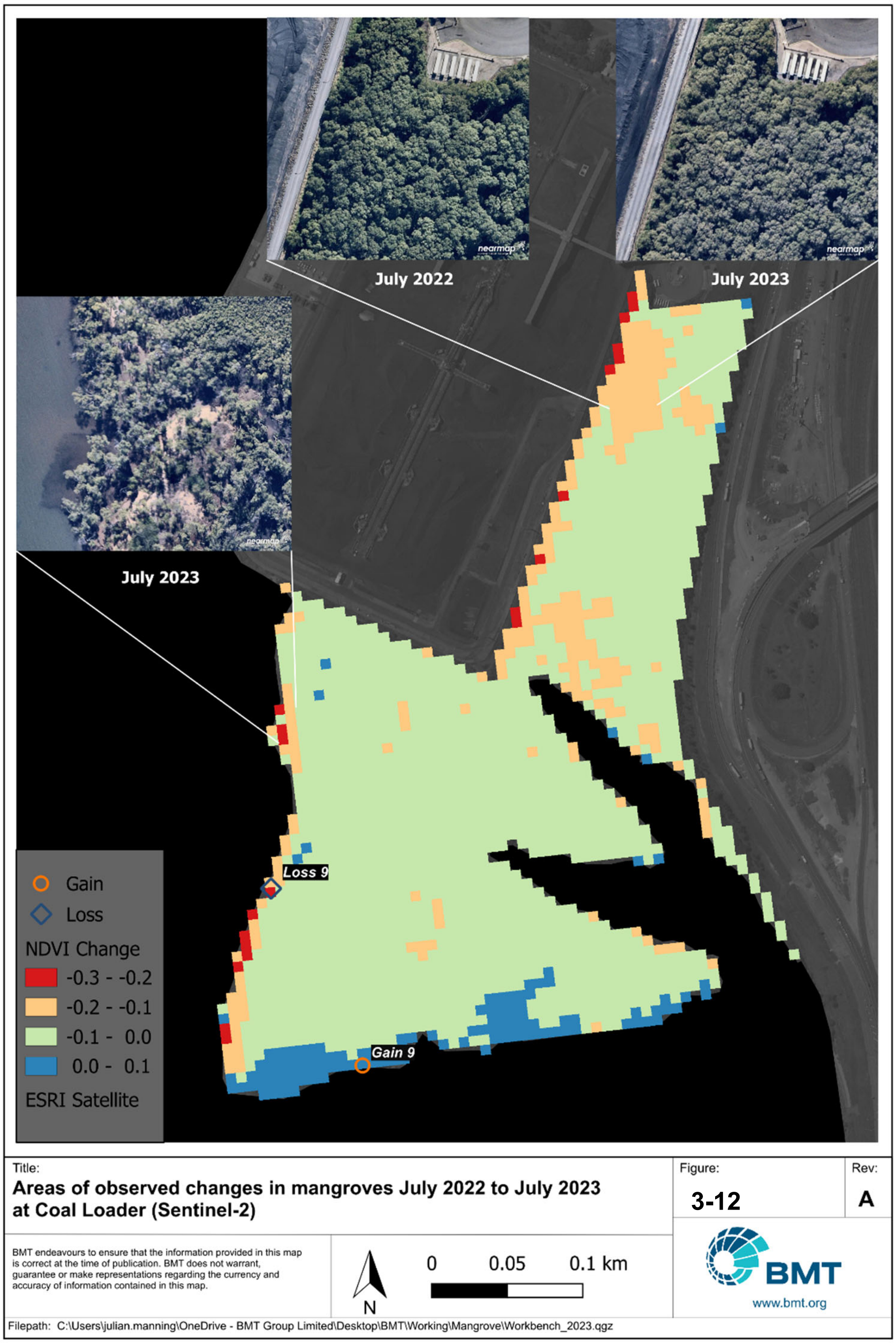


Figure 3.12 Areas of observed changes in mangroves July 2022 to July 2023 at Coal Loader

Luggage Point

The vegetation health trend was mostly stable or marginally declined overall. However, some major declines in vegetation health conditions were observed along the narrow inlet from Moreton Bay into the Luggage Point wetland ecosystem as well as northwest of the site adjacent to the Brisbane Airport. With the absence of GCPs in this site it is not easy to draw a conclusion, but previous reports highlighted some issues with erosion that had resulted in tree fall. It also could be the result of losses in weedy vegetation.

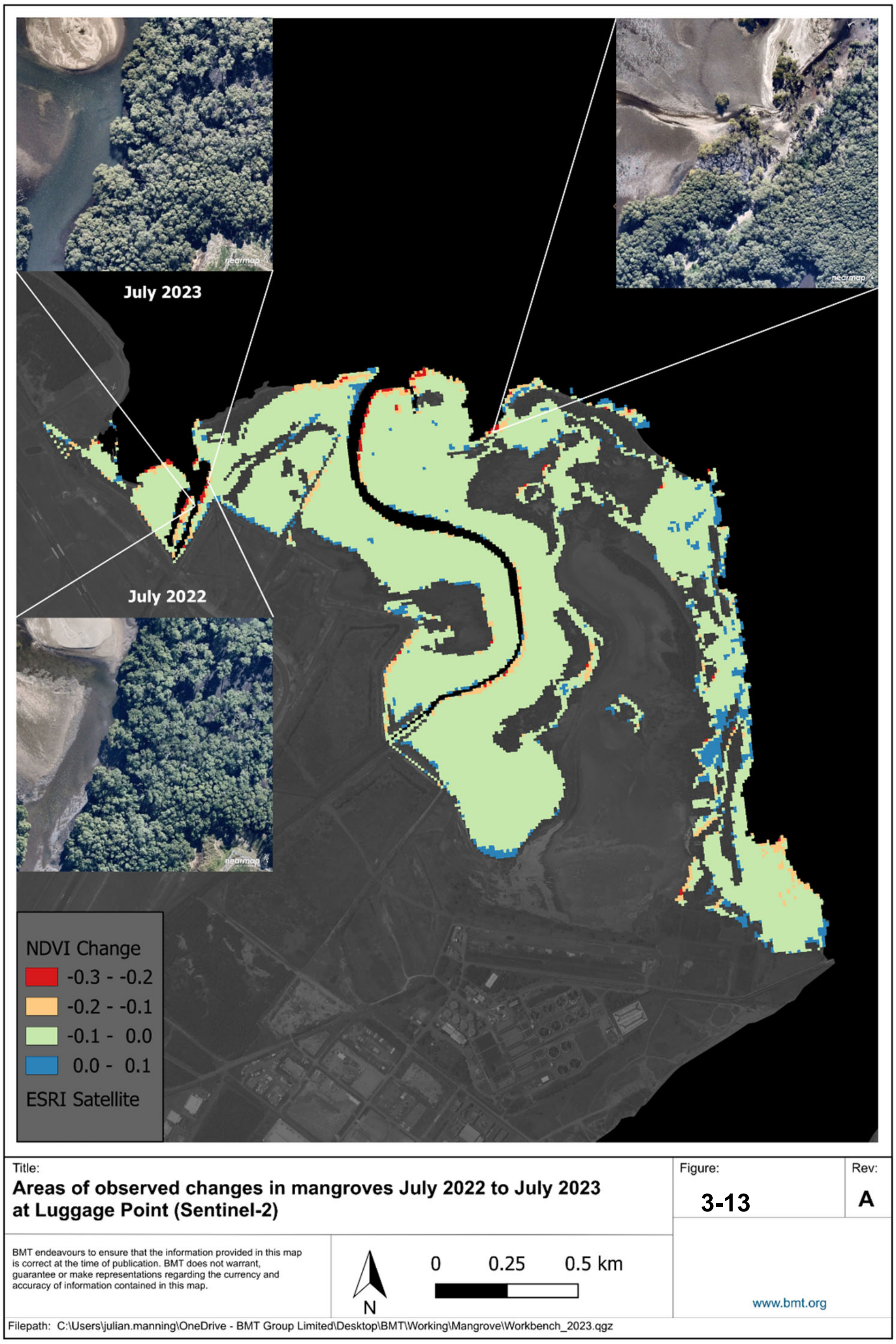


Figure 3.13 Areas of observed changes in mangroves July 2022 to July 2023 at Coal Loader

Fisherman Islands

The vegetation health trend was mostly stable with both marginal increase and decrease overall (Figure 3.13). However, eastern, and northeastern parts of the side had experienced a slight increase in overall health conditions which were confirmed through GCPs. Investigation of the aerial revealed that there are some minor leaf losses in the middle of the southern claypan as well as around the edges of a narrow inlet in the west and the middle of the site.

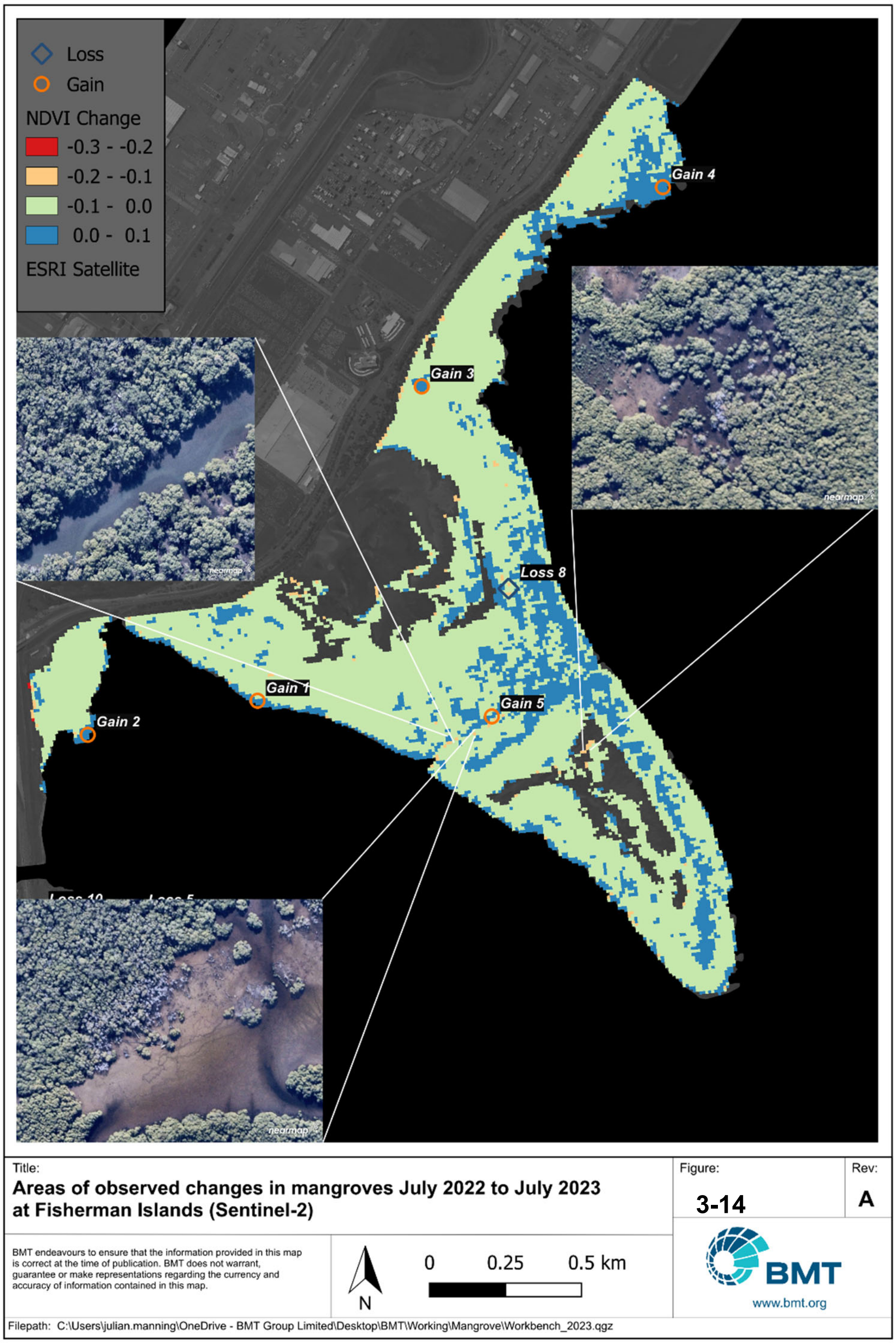
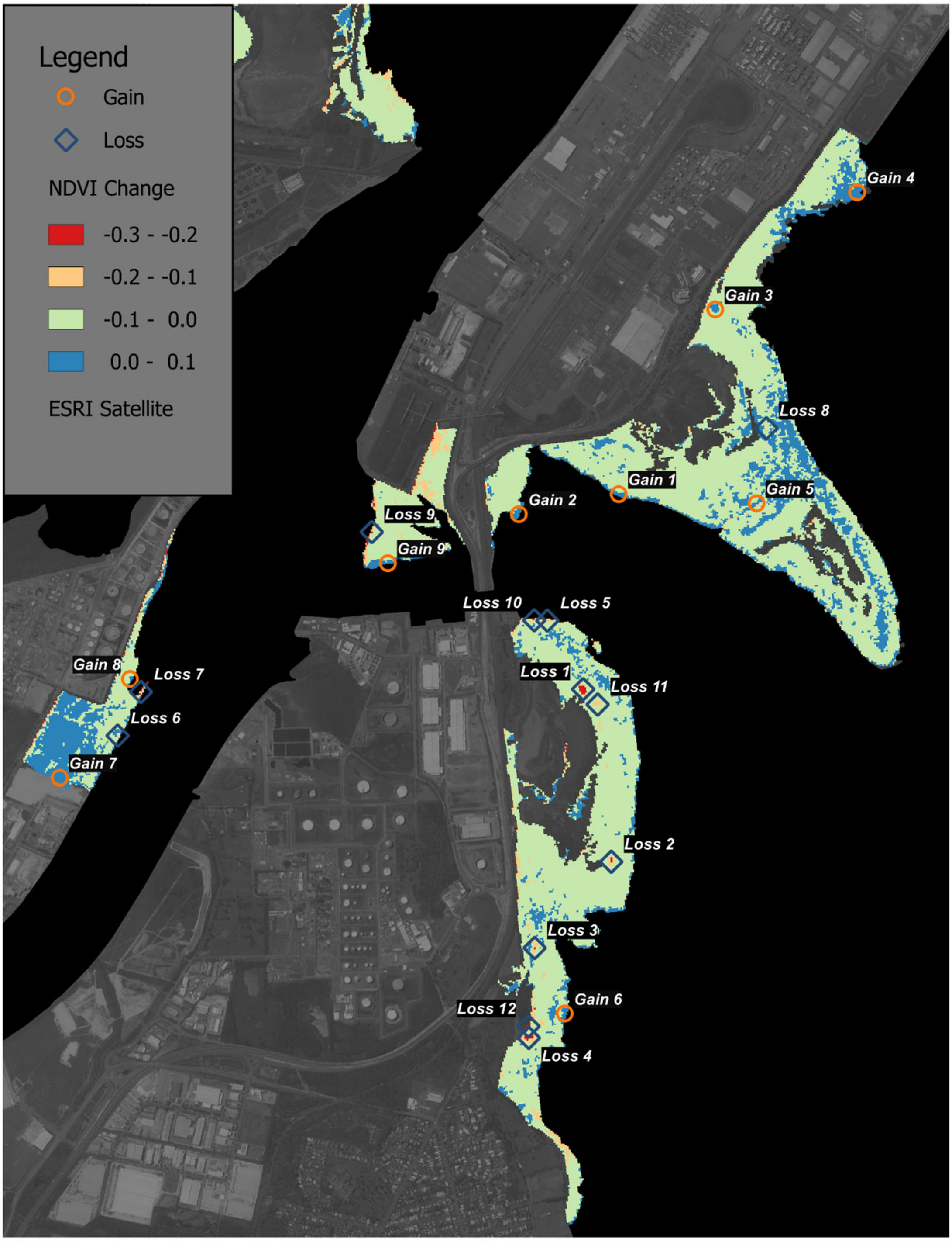


Figure 3.14 Areas of observed changes in mangroves July 2022 to July 2023 at Fisherman Islands



Title:
Ground control points over changes in NDVI, from July 2022 to July 2023

Figure: 3-15

Rev: A

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Figure 3.15 Ground control points over changes in NDVI, from July 2022 to July 2023

4 Conclusion

The present study found that:

Temporal extent: The long-term (July 1988 and July 2023) analysis of 12 monthly rolling averages of NDVI scores at both the test and control sites showed variations both above and below the overall long-term NDVI average. However, the overall condition of all the test and control sites between July 2022 and July 2023 remained above the overall long-term NDVI average. Among the test sites Bulwer Island, Luggage Point, and Whyte Island showed an increase in NDVI while the remaining sites including Fisherman Islands and Coal Loader remained almost stable. Amongst the control sites, Green Island showed a decrease in NDVI while the remaining sites including Mud Island, St Helena Island and Nudgee Wetland remained almost stable.

Spatial extent: While the overall mangrove health condition in 2023 was higher than the long-term average (July 1988 to July 20) there was not a broad-scale improvement in mangrove condition between 2022-2023. The direction (i.e., improvement, stability, decline) and magnitude of change varied among and within locations. At broad scales, mangrove conditions across all the sites either showed a stable condition or marginal decrease in NDVI value (≤ -0.1), while some patches particularly at Fisherman Islands and Bulwer Island showed a marginal increase in NDVI value (≤ 0.1). Although there were no significant NDVI losses overall, some small patches with a major decrease in NDVI value (≤ -0.3) were observed in several sites including Mud Island, Coal Loader, and Whyte Island.

Bulwer Island: rehabilitation works has resulted in improve tidal flushing of mangrove forests in the main (southern) portion of the forest. Some minor tree falls had been observed in previous monitoring near the rehabilitation site (i.e. prior to the rock wall breach), but since this time mangroves remain stable and healthy. The largest changes in mangrove condition (positive and negative) were observed in the narrow mangrove fringe on the northern tip of the island, remote from the rehabilitation works. Canopy losses on the northern tip the boundary could be due to erosion, loss of individual trees or weedy species. Gains were also observed on the northern tip. Overall, there was a net gain in mangrove extent of around 1 ha at Bulwer Island between 2022-2023.

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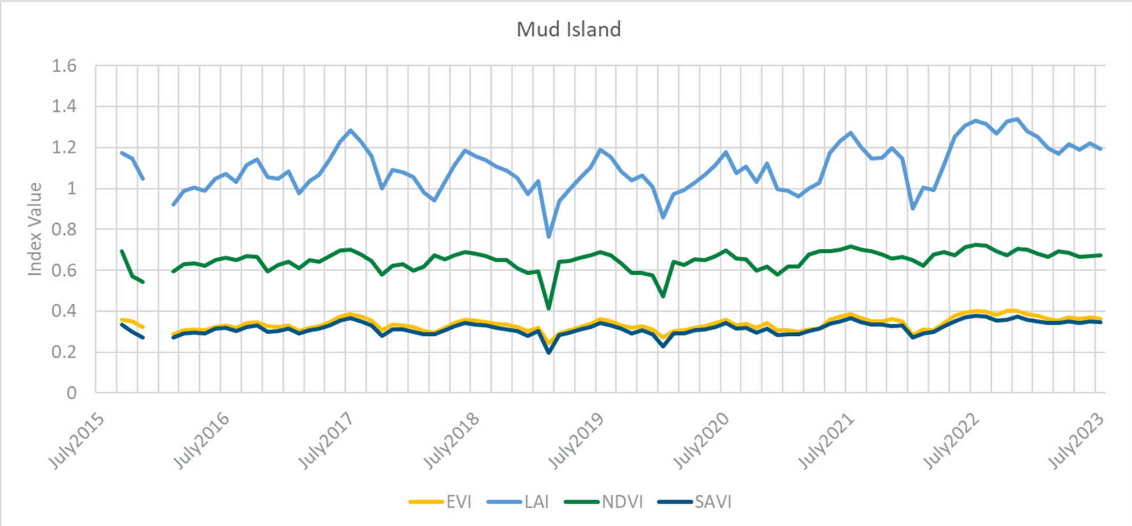
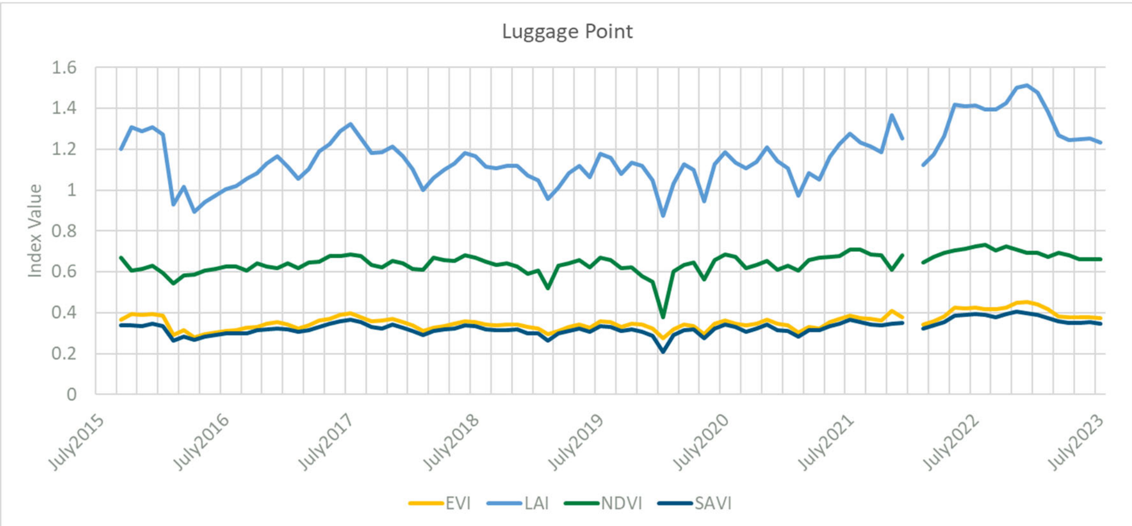
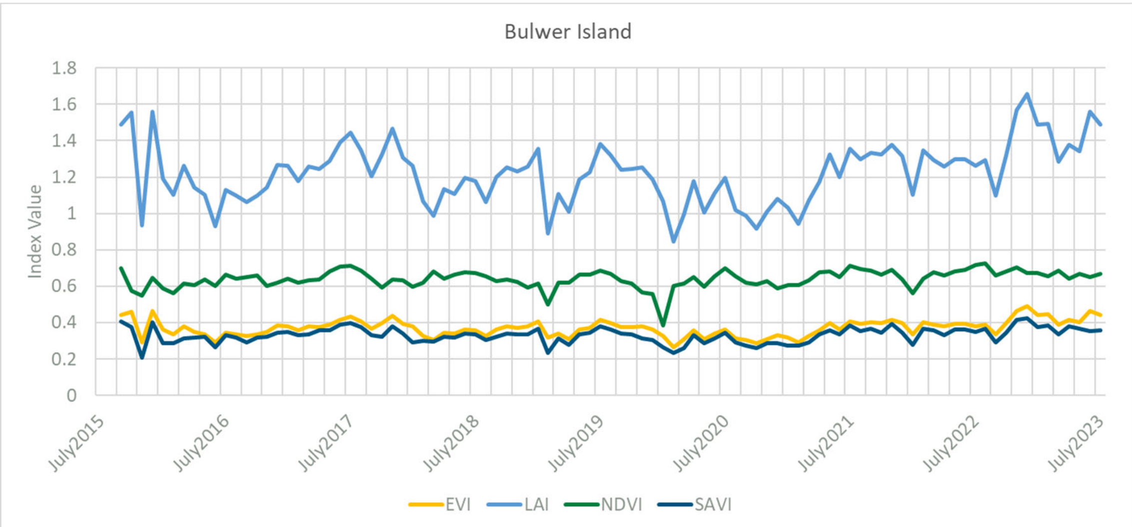
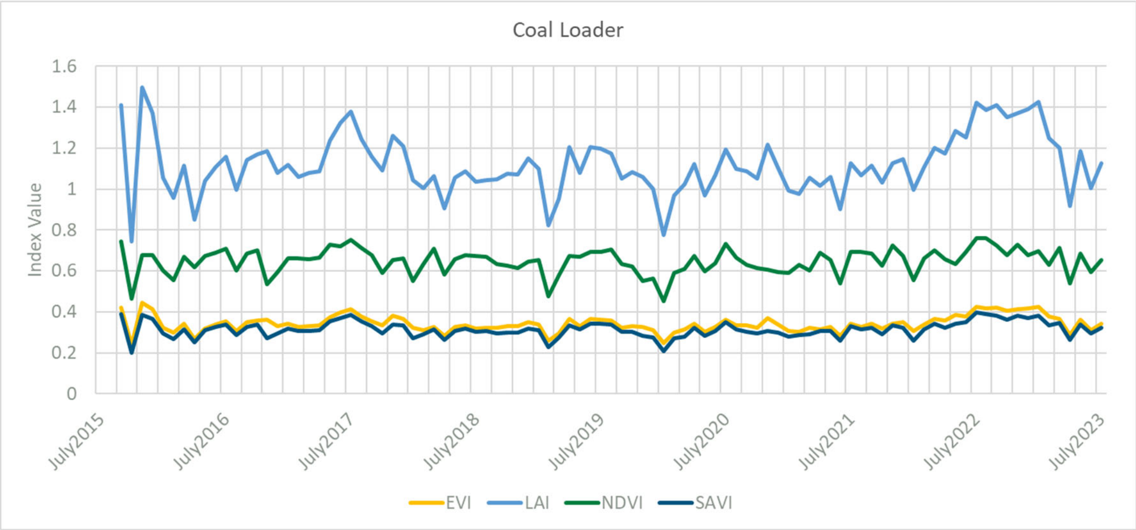
Annex A Sentinel-2 Monthly Vegetation Indices





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1
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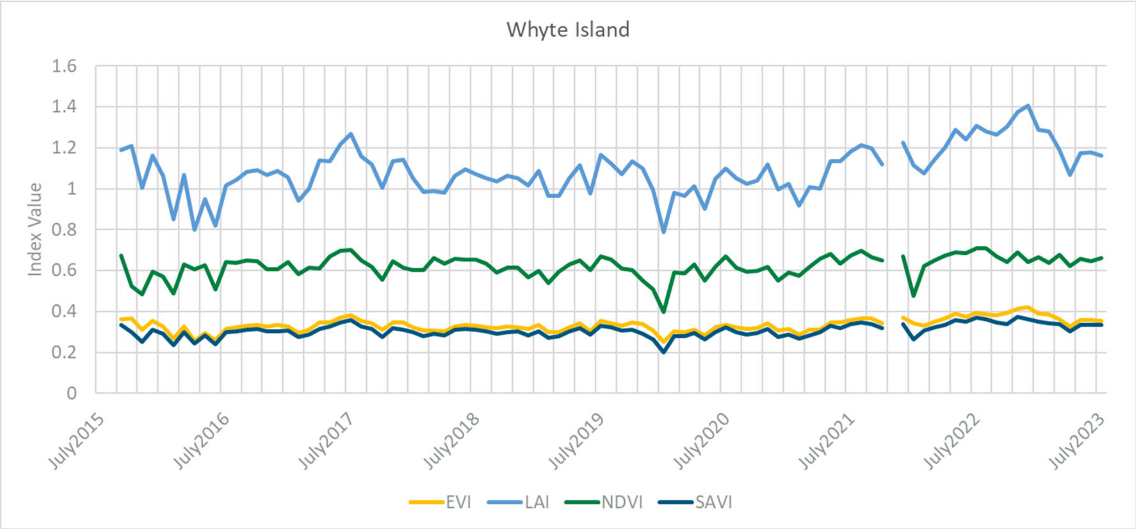
July2017
July2018
July2019
July2020
July2021
July2022
July2023
EVI
LAI
NDVI
SAVI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0.2
0
Index Value
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July2016
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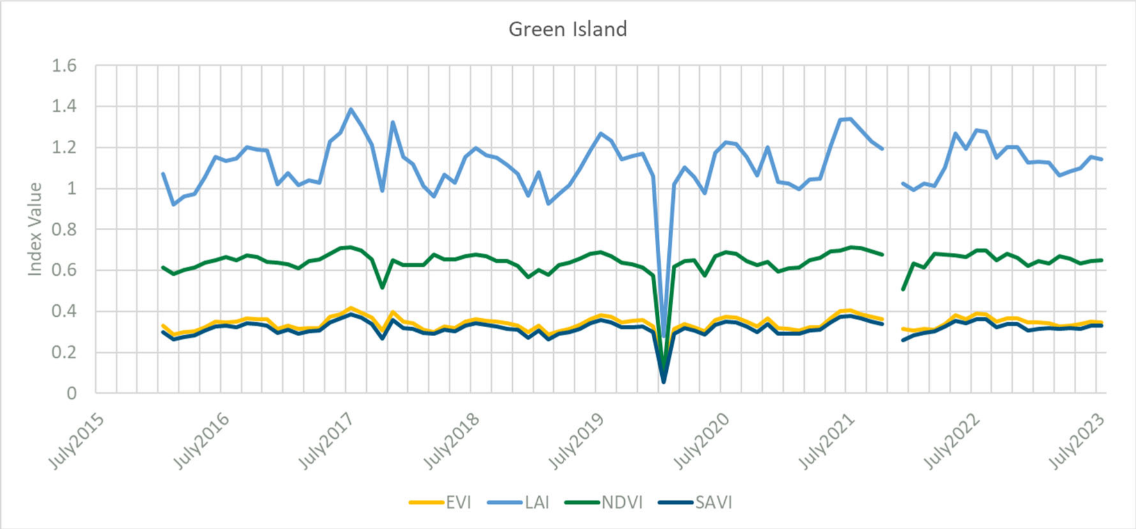
July2018
July2019
July2020
July2021
July2022
July2023
EVI
LAI
NDVI
SAVI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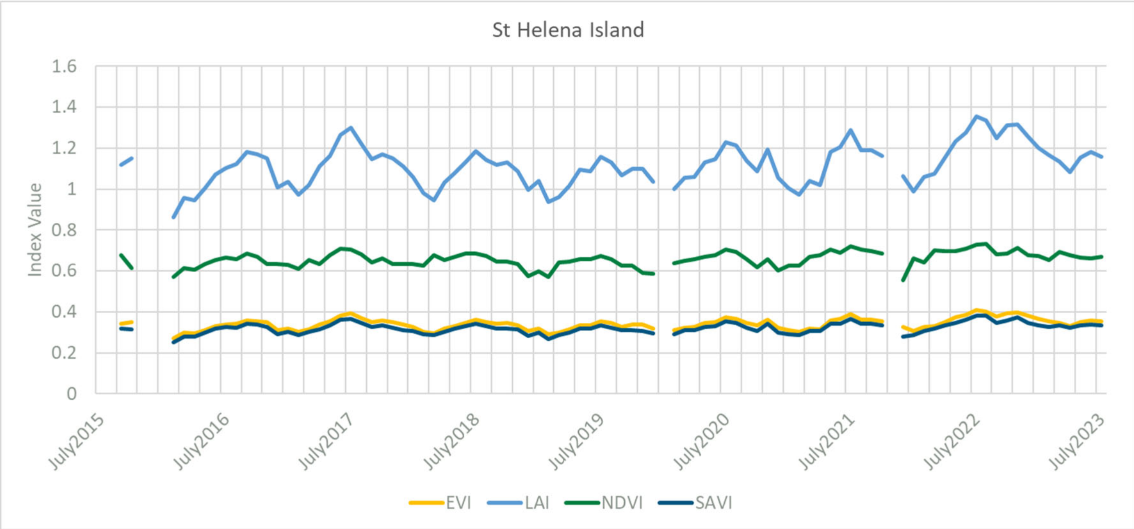
July2022
July2023
EVI
LAI
NDVI
SAVI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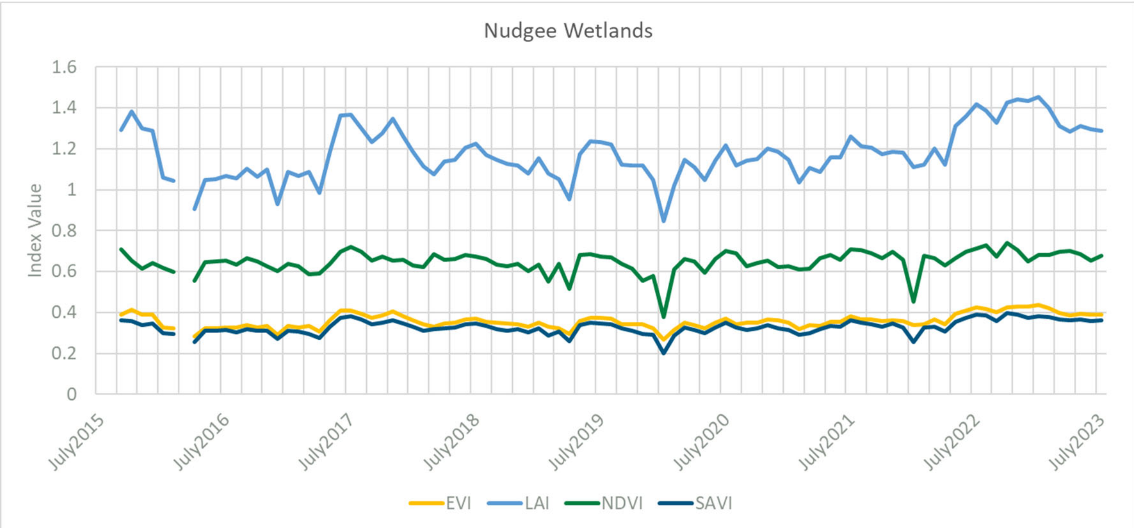
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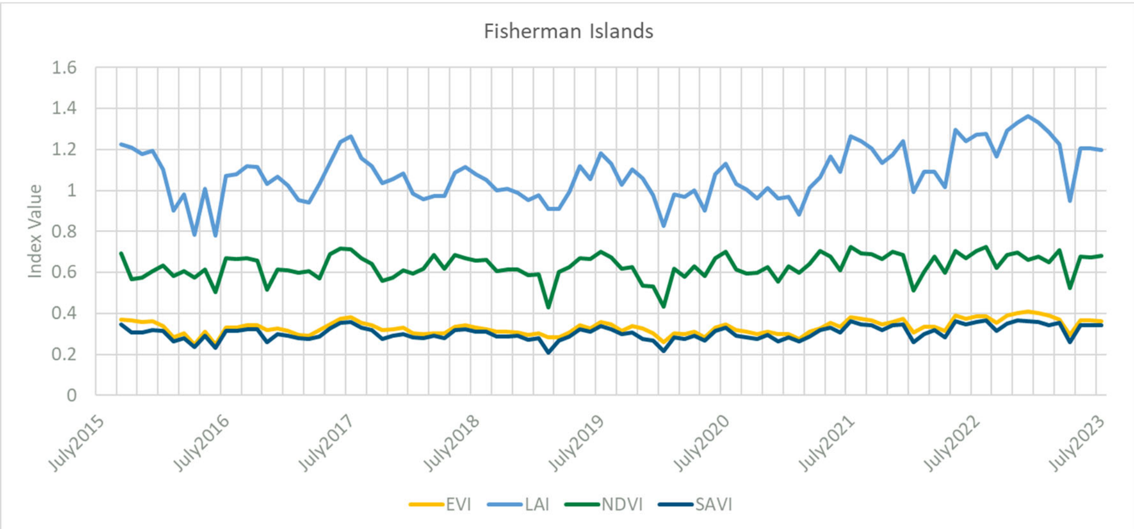
EVI
LAI
NDVI
SAVI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LAI
NDVI
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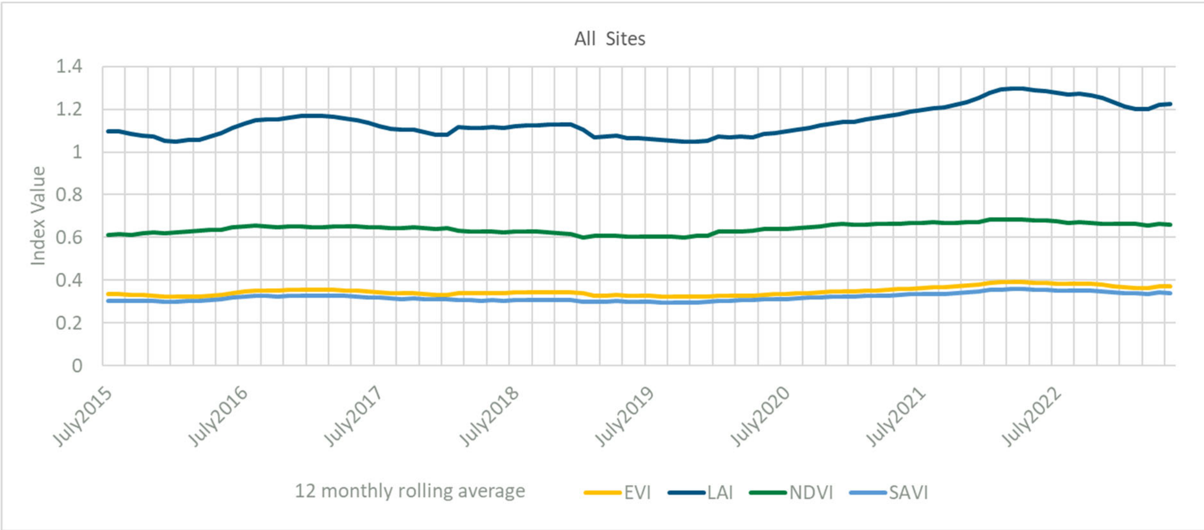


Figure 5.1 Time-series of NDVI, SAVI, EVI and LAI from Sentinel-2 between July 2015 and July 2021 for individual sites (monthly average) and all sites (12-month rolling average)

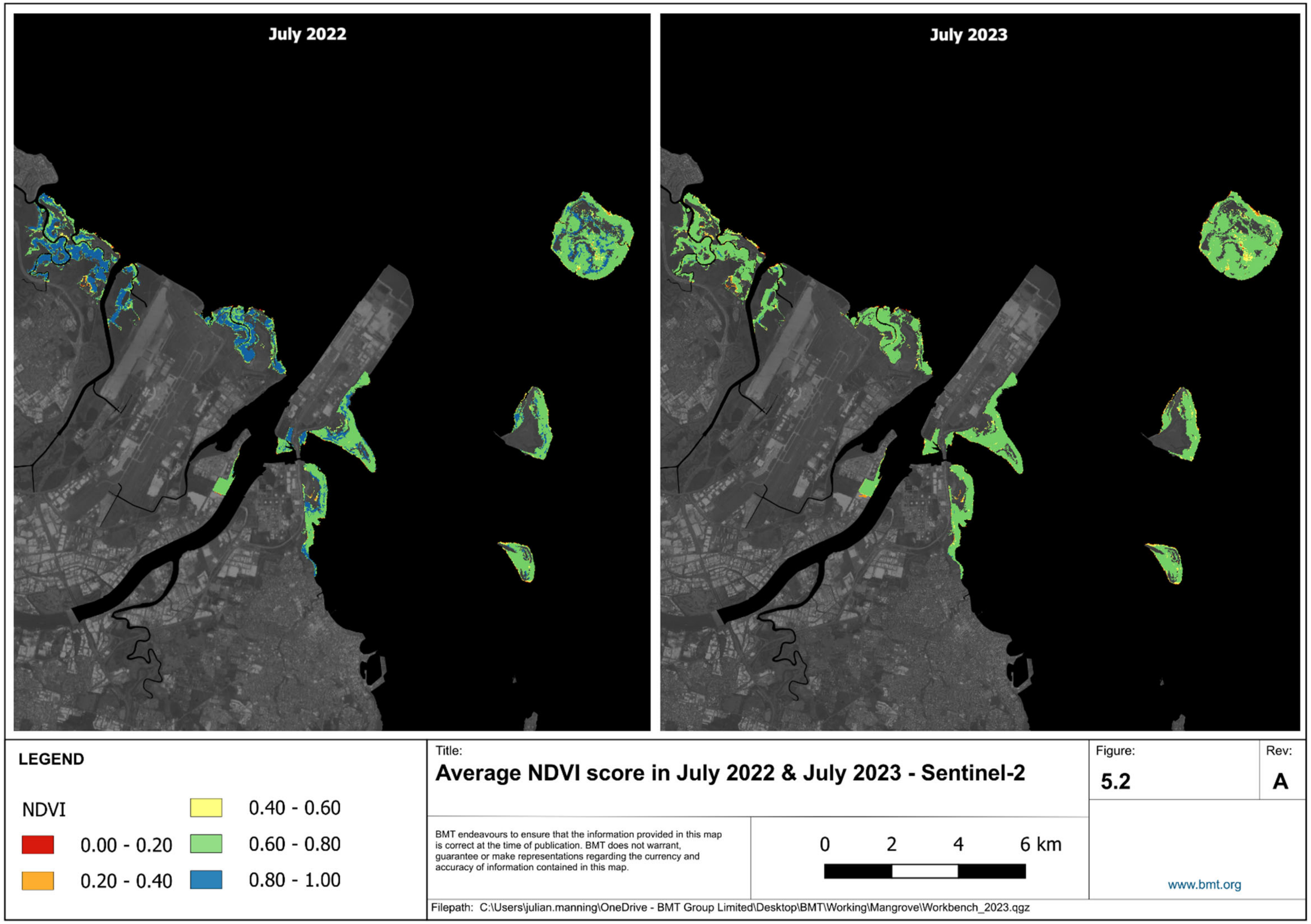


Figure 5.2 Average NDVI score in July 2022 and July 2023 – Sentinel-2

Annex B Field Photos

Whyte Island

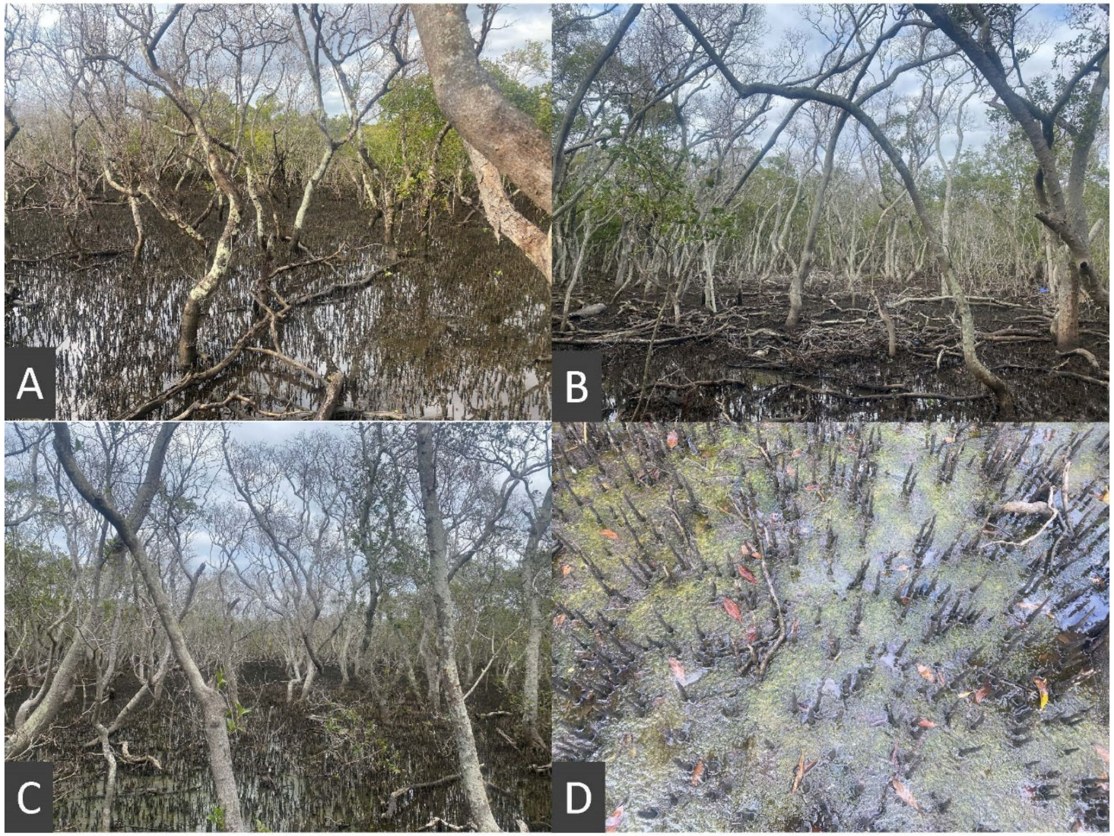


Figure 5.3 Whyte Island—a) Loss 1 site—Little to no evidence of regeneration at the site. Some evidence of sapling recruitment on the fringes of the dead zone. Strong sulphur odours present ; b) Loss 2 site—Evidence of loss of mangrove trees (~8-9 m tall) ; c) Loss 3 site—Evidence of loss of mangrove trees (~8-9 m tall). Moderate sulphur odour present. ; d) Loss 12 site— Strong sulphur odour and algae scum present

Bulwer Island

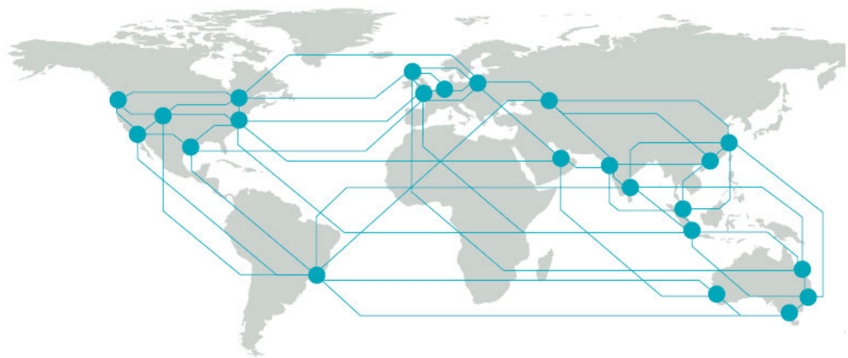
Figure 5.4 Bulwer Island—e) Gain 7 site—Successful recruitment of mangrove saplings (~1-4 m tall) with dense mats of saplings in the understorey. ; f) Loss 7 site—Some defoliation on mangrove canopy and some fallen mangroves in the understorey.; g) Gain 8 site—Mangrove canopy has dense and green foliage, however no evidence of recruitment. ; h) Logging on western edge of Bulwer Island adjacent to Tingira Rd.

Coal Loader

Figure 5.5 Coal Loader—i) Loss 9 site—Moderate die back with some fallen mangroves in the understorey.; j) Loss 9 site— Moderate defoliation on mangrove trees; k and l) Gain 9 site— Successful sapling recruitment

Fisherman Islands

Figure 5.1 Fisherman Island— m) Gain 4 site—Evidence of some sapling recruitment; n) Gain 3 site—Evidence of few saplings in the understorey. Some defoliation in the larger mangrove species; o) Gain 1 site—successful recruitment of saplings and recruitment of seedlings. Evidence of a patchy overstory coverage ; p) Gain 2 site—Successful sapling recruitment with minimal defoliation in the overstory canopy



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