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Mangrove Health Assessment: 2014 Monitoring Results

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Mangrove Health Assessment: 2014 Monitoring Results

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Synopsis: **Mangrove monitoring is undertaken at the Port of Brisbane on a biennial basis. Monitoring encompasses four broad components: mangrove health mapping, photographic monitoring, sediment quality and pore water salinity. This report presents the results of the most recent monitoring event, conducted in June 2014.**

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Executive Summary

Introduction

The Port of Brisbane Pty Ltd (PBPL) undertakes biennial monitoring of mangrove health in the Fisherman Islands area as part of its environmental monitoring program. The mangrove health assessment is comprised of four components:

1) Mapping mangrove health;
2) Photographic monitoring;
3) Sediment quality; and
4) Pore water salinity.

Mangrove Health Results

The distribution and patterns of mangrove health were generally consistent to those recorded in 2012. There was however a decline in mangrove health across the study area since the 2012 survey. Key areas exhibiting a decline in mangrove health included (by category):

- *Dead* – Patches of dead mangroves mapped towards the outer seaward boundaries around Whyte island and the eastern section of Fisherman Islands;
- *Recently dead* – New patches of recent dieback observed across Fisherman Island, including the outer boundaries of the northern, western and eastern sections, as well as the Coal Loading Area; and
- *Poor* – There was an increase in the area of mangroves in poor condition across Fisherman Islands, including significant bands towards the eastern boundary of both the western and eastern sections, and areas on the outer boundary of the Coal Loading Area.

Mangrove recovery was also observed but typically in small and/or isolated areas, including:

- Continued establishment of regrowth mangrove vegetation, at two photographic monitoring sites (western and eastern sections of Fisherman Islands), and where regrowth had previously been mapped at the eastern section of Fisherman Islands; and
- Improved saltmarsh condition and extent at one photographic monitoring site at Fisherman Islands.

Environmental Factors

To date, examination of potential causal factors as part of this monitoring program has concentrated on sediment quality and pore water salinity, which have returned mixed results in terms of correlation with mangrove health.

Up until 2010, pore water salinity was greatest in the most degraded areas. While this trend has been less pronounced during the last two surveys, pore water salinity remained lowest within the 'good' mangrove health category compared to the degraded mangrove categories (i.e. fair to dead) at the same location. Areas of dead mangroves and mangroves in poor condition were typically associated with ponded surface water, which usually indicates inadequate drainage and poor tidal flushing, and can lead to degraded water quality over time.

Sediment concentrations of nickel and *p,p'DDE* exceeded toxicity trigger values in areas, but not consistently in degraded mangrove areas. Previous investigations by WBM suggested a potential linkage between mangrove health, and nutrient and contaminant (metals, TPH) concentrations at Whyte Island. It is recommended that additional sampling of contaminants from within the 'dead mangrove' centre of Whyte Island be undertaken to determine potential linkages with mangrove health.

Other factors contributing to mangrove degradation across the study area were observed during the survey, most notably:

- *Sediment deposition* – Where new dieback and poor condition mangroves were mapped at the (eastern) Coal Loading Area, there was a substantial build-up of sand among the mangroves. This sediment had buried mangrove pneumatophores, and is presumably the key factor causing the decline in mangrove health in this area.
- *Ponding water* – Aside from the range of secondary effects occurring that are associated with ponding water and may contribute to poor mangrove health (i.e. reduced water quality, anoxic conditions, macroalgal mats, reduced benthic diversity and associated bioturbation etc.), ponding water alone can be detrimental to mangrove health by impairing mangrove respiration.

Conclusion

While mangrove forests across the Fisherman Islands and Whyte Island were mostly in good to fair condition, there were extensive areas of dead or dying mangroves, consistent with the steady decline in mangrove condition observed over the last two decades. There is presently insufficient information to assess long term trends in coastal saltmarsh extent and condition. This vegetation community is listed as a Vulnerable Ecological Community under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*, and is considered particularly vulnerable to altered hydrology and invasion by mangroves.

Historical clearing and reclamation projects at the Port have resulted in major changes to mangrove forest extent within the study area (WBM 2000). However, the relative influence of these historical activities compared to contemporary processes on patterns in mangrove health have not been determined to date. Given current trends, it is expected that there will be further mangrove degradation unless key stressors can be effectively identified and mitigated.

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1 Introduction

1.1 Background

The Fisherman Islands area at the mouth of the Brisbane River contains large areas of remnant mangrove forest. Parts of the mangrove forest are located within Moreton Bay Ramsar site, a wetland of international significance protected under the *Environment Protection and Biodiversity Conservation Act 1999*.

The Port of Brisbane Pty Ltd (PBPL) undertakes biennial monitoring of mangrove forests in the Fisherman Islands area as part of its environmental monitoring program. Following the first quantitative assessment of mangrove dieback at the Port of Brisbane during a mangrove health assessment in 1999 (WBM 2000), monitoring of mangrove health and distribution was again undertaken at Fisherman Islands and Whyte Island in 2002 (WBM 2002a, b) and has continued biennially since (i.e. FRC Environmental 2004, 2006, 2008a, b, 2010, 2012). Previous monitoring also included the establishment of photographic monitoring sites and assessments of sediment quality from 2000 onwards, and pore water quality (salinity) since 2008.

The present mangrove health assessment incorporates four monitoring components, including:

1) Mapping mangrove health;
2) Photographic monitoring;
3) Sediment quality; and
4) Pore water salinity.

This report presents the results of the 2014 mangrove health assessment, together with discussion highlighting key changes since the previous survey and other relevant comparisons with past monitoring results.

1.2 Aims and Objectives

There are two primary objectives of the PBPL's overall environmental monitoring program:

1) To assess the health and long tern trends in the condition of the environment to determine the potential environmental effects of the port
2) Provide information that supports and informs port planning and management activities.

Specific aims of the mangrove health assessment are to:

- Determine and map current mangrove health condition and distribution at Fisherman Islands (including the Coal Loader area) and Whyte Island
- Photograph mangrove communities at each of the permanent photographic monitoring sites
- Assess sediment quality within the study area in terms of both nutrients and potential contaminants
- Assess pore water salinity along previously surveyed pore water transects

- Compare current data, for all parameters above, with that acquired during past surveys to identify recent changes, key trends and any relevant correlations
- Discuss recent results, particularly changes in mangrove health, in the context of potential causes and recommended future actions.

1.3 Study Area Context

The Port of Brisbane is located at Fisherman Islands, which is situated at the mouth of the Brisbane River. Port facilities have been established on land reclaimed over a shallow tidal river delta, including a series of low-lying mangrove islands. Significant intertidal mangrove and saltmarsh communities continue to occur at various locations at the Port of Brisbane and adjacent surrounds, most notably along the south-eastern side of Fisherman Islands and on the eastern side of Whyte Island. The study area for the monitoring program (Figure 1-1) essentially encompasses all mangrove communities in, or adjacent to PBPL controlled lands.

Mangroves within the study area are diverse in a western Moreton Bay context, with five of the eight mangrove species known to occur in the wider Moreton Bay area recorded here to date. Mangrove forests, together with extensive areas of saltmarsh vegetation, clay pans and unvegetated sediments, form a complex mosaic of intertidal habitats. Mangrove and saltmarsh species recorded in the study area throughout the monitoring program to date are listed in Table 1-1.

Table 1-1 Mangrove and saltmarsh species present in the study area

Scientific name	Common name
Mangrove	
Avicennia marina	grey mangrove
Aegiceras corniculatum	river mangrove
Rhizophora stylosa	red mangrove
Bruguiera gymnorrhiza	orange mangrove
Ceriops tagal	yellow mangrove
Saltmarsh	
Sesuvium portulacastrum	sea purslane
Enchylaena tomentosa	ruby saltbush
Suaeda australis	seablite
Suaeda arbusculoides	seablite
Sarcocornia quinqueflora	beadweed

Surrounding lands are predominantly used for port operations and associated industries. These primarily include: container handling; coal loading; cement, bitumen and grain handling, a major oil refinery; sewage treatment plant; and accompanying industrial/commercial precincts.

Title:

Study Area Location

Figure: 1-1

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2 Methodology

2.1 Mangrove Health Mapping

2.1.1 Field Surveys

Mapping aspects of the monitoring focussed on obtaining a spatial record of mangrove health and condition, as well as related parameters such as mangrove extent, mangrove community composition and structure. Using global positioning systems (GPS) with a horizontal accuracy of ± 1 m, each of the sites established during past monitoring (refer 'photo-monitoring' sites in Figure 2-1) were sampled. Numerous additional survey points were also regularly recorded for ground truthing purposes while traversing the study area, particularly along the perimeters of areas where there was a change in mangrove condition and die-back areas. Recent aerial photography was examined prior to the survey to ensure the survey effort targeted any likely 'hot spots' of new mangrove degradation, i.e. suspected dieback not captured on past mapping.

Each site was classified by assigning a qualitative (observed) measure of its apparent health, in line with the categories listed in Table 2-1 (FRC Environmental 2012).

Table 2-1 Mangrove health categories used for mapping assessments (FRC Environmental 2012)

Grade	Category	Criteria
Mangroves		
1	Dead mangroves /bare substrate	No leaves or twigs, sometimes no small branches on mangroves. Trees have typically been dead for years (i.e. stags). This category also includes bare substrates without mangrove stags, which includes saltpan (both disturbed and undisturbed - see Section 4.2.1) and areas where mangroves stags are no longer evident
2	Recently dead	Leaves brown or absent with no new growth (note: while trees appear to be dead, they can sometimes regrow)
3	Poor	Significant leaf yellowing and deformation; reduced canopy cover, insect damage prominent and abundant epicormic growth
4	Fair	Most leaves green with <20% of the canopy affected by yellowing, deformation and insect damage
5	Good	Green leaves with no yellowing or deformation; little evidence of insect damage and no abnormal leaf abscission (loss)
6	Regrowth	Canopy short but healthy and new trees (or established seedlings/saplings) evident; new growth shooting from the base or trunks of older trees; previous disturbance such as dead trees sometimes evident
Other habitat type		
7	Saltmarsh	Area dominated by saltmarsh vegetation; few or no mangroves present

Numerous health indicators were recorded at each site, along with information on the mangrove community composition and structure. The following parameters were recorded based on visual observations:

- Mangrove species present (noting dominant species)
- Canopy cover
- Leaf colour
- Extent of leaf loss and insect damage
- Extent of epicormic growth
- Pneumatophore condition
- Seedling density
- Occurrence of epiphytic algae, algal mats, and seagrass or macroalgae wrack
- Indicative macrofauna abundance rank (based on burrow numbers)
- Notes on any relevant features potentially affecting mangrove health (e.g. water ponding).

2.1.2 GIS Mapping

High resolution 'Nearmap' aerial photography (dated April 2014) was geo-referenced and the extent of the following features was digitised using MapInfo software:

- Mangrove condition categories presented in Table 2-1
- Mangrove regrowth
- Saltmarsh.

This preliminary map was overlain with the field survey coordinates and categories, and then thematically mapped to create a map showing multiple polygons representing areas of similar mangrove health/condition. Mapping is presented for five geographic locations:

1) Northern section (Fisherman Islands)
2) Western section (Fisherman Islands)
3) Eastern section (Fisherman Islands)
4) Coal loading area section (Fisherman Islands)
5) Whyte Island.

Each map was compared with the previous maps of the study area (particularly FRC Environmental 2012) to identify the major changes in mangrove health.

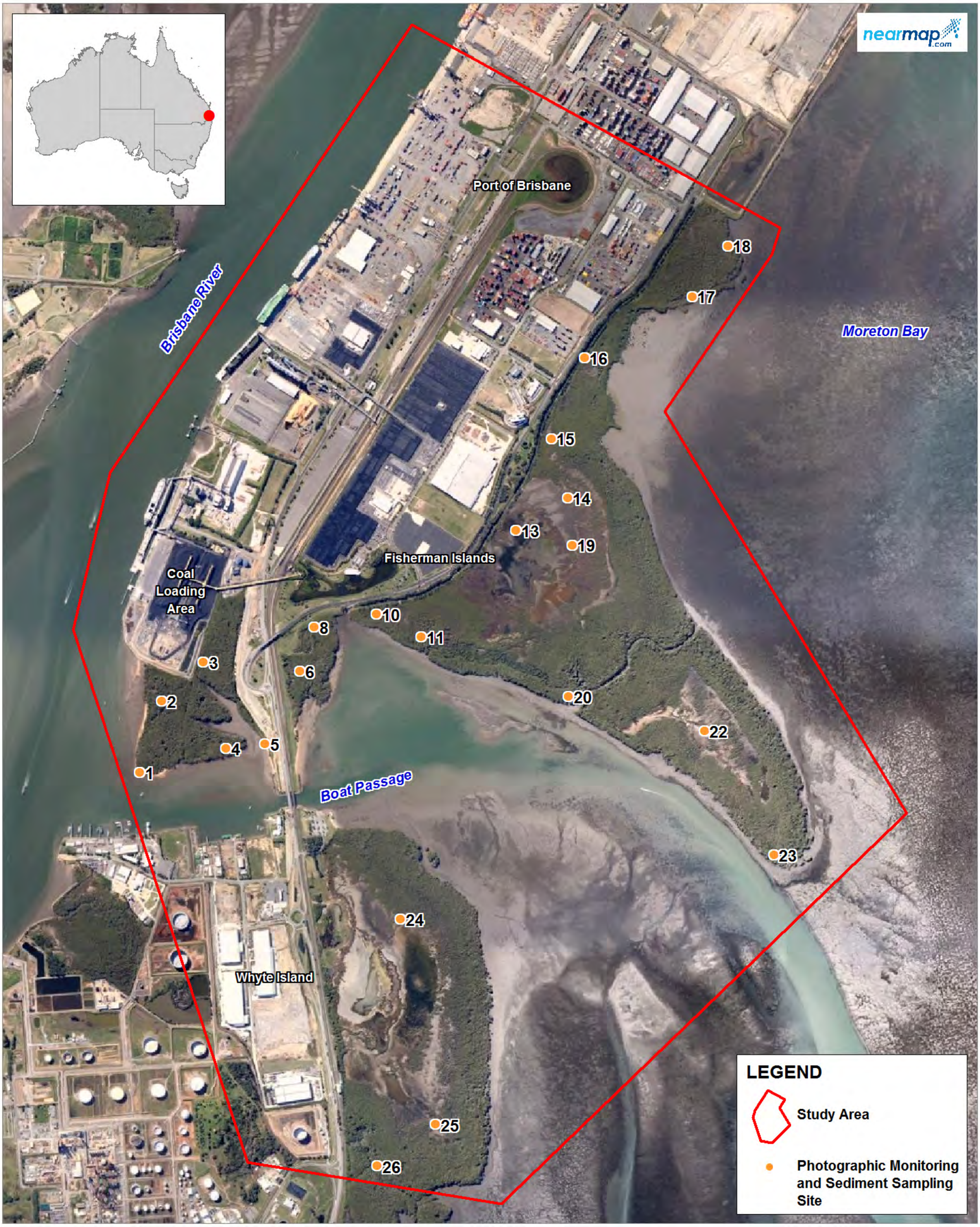
Species composition was mapped separately, focussing on highlighting the presence of species (typically sub-dominant) not yet identified in mapping elsewhere.

2.2 Mangrove Photographic Monitoring

Photographic monitoring of mangrove communities was undertaken at 18 sites on Fisherman Islands and three sites on Whyte Island. The Fisherman Islands sites (and photograph bearings) were the same as those sampled previously (WBM 2002a, b; FRC Environmental 2004, 2006, 2008a, 2010, 2012). Three new photographic monitoring sites were established at Whyte Island in the present survey.

Each site was located using GPS; most sites are also marked with a star picket. Four digital photographs were obtained at each site, with one photograph facing each cardinal direction (i.e. north, east, south and west). The photograph numbers and site coordinates were recorded for each series of photographs. Within each photograph, a PVC pipe was shown as a reference point, with different combinations of coloured tape on the pipe indicating the direction.

Photographs of the mangrove communities were compared with corresponding past photographs to visually assess changes in the mangrove community structure and condition over time. Where applicable, any obvious changes were also incorporated into the refinement of mangrove health mapping.



Title:
Location of Photo Monitoring and Sediment Sampling Sites

Figure: 2-1

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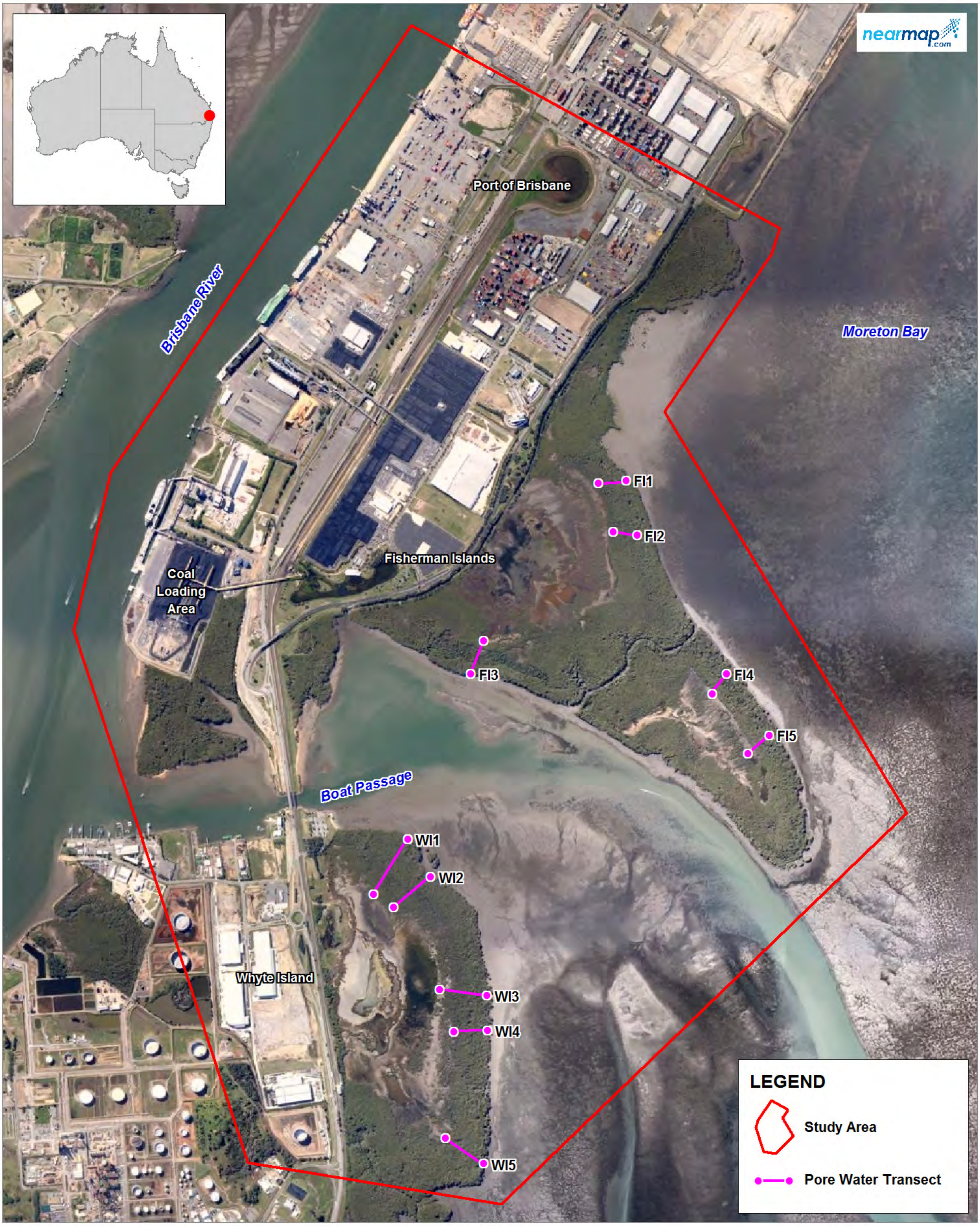
2.3 Pore Water Salinity

The term 'pore water' is defined here as interstitial water in the surface sediment layer. The salinity concentration of pore water was sampled on transects at Fisherman Islands and Whyte Island, as shown in Figure 2-2. Samples were collected from sites representative of each mangrove health category (i.e. good, fair, poor condition and from die-back areas) present along transects. Three samples were typically collected along each transect. In total, 30 pore water samples were collected from Fishman and Whyte Islands, representing the following mangrove health categories:

- 10 samples from areas of 'good' health
- Eight samples from areas of 'fair' health
- Seven samples from areas of 'poor' health
- Five samples from mangrove die-back areas (comprising both 'dead' and 'recently dead' mangroves).

A pore water sampling device was custom designed for the survey, based on the apparatus described by McKee *et al.* (1988). This sampling device consisted of an outer rigid plastic tube (15mm diameter and sealed at the lower end) and an inner plastic tube (6mm diameter), both of which were perforated by small holes and connected to a 50 ml syringe. To collect a sample, the plastic tube was inserted into the sediment next to mangrove roots to a depth of approximately 20 cm. Note that the perforated sections of the outer tube were buried at least 3 cm below the sediment surface to prevent surface water entering the apparatus. Suction was applied using the syringe to extract a pore water sample from the sediment.

The salinity of each pore water sample was measured *in situ* using a calibrated TPS Aqua-CPA salinity probe. Measurements of salinity were recorded in practical salinity units (PSU).



Title:
Pore Water Transect Locations

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2.4 Sediment Quality

Sediment quality was assessed at 22 sites, consistent with the sites sampled previously by WBM (2002a,b) and FRC Environmental (2004, 2006, 2008a, 2010, 2012). This included 19 sites at Fisherman Islands and three sites at Whyte Island, as shown in Figure 2-1.

Samples were collected from the surface sediment (up to 10 cm depth) at each site using a hand trowel. Each sample was carefully homogenized on a clean container, prior to placing the sample in a clean sample jar supplied by the analytical laboratory. All samples were chilled on ice following collection, with all samples transferred to a refrigerator at the end of each day. At the end of the sampling program, all samples were submitted to the primary and secondary analytical laboratories for processing.

Both primary and secondary laboratories (Advanced Analytical Australia and ALS, respectively) were NATA accredited and analysed the sediment samples for the following contaminants of (potential) concern:

- Metals and metalloids (arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc)
- Total petroleum hydrocarbons (TPH)
- BTEX (benzene, toluene, ethylene and xylene)
- Organochlorine pesticides (total chlordane, oxychlordane, dieldrin, aldrin, heptachlor, heptachlor epoxide, methoxychlor, endrin, DDD, DDE, DDT, alpha and beta BHC, lindane, endosulfan (total alpha, beta and sulfate) and hexachlorobenzene)
- Nutrients (nitrogen oxides, total Kjeldahl nitrogen, total nitrogen and total phosphorus).

In accordance with the National Assessment Guidelines for Dredging (NAGD) 2009 (DEWHA 2009), and based on the number of sampling sites, the following field and laboratory control samples were also collected for Quality Assurance / Quality Control purposes:

- Three field triplicate samples at 10% of the sites to determine the small scale spatial variability of sediment quality (i.e. two additional samples at Sites 2 and 4);
- One triplicate split sample at 5% of the sites (each sample homogenised and split into three sample jars) to assess laboratory variation, with one of the three samples sent to the secondary laboratory (ALS) for analysis. An additional sample was collected from Site 8 for a triplicate split; and
- One trip blank laboratory-supplied jar taken into the field with inert material, then analysed in the laboratory concurrent with the analyses already being undertaken for the more volatile organic substances (e.g. BTEX, TPH C6-C9).

The precision (or repeatability) of duplicate samples were assessed by determining the Relative Percent Difference (RPD) values of two samples for a specific contaminant. NAGD recommends that duplicates should agree within a typical RPD of the ±35 percent.

Once data were collated, the concentrations of each analyte measured were compared to the Interim Sediment Quality Guidelines (ISQG) (ANZECC & ARMCANZ 2000), using both the ISQG-low and ISQG-high guideline values. Results were also compared against NAGD, as well as the

Draft Guidelines for the Assessment and Management of Contaminated Land in Queensland, Environmental Investigation Levels (EIL's) and Background Levels (BL) (DoE 1998). These sediment guidelines values are summarised in Table 2-2.

Table 2-2 Guideline values for parameters of concern within sediments from Fisherman and Whyte Islands

Parameter	ISQG – low	ISQG – high	NAGD	EIL	BL
Metals (mg/kg)					
Arsenic	20	70	20	20	0.2 – 30
Cadmium	1.5	10	1.5	3	0.04 – 2
Chromium	80	370	80	50	0.5 – 110
Copper	65	270	65	60	1 – 190
Mercury	0.15	1	0.15	1	0.001 – 0.1
Nickel	21	52	21	60	2 – 400
Lead	50	220	50	300	<2 – 200
Zinc	200	410	200	200	2 – 180
Total Petroleum hydrocarbons (mg/kg)					
TPH C6-C-9	-	-	550	-	-
TPH C10-C14	-	-	550	-	-
TPHC15-28	-	-	550	-	-
TPH C29-C36	-	-	550	-	-
Pesticides (µg/kg)					
Aldrin	-	-	-	-	-
alpha-BHC	-	-	-	-	-
Beta-BHC	-	-	-	-	-
gamma-BHC (Lindane)	0.32	1	0.32	-	-
delta-BHC	-	-	-	-	-
cis-Chlordane	-	-	-	-	-
trans-Chlordane	-	-	-	-	-
p,p'-DDD	-	-	2	-	-
p,p'-DDE	2.2	27	2.2	-	-
p,p'-DDT	-	-	-	-	-
Dieldrin	0.02	8	280	-	-
Alpha-Endosulfan	-	-	-	-	-
Beta-Endisulfan	-	-	-	-	-
Endosulfan sulphate	-	-	-	-	-
Endrin	0.02	8	10	-	-

Parameter	ISQG – low	ISQG – high	NAGD	EIL	BL
Endrin ketone	-	-	-	-	-
Endrin aldehyde	-	-	-	-	-
Heptachlor	-	-	-	-	-
Heptachlor epoxide	-	-	-	-	-
Hexachlorobenzene	-	-	-	-	-
Methoxychlor	-	-	-	-	-
Oxychlordane	-	-	-	-	-

3 Results

3.1 Mangrove Condition

3.1.1 Spatial Assessment of Mangrove Condition

Fisherman Islands – Northern Section

Most mangroves in this section were classified as being in good (59%) or fair (26%) condition (Figure 3-1; Figure 3-8). Mangroves in poor condition (13%) continued to dominate the landward side of the Fisherman Islands northern section (Figure 3-1), consistent with the previous 2012 survey (refer FRC Environmental 2012). Small patches of old dead mangroves (0.6%) also occurred towards this landward margin. Much of the area categorised as poor or dead mangroves had surface water ponding at low tide. The high occurrence of deformed/tall pneumatophores among the poor mangroves is likely symptomatic of the continued exposure to surface water, and other associated effects (e.g. reduced water quality, anoxic sediment, macroalgal mats etc.).

The most notable change since 2012 was the occurrence of patches of recently dead mangroves (area totalling 0.41 ha, 1.2%) located towards the seaward margin (i.e. away from the mangroves mapped as dead or in poor condition during both the recent and past surveys) (see also photograph in Figure 3-6). Water ponding was present in these patches of recently dead mangroves, suggesting that this may have been caused by physical processes. The factor(s) driving the mangrove degradation in these areas appears to be operating at a highly localised spatial scale (measured in 10s of metres), as these patches were surrounded by mangroves in good condition.

Fisherman Islands – Western Section

This section in Fisherman Islands (Figure 3-2) contains extensive areas of dead mangroves which have been mapped since 1999 (WBM 2000). In the present survey, approximately 20% of this section was mapped as either dead or recently dead, with an additional 24% considered to be in poor condition (Figure 3-2). Mangroves in good and fair health equate to approximately 32% and 23% of the total area, respectively. Saltmarsh has been accurately mapped on this sampling occasion to distinguish it more clearly from the mangrove health categories. Much of the area previously mapped as saltmarsh did not contain saltmarsh and was actually ‘dead’ mangroves and bare substrate. This dead mangrove area contained the occasional very old mangrove stump, and is now more representative of a salt pan or clay pan environment. Alternatively, this area may have historically been saltmarsh or clay pan dominated with isolated mangroves interspersed.

Large areas along the north-eastern side of this section previously mapped as good condition were mapped in the present study as poor condition or recently dead mangroves. Two patches of recently dead mangroves occur on this north-eastern area and have a combined area of 0.46 ha. Poor condition mangroves dominate between the recent dieback areas, along a strip located approximately parallel to the shoreline. Regrowth continues to occur along the outer northern margin of dead mangroves, and has now also been identified on part of the outer southern margin of dead mangroves.

Fisherman Islands – Eastern Section

The eastern section of Fisherman Islands (Figure 3-3) remains relatively unchanged since the 2012 survey in terms of the overall extent and distribution of each of the mangrove health categories. In the present survey, approximately 15% of the area was mapped as dead or recently dead mangroves (concentrated in the central part of this section), 16% poor, 32% fair and 37% were mapped as good condition mangroves (Figure 3-8). A small proportion (< 1%) of regrowth also continued to occur on one of the central boundaries between some poor and dead mangroves.

Some changes have occurred over time, most notably new areas of dead, recently dead and poor condition mangroves. These changes have mainly occurred along the seaward margins of this section near areas of good and fair condition mangroves. This specifically included a patch each of dead and recently dead mangroves near the northern cross-channel; and a patch each of poor, dead and recently dead mangroves (Figure 3-6) among the eastern extent of the fair mangrove category. The area previously mapped as regrowth (along a drainage line in the northeast of this section) now appears to have become established and was classified as good condition mangroves. Note that the southernmost tip of the eastern section has also been reclassified as good condition mangrove, as opposed to the prior classification as poor.

Fisherman Islands – Coal Loading Area

In comparison to other sections, the Coal Loading Area section of Fisherman Islands was in the healthiest condition consisting of a very high area (81%) of mangroves in good condition (Figure 3-4). Mangroves in fair condition also occurred (14%), together and poor (4%) condition mangroves and recent dieback (2%).

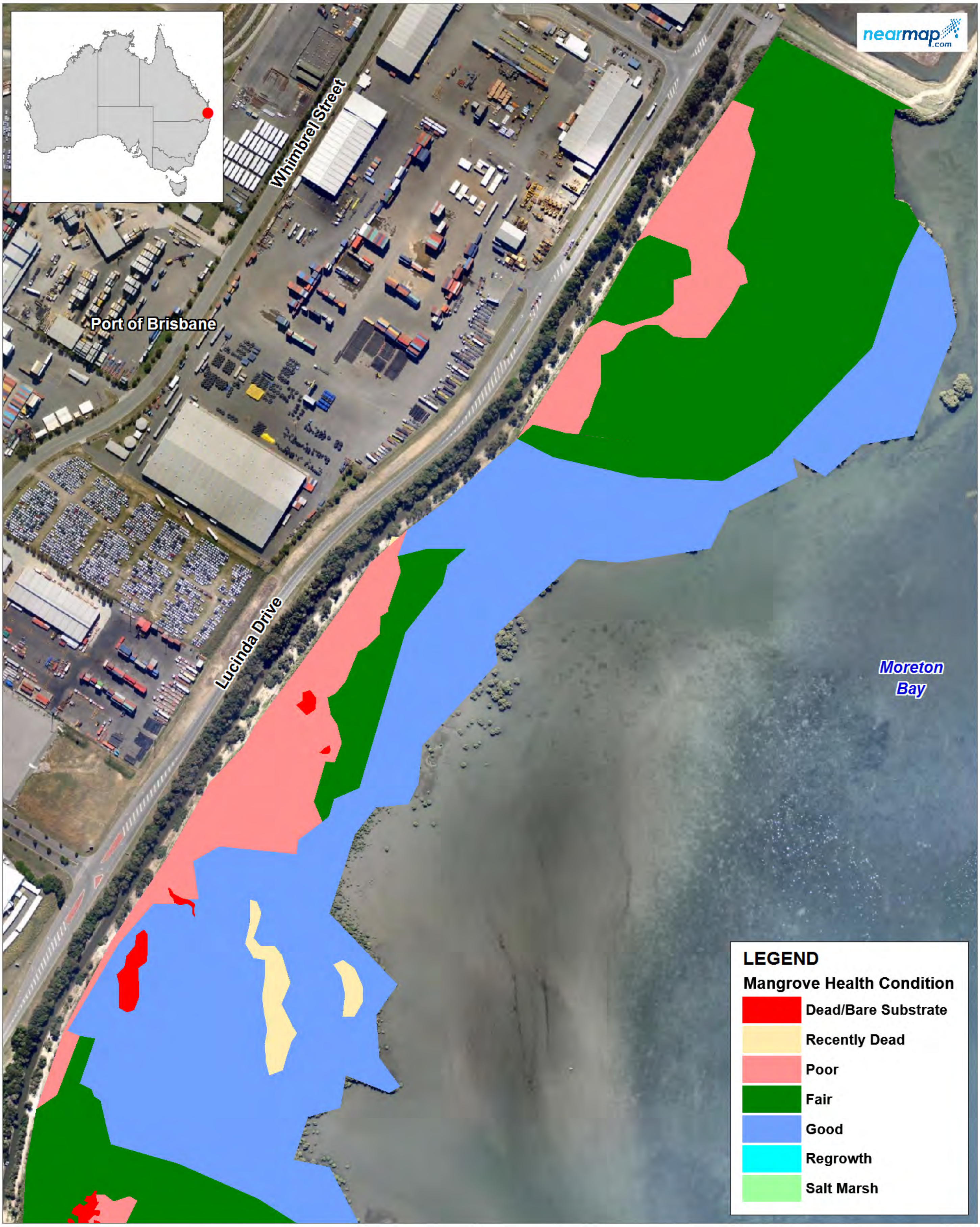
New areas of mangroves in poor condition were observed on both the outer eastern (Figure 3-6) and western boundaries of the Coal Loading Area, totalling an approximate area of 0.8 ha. New recent dieback was also recorded towards the south-western part where a high degree of sand deposition has occurred, burying pneumatophores. Mangrove condition throughout the rest of this section was comparable with that of the previous survey.

Whyte Island

Whyte Island included a large area classified as dead mangroves (30%), together with mangroves in good (25%), poor (20%) and fair (20%) condition (Figure 3-5; Figure 3-8). The remaining area (5%) was comprised of saltmarsh. The dead and poor condition mangroves were concentrated towards the central and landward side of the area. Like the western section of Fisherman Islands, much of the area mapped as dead is actually a salt pan/clay pan community, or unvegetated ponded water. Mangroves in good and fair condition are restricted to the (well flushed/drained) outer margin of Whyte Island.

A new large patch of dead mangroves was recorded in the south-western corner of Whyte Island (Figure 3-6). No surface water pooling or other visually obvious stressors were observed here at the time of the surveys. A smaller patch of dead mangroves was also recorded towards the south-eastern corner. Both these areas of dead mangroves were entirely surrounded by mangroves in good condition, suggesting that the controlling process/es were resulting in highly localised effects (see Discussion section for potential causes).

While the area of saltmarsh superficially appears changed compared to past surveys, this is an artefact of increased effort to more accurately map saltmarsh communities. Consequently, much of the area previously mapped as saltmarsh has now been reclassified as ‘dead/bare’, on the basis that this saltpan area: (i) does not contain saltmarsh vegetation, and (ii) once contained both remnant saltpan (that was extensively disturbed by road development in the 1970’s), and mangrove forests (see historical imagery shown in Figure 3-7, and Section 4.2.1). Elsewhere, the extent and distribution of each mangrove health category was largely consistent with the results of the previous survey.



Title:
Mangrove Health Condition - Northern Section

Figure: 3-1

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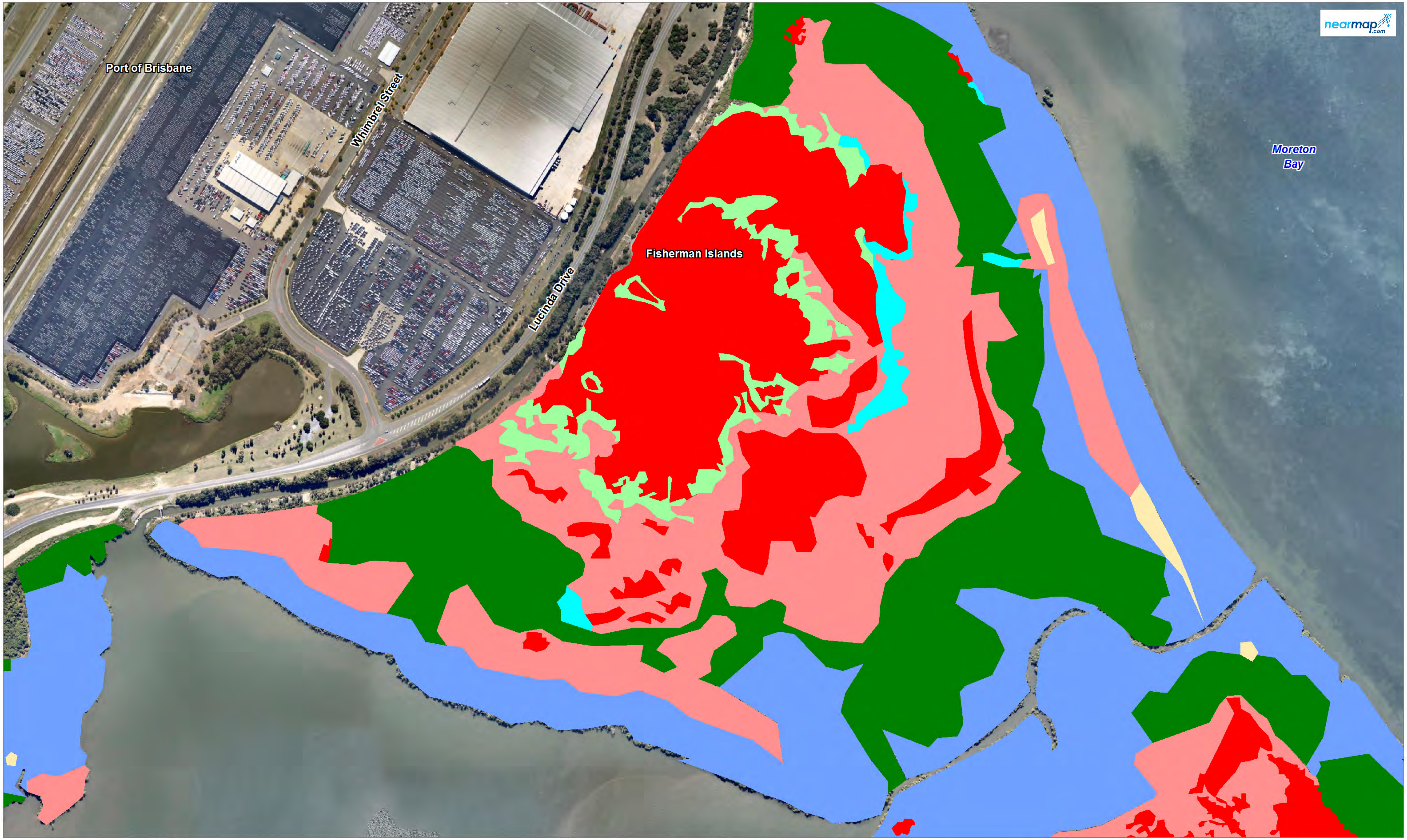

LEGEND

Mangrove Health Condition

- Dead/Bare Substrate
- Recently Dead
- Poor
- Fair
- Good
- Regrowth
- Salt Marsh

Title:

Mangrove Health Condition - Western Section

Drawing: 3-2

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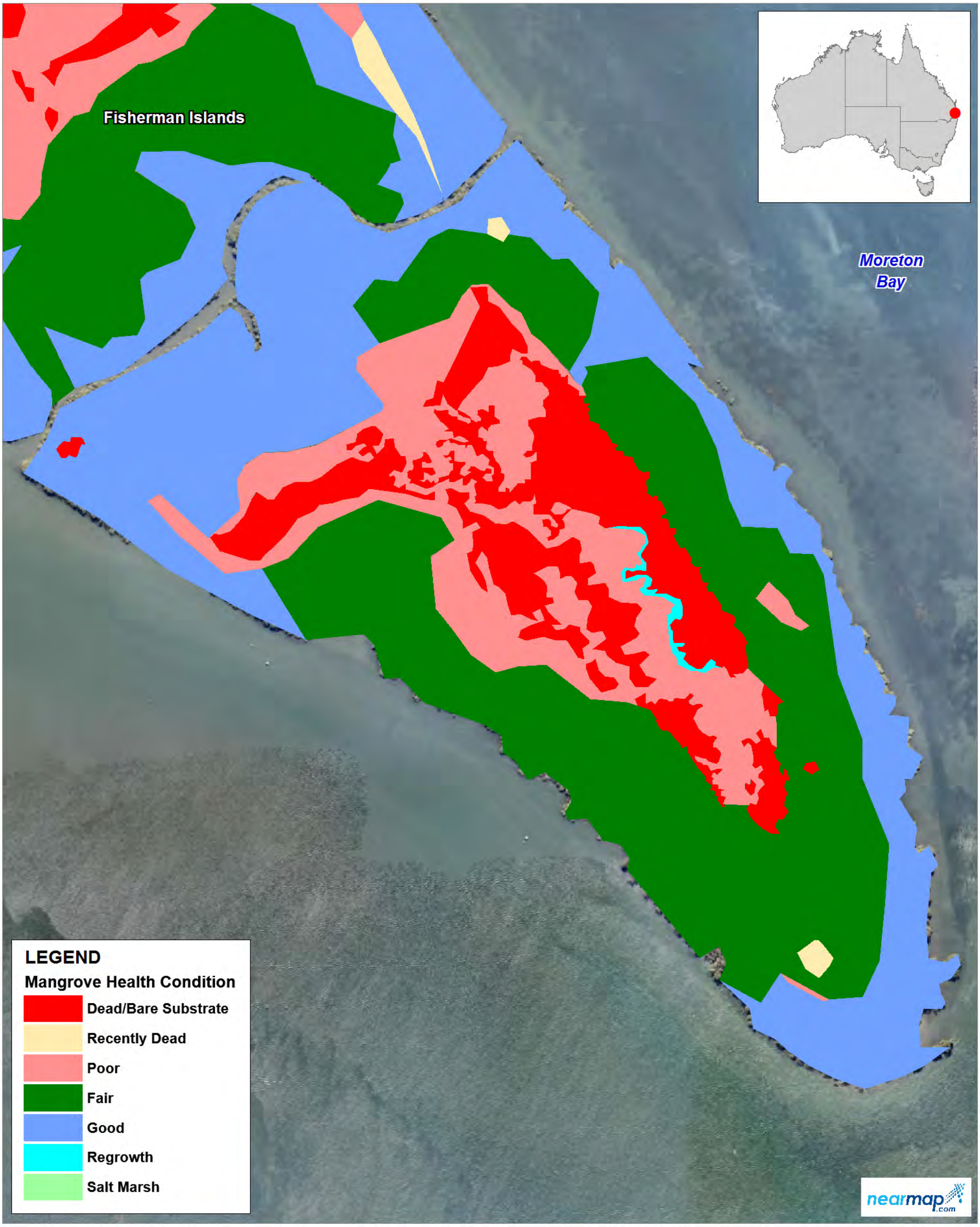

Title:

Mangrove Health Condition - Eastern Section

Figure: 3-3

Rev: A

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Approx. Scale

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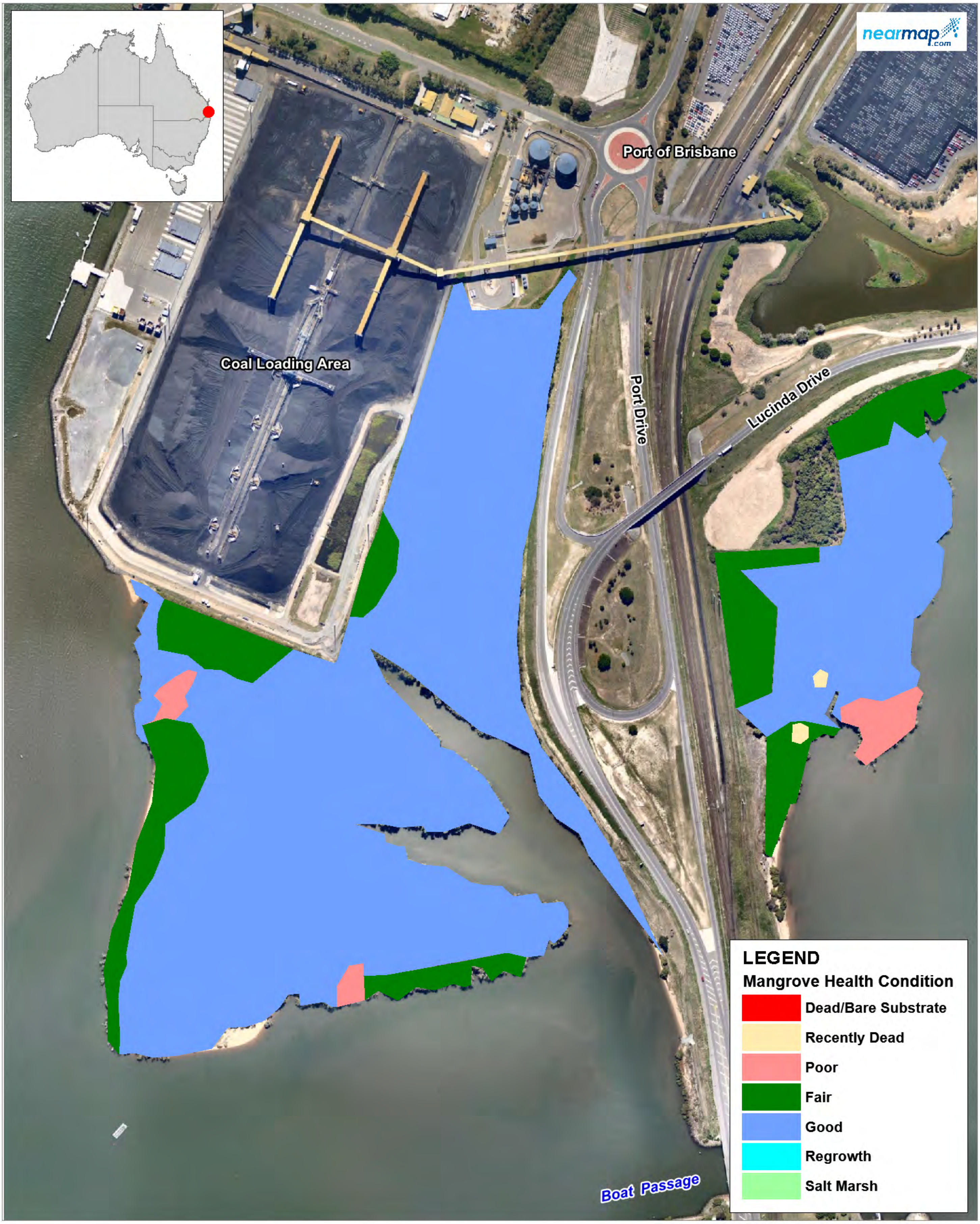

Title:

Mangrove Health Condition - Coal Loading Area

Figure: 3-4

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Approx. Scale

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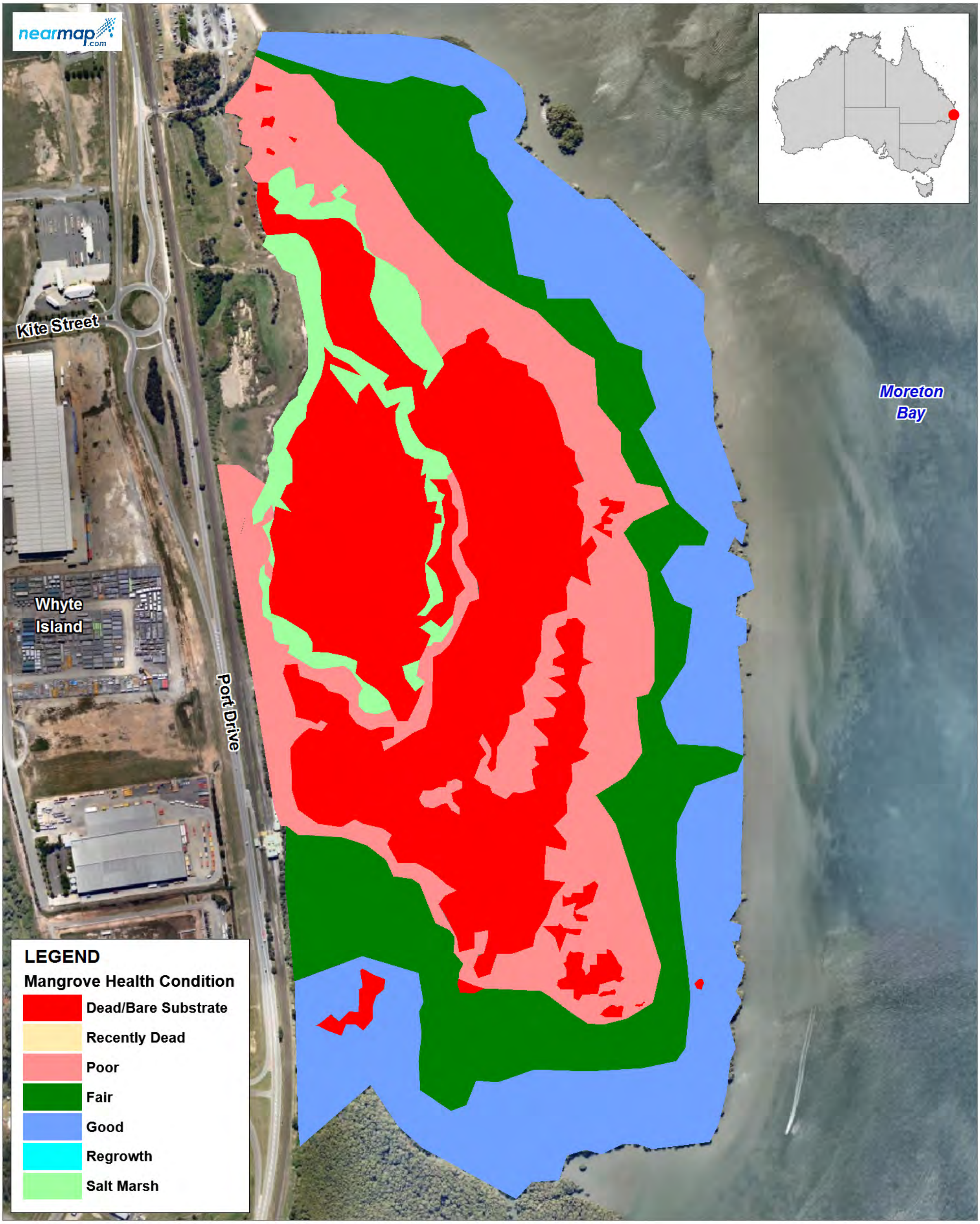

Title:

Mangrove Health Condition - Whyte Island

Figure: 3-5

Rev: A

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

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Figure 3-6 Photographs of recent dieback and poor health recorded at a) Fisherman Islands northern section, b) Fisherman Islands eastern section, c) Coal Loading Area, d) Whyte Island, 2014

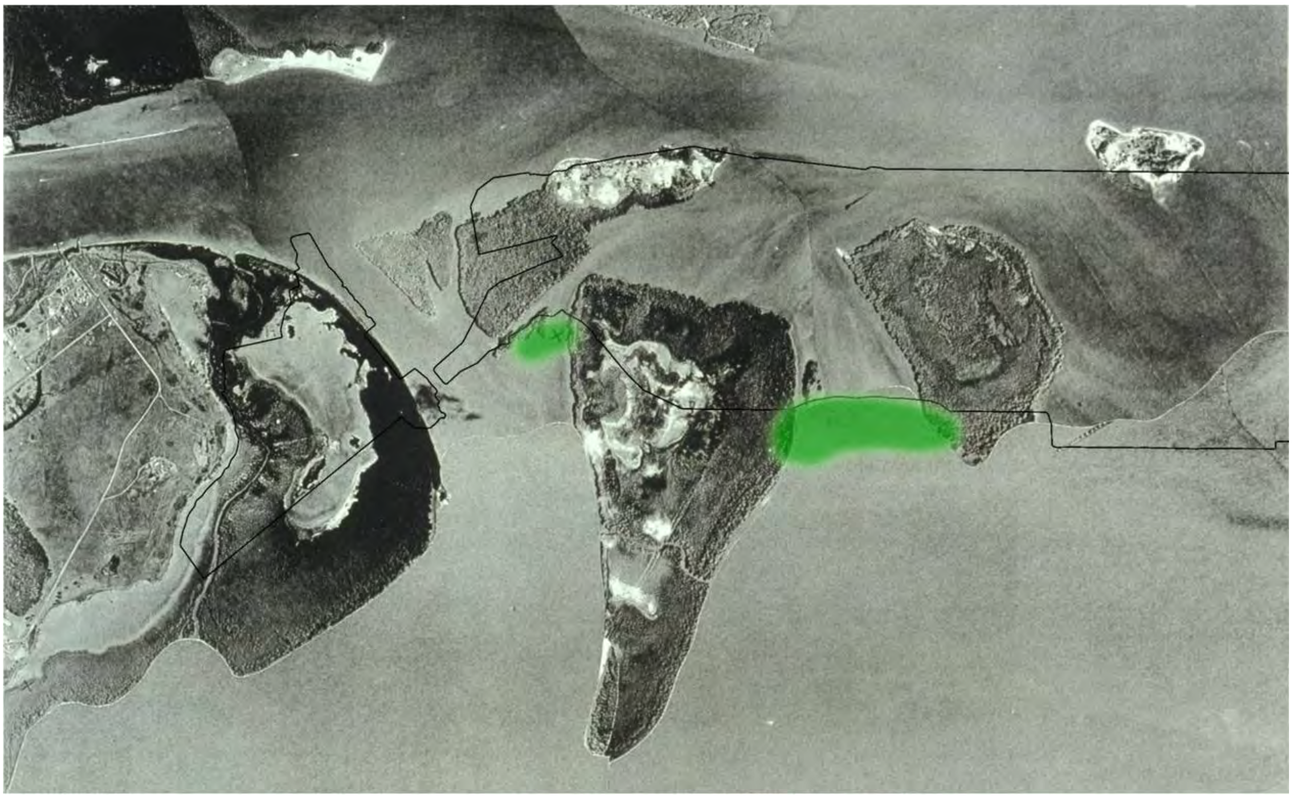

Figure 3-7 Historical aerial photograph of study area prior to port construction

Comparison among Locations

Figure 3-8 provides a comparison of the proportion of each mangrove health category, by area, contributing to each of the five locations. Proportional to size, the Coal Loading Area was in the best condition, while Whyte Island and the western and eastern sections of Fisherman Islands contained high proportions of both dead and poor condition mangroves (contributing up to 50% of the total area at Whyte Island).

The occurrence of a high proportion of the ‘dead mangrove/bare’ category at these locations is consistent with the findings of the previous survey, as is their distribution, largely concentrated toward the central (landward) area of each of these areas. Here, dead and recently dead mangrove categories were typically comprised of: dead mangroves and old dead stumps (with little or no evidence of regrowth), or bare saltpan areas with no dead mangroves evident. Ponding of water and algal mats were a common feature of these ‘dead mangrove/bare’ areas.

Table 3-1 is a summary of major changes in mangrove health condition categories between the present and previous surveys. Increases in the extent of degraded mangrove areas are primarily limited to:

- Dead/bare – Patches of dead mangroves mapped towards the outer boundaries around Whyte Island and the eastern section of Fishman Islands;

- Recently dead – New patches of recent dieback observed across Fishman Island, including towards the outer boundaries of the northern, western and eastern sections, as well as the Coal Loading Area; and
- Poor – Considerable increase in the area of mangroves in poor condition across Fisherman Islands, particularly including significant bands towards the eastern boundary of both the western and eastern sections, and areas on the outer boundary of the Coal Loading Area.

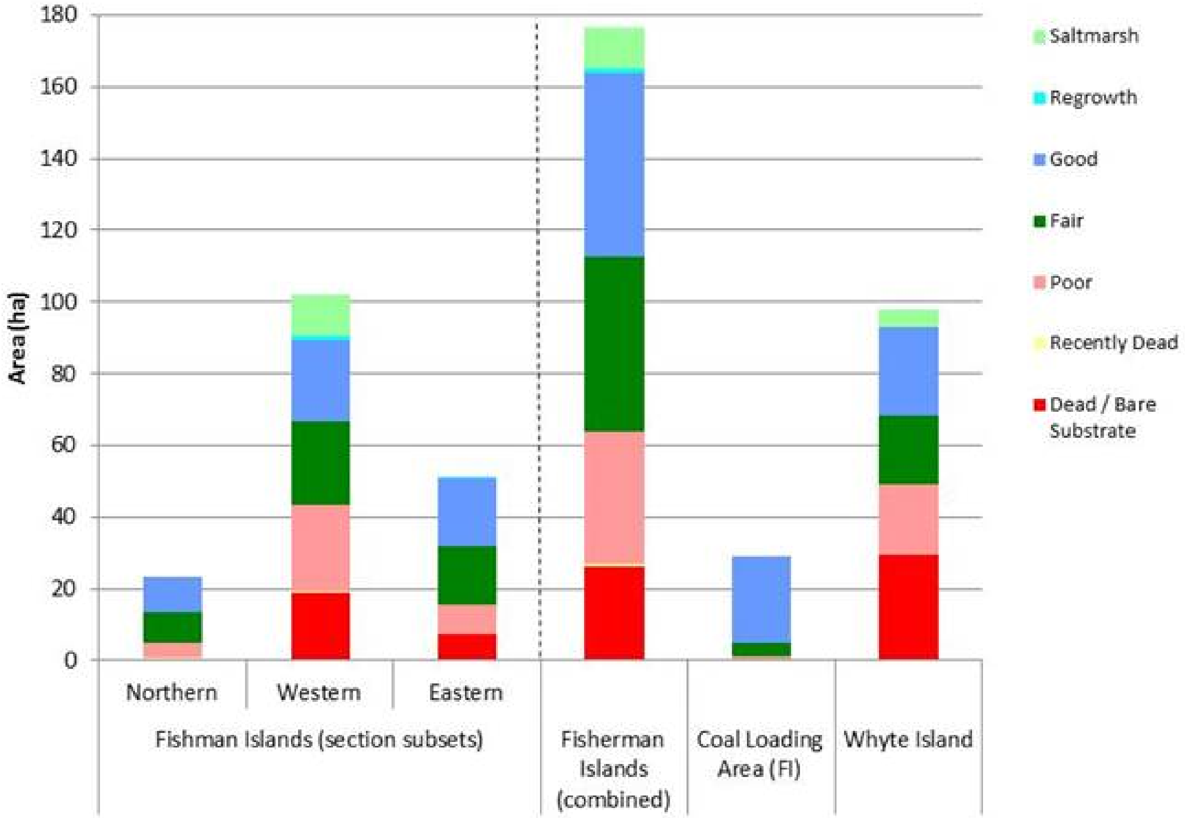

Figure 3-8 Mangrove health categories contributing to the total area mapped for each study area section

For comparative purposes, graphs showing the area covered by each mangrove health category during past years are reproduced below (from FRC Environmental 2012) in Figure 3-9. While these past figures are presented in a slightly different format, essentially the overarching trends are consistent with for each location. Key changes since the previous 2012 survey are consistent with the above descriptions. Namely, the inclusion of significant areas of saltmarsh at Fisherman Islands and Whyte Island (accounting for a smaller area mapped as dead); and reduced areas of regrowth vegetation at Fisherman Islands. Over the longer term, since approximately 2004, there has been a gradual increase in the area of poor condition and/or dead mangroves at both Fisherman Islands and Whyte Islands, along with a corresponding decrease in the area of mangroves in good and/or fair condition.

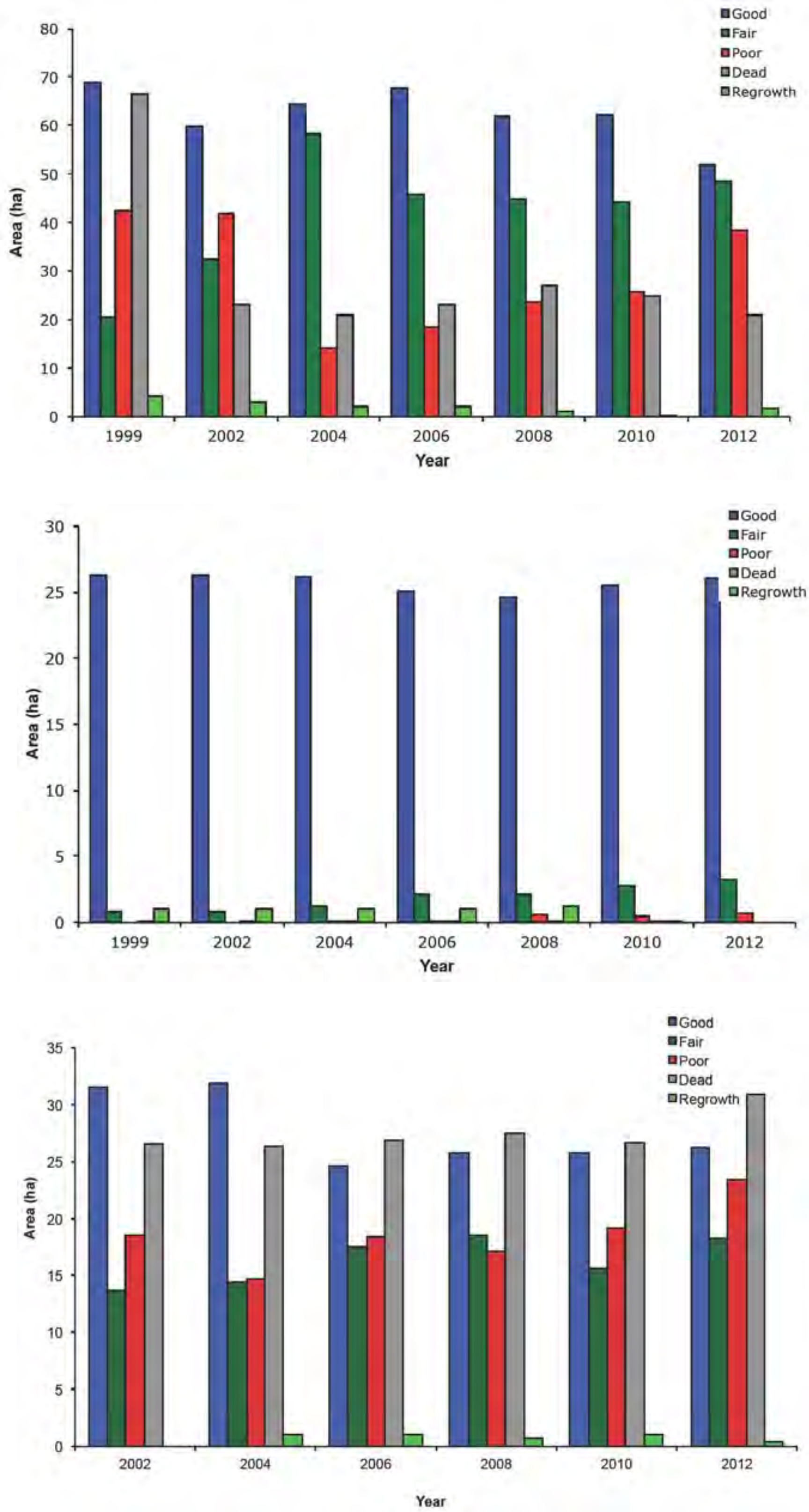

Figure 3-9 Area of each health category at Fisherman Islands (top), the Coal Loading Area (middle) and Whyte Island (bottom) (FRC Environmental 2012)

Table 3-1 Summary of key changes in mangrove condition, 2014

	Fisherman Islands				Whyte Island
	Northern	Western	Eastern	Coal Loading Area	
Dead	-	Refer ‘saltmarsh’ below	Small dead patch near northern cross-channel and eastern extent of fair mangroves	-	New area of dead mangroves in south-western corner and smaller new dead patches elsewhere; refer also ‘saltmarsh’ below
Recently Dead	Large (>800 square metres) patches of recent dieback; located seaward and surrounded by mangroves in good condition	Two new patches of dieback towards north-eastern boundary	Patches of recent dieback in vicinity of: northern cross-channel, eastern extent of fair mangroves	-	-
Poor	-	Band of poor condition present between the new dieback (above), located approximately parallel to shoreline	Patches of poor mangroves among eastern extent of fair mangroves	Increase in area of mangroves in poor condition, primarily on outer boundaries	-
Fair	-	-	-	-	-
Good	-	Reduction in area of good condition towards northeaster boundary (replaced by poor and recently dead – refer above)	Past regrowth now established and classified as good; southern tip (previously poor) reclassified as good	-	-
Regrowth	-	Slight increase in area of regrowth, near margin of central dead mangroves	-	-	-
Saltmarsh	-	Reclassification of much of previous saltmarsh area to dead (not indicative of actual saltmarsh change)			Reclassification of much of previous saltmarsh area to dead (not indicative of actual saltmarsh change)

3.1.2 Species Composition/Distribution

The spatial distribution of mangrove community types and dominant species recorded in the present study were consistent with FRC Environmental (2012), which are reproduced in Figure 3-10 and Figure 3-11. The Fisherman Islands mangrove forests were comprised on the following community types:

- *Avicennia marina* low closed forest with *Ceriops tagal* and/or *Rhizophora stylosa* - located throughout the northern, western and eastern sections
- *Avicennia marina* open forest – located along the seaward margins of all areas and throughout the Coal Loading Area
- Areas of *Ceriops tagal* low closed forest, mixed *Avicennia marina* and *Ceriops tagal* low closed forest, and mixed low closed forest – located at the south-eastern corner of the Coal Loading Area and along the south-western side of the Fisherman Islands western section (i.e. between the *A. marina* open and *A. marina* low closed forest types).

At Whyte Island mangrove forests were comprised of the following community types:

- *Avicennia marina* open forest – located on the seaward margin
- *Avicennia marina* low closed forest – located throughout the interior of Whyte Island
- *Avicennia* marina low open forest – located along a narrow band occurring between these two community types.

Additional information on the other species co-occurring (e.g. secondary species) at specific sites examined in the 2014 survey is presented in Figure 3-12 for Fisherman Islands and Figure 3-13 for Whyte Island. Sub-dominant species recorded in these community types were *Rhizophora stylosa*, *Aegiceras corniculatum*, *Ceriops tagal* and *Bruguiera gymnorhiza*.

Figure 3-10 Mangrove species composition and community types at Fisherman Islands, 2012 survey (FRC Environmental 2012)

Figure 3-11 Mangrove species composition and community types at Whyte Island, 2012 survey (FRC Environmental)

Title:

Sub-Dominant Mangrove Species Recorded at Sampling Sites - Fisherman Islands

Figure: 3-12

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Approx. Scale

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Title:

Sub-Dominant Mangrove Species Recorded at Sampling Sites - Whyte Island

Figure: **3-13**

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Approx. Scale

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3.2 Mangrove Photographic Monitoring

Results of the 2014 photographic monitoring are summarised in Table 3-2. The 2014 photographs for each photographic monitoring point are provided in Appendix A. For comparative reference, photographs from each previous survey can be found in the past reports provided to PBPL (WBM 2002a, b; FRC Environmental 2004, 2006, 2008a, b, 2010, 2012).

Temporal trends in mangrove health and condition were inconsistent across the study area, with recovery observed at some sites, and deterioration at others. Many sites also exhibited no notable change since the previous survey. Key changes observed in 2014 through the photographic monitoring include:

- Health recovery – Marked by increasing establishment of regrowth mangrove vegetation (i.e. taller and in good condition) at Sites 15 and 22; as well as improved saltmarsh condition and extent at Site 14.
- Health decline – Exhibited through the presence of one or more recently dead and fallen trees at Sites 3, 8, 11 and 20; and through increased pooling water, macroalgae, and seedling density decline at Sites 11 and 16.

Table 3-2 Summary of mangrove communities at each photographic monitoring sites (refer to Figure 2-1 for locations)

Site	Existing Description (2012)[1]	Notable changes observed in 2014
Fisherman Islands		
1	Open *Ceriops tagal* forest with *Avicennia marina* understory in fair condition, substrate dominated by sands	A slight increase in macroalgae on roots in some places
2	Mature *A. marina* forest in good health. Dense seedling and sapling cover in the south and east quadrants, with understory gradually increasing in height	Seedling density reduced to the south but remains dense to the east
3	Mature, open *A. marina* forest with some river mangrove (*Aegiceras corniculatum*) in good health; some epicormic growth on *A. marina* trunks and seedling/sapling continue to be present (especially to east)	Two large dead fallen *A. marina* now present (one south and one east)
4	Mature, open *A. marina* forest with some *A. corniculatum* and *Rhizophora stylosa*, of fair health; sparse cover of seedlings overall but relatively dense to the east of the marker	Increase in seedling density
5	Thin fringe of *A. marina* shrubs along sandy shore, of fair health; sandy substrate, reduce pneumatophore density likely from deposition or erosion	No notable change, though appears in good condition overall (as opposed to previous 'fair')
6	Low, closed *A. marina* forest, of good health; decline of seedling density and foliage cover	No notable change; seedling density and foliage cover remains reduced in comparison to 2010 survey
8	Low, closed *A. marina* forest with *R. stylosa* saplings of good health.	Numerous small fallen small trees or branches (west); seedlings and saplings abundant (most comparable with 2010); mature *A. marina* in fair health
10	Low, closed *C. tagal* forest next to *A. marina* forest, of fair to good health with some yellowing leaves.	As per previous survey

Site	Existing Description (2012)[1]	Notable changes observed in 2014
11	Low, closed *C. tagal* forest with scattered *A. marina* of fair health; areas of pooling water observed	A few fallen trees; low seedling density and surface water remains; approaching poor condition
13	Claypan fringed with *A. marina* in poor health or dead, and saltmarsh; pooling water with dense algae mat	As per previous; extensive pooling water and algal mat remains; all mangroves in close vicinity old dead stumps
14	Dieback area fringed with low, closed *A. marina* forest in poor health, and saltmarsh; pooling water with dense algae mat	Saltmarsh vegetation present in good health and appears to be gradually expanding coverage; extensive pooling water and algal mats remain; old dead mangrove stumps deteriorating and becoming less obvious
15	Low, open *A. marina* forest in poor health due to epicormic growth and leaf damage by insects; forest represents an area of regrowth with saplings continuing to increase in height	Regrowth now well established, taller and in good to fair condition
16	Tall, open *A. marina* forest in fair health with seagrass wrack and debris on the forest floor; decline in seedling/sapling density since 2010 survey	Forest appears more open with few seedlings or saplings present and in poor health; pooling surface water and macroalgae on pneumatophores evident
17	Mature, tall and open *A. marina* forest in good health; general decline in seedling/sapling health due to leaf loss and smothering by seagrass wrack	Condition as per previous; saplings becoming established
18	Mature open *A. marina* forest with some *R. stylosa* of good health; increased occurrence of seagrass wrack across the site	Remains in good to fair condition, although extensive accumulation of seagrass wrack persists
20	*A. marina* forest with scattered *R. stylosa*, of good health; decline in seedling/sapling health due to leaf loss and smothering by seagrass wrack	Largely as per previous, although at least one *A. marina* has died and fallen
22	Dieback area fringed with *A. marina* forest in poor health and regrowth; saltmarsh patches present; mangrove/saltmarsh cover increased since 2010 and areas of pooling water with dense algae mat	Marked recovery evident – regrowth more established and improving in condition and cover, although extensive pooling surface water and algal mats still present
23	*A. marina* forest in fair to poor health, with scattered *C.* tagal; understory dominated by seedlings and saplings; epicormic growth on trunks	As per previous
Whyte Island		
24	-	Low open *A. marina* forest in fair health; remains of a few old dead trees though regrowth now established
25	-	Dead mangroves fringed by low *A. marina* forest in poor to fair health; ponded water and thick macroalgae mats present among dead mangroves
26	-	Mature, tall and open *A. marina* forest in fair health; numerous fallen branches present

1 – Based on FRC Environmental (2012)

3.3 Pore Water Salinity

Pore water salinity ranged from 34.7 to 73.6 PSU during the 2014 survey, with the highest salinity recorded among mangroves of ‘poor’ and ‘dead’ condition at Whyte Island (Figure 3-14). The mean salinity for each mangrove health category was higher at Whyte Island compared to corresponding health category at Fisherman Islands. At both Fisherman Islands and Whyte Island, mean pore water salinity was lowest within the ‘good’ mangrove health category compared to the degraded mangrove categories (i.e. fair to dead) at the same location. Note that at both locations, mean pore water salinity for both the poor and fair mangrove categories was within the range of that for the respective dead mangrove category.

It is hypothesised that the lower salinity concentrations in sediments from mangrove areas in good health may be partly due to differences in the local elevation and drainage patterns. Areas of dead mangroves and mangroves in poor condition were typically associated with ponded surface water. Ponded surface water usually indicates inadequate drainage and poor tidal flushing, which can lead to degraded water quality over time. This is particularly the case during periods of low rainfall and/or increased evaporation.

The trends observed in pore water salinity (i.e. between locations and mangrove health categories) during the present survey were similar to those reported for the previous survey (see Figure 3-15, FRC Environmental 2012). However, salinity was slightly lower at both Fisherman Islands and Whyte Island during the previous survey (mean salinity ranging from approximately 25 – 48 PSU), on account of rainfall prior to sampling. While the recent salinity values were more reflective of those recorded during the earlier 2008 and 2010 surveys, particularly at Whyte Island, they did not display the marked and consistent trend between mangrove health categories. For instance, in 2008 and 2010, at both Fisherman Islands and Whyte Island salinity concentrations clearly increased with increasing mangrove degradation (i.e. salinity increased across each mangrove health category, from good to fair, then poor and dead).

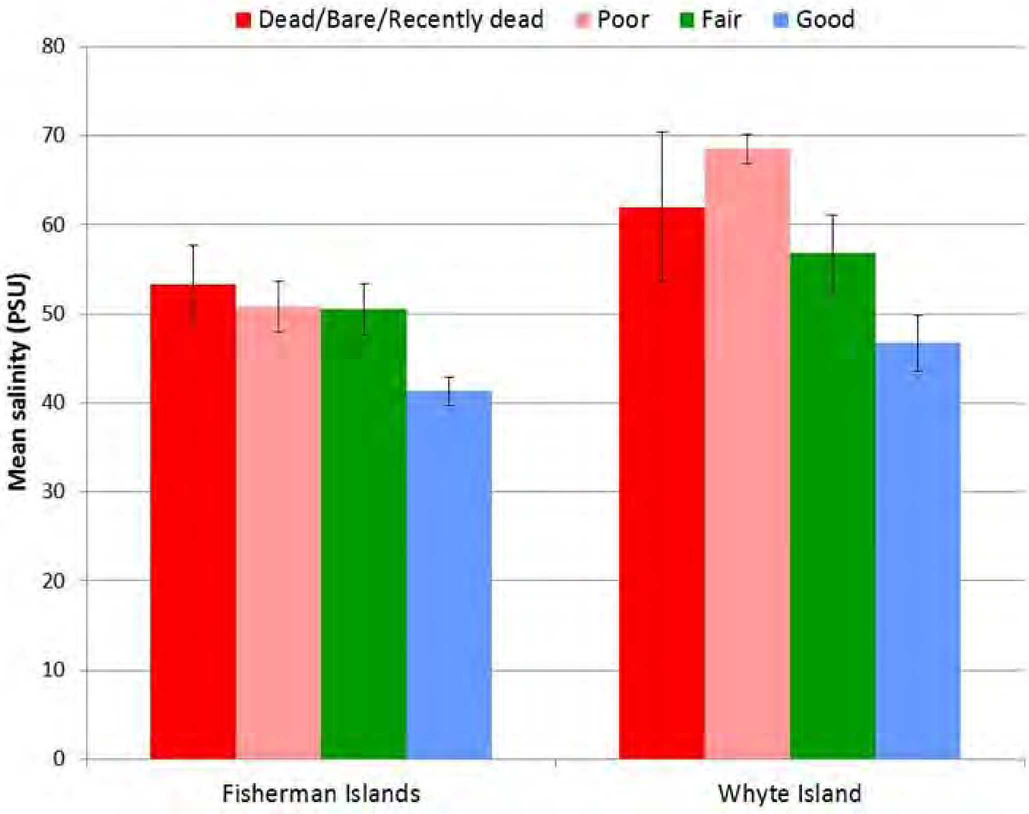


Figure 3-14 Mean (±S.E) salinity of pore water across the study area during 2014

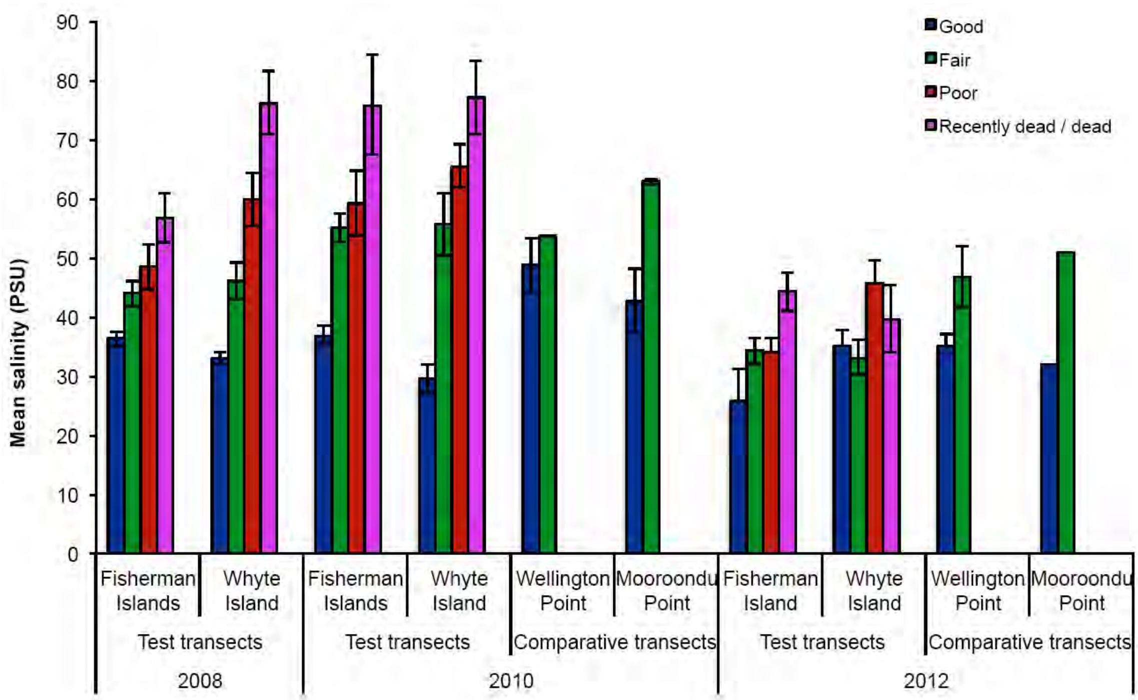


Figure 3-15 Pore water salinity results for previous surveys, 2008 to 2012 (FRC Environmental 2012)

3.4 Sediment Quality

3.4.1 Metals and Metalloids

Concentrations of most metals and metalloids were generally below ISQG-low trigger values (ANZECC/ARMCNAZ 2000). The exception was Nickel at Site 14 (Fisherman Islands western section), which had a concentration equal to the ISQG-low trigger value of 21 mg/kg (Table 3-3). The nickel concentration in sediments at Sites 2, 6, 13, 19 (Fishman Islands) and Site 24 (Whyte Island) were only slightly below this ISQG-low trigger value, noting that Sites 13 and 19 were both located in relatively close proximity to Site 19.

Slightly elevated nickel concentration(s) in this western section of the Fisherman Islands area are consistent with past results. In 2012, Sites 13 and 19 had nickel concentrations above the ISQG-low trigger value, as did Site 13 in 2010. All nickel exceedances recorded during the past two surveys (i.e. Sites 13, 14, 19) were located in the area mapped as 'dead' mangroves at the Fisherman Islands western section (Figure 3-16). Note that sediments in Australia commonly have high natural levels of nickel (refer DEWHA 2009), including coastal marine sediments in parts of Moreton Bay (BMT WBM 2013) and elsewhere in Queensland (e.g. Reichelt and Jones 1994, Ward and Larcombe 1996).

3.4.2 Nutrients

Nutrient concentrations recorded during the present survey are provided in Table 3-4, noting that there are no ISQG trigger values available to provide guidelines for nutrients in sediment. The total nitrogen concentration in sediments collected from the study area ranged from 76 mg/kg at Site 23 (Fisherman Islands – eastern section) to 12,600 mg/kg at site 25 (Whyte Island). Samples from nine of the 26 sites recorded total nitrogen concentrations that were greater than 4,000 mg/kg. In terms of spatial distribution, these high nitrogen concentrations were from sites located: i) adjacent to and opposite the Coal Loader Area of Fisherman Islands (Sites 2, 3, 6 and 8); ii) Sites 22 and 16 on Fisherman Islands; and iii) at all sites sampled on Whyte Island. Total phosphorus concentrations ranged between 150mg/kg at Site 5 to 1,300 mg/kg at Site 22 (both sites located on Fisherman Islands).

Of the nine sites indicating elevated nutrient levels (i.e. greater than 4,000 mg/kg of total nitrogen), six were located in areas mapped as being in good to fair mangrove condition, while the remaining three were located in dead mangroves (i.e. Sites 16, 22 and 26; refer Figure 3-16).

3.4.3 Petroleum Hydrocarbons and BTEX

Results for petroleum hydrocarbons and BTEX are presented in Table 3-5, noting that there are no ISQG trigger values available for total petroleum hydrocarbons (TPH) or for the individual petroleum hydrocarbons fractions. A screening level for total petroleum hydrocarbons is provided by the National Assessment Guidelines for Dredging (DEWHA 2009) and is adopted here.

The range of TPH concentrations measured at Fisherman Islands was comparatively lower than that at Whyte Island, with concentrations ranging from 60 to 931 mg/kg at Fisherman Islands, and from 651 to 1378 mg/kg at Whyte Island. TPH exceeded the NAGD screening level at seven sites, including Sites 6, 8, 16 and 22 on Fisherman Islands, and at all three sites on Whyte Island (Sites

24, 25 and 26). Overall, the elevated concentrations of TPH detected were primarily comprised of C15-C28 (fuel and oil/lubricants) and C29-C36 (asphalt and tar) petroleum hydrocarbon fractions.

There was no consistent relationship between mangrove condition and elevated TPH concentrations. Four of the sites with elevated TPH were located in areas considered to be of good/fair mangrove condition, while three sites were located in dead mangroves. Each of the sites with high TPH also had elevated nutrient concentrations (Section 3.4.2).

For the BTEX concentrations, all analytes (i.e. benzene, toluene, ethylbenzene and xylene) were below the laboratory limit of reporting for all sediment samples.

3.4.4 Organochlorine Pesticides (OCPs)

Concentrations of organochlorine pesticides (OCPs) in sediments from Fisherman Islands and Whyte Island were generally below the laboratory limits of reporting and relevant trigger values at most sites in 2014 (Table 3-6). Four of the organochlorine pesticides (gamma-BHC (Lindane), *p,p'*-DDD, dieldrin and endrin) had concentrations below laboratory detection limits, and these levels were greater than ISQG-low trigger values (note: laboratory raised limits of reporting for organochlorine pesticides due to moisture content and matrix interference).

*p,p'*DDE at sites 2, 3, 4, and 6 (all within the Coal Loading Area of Fisherman Islands) had concentrations that exceeded the ISQG-low value of 2.2 µg/kg. These results are consistent with WBM (2000, 2002) and FRC Environmental (2004 to 2012), which reported elevated concentrations of *p,p'*DDE but not other OCPs. DDE is a breakdown product of the insecticide DDT. It persists in the environment and has the potential to bio-accumulate (ANZECC/ARMCANZ 2000). DDT is not used in the present day insect control methods applied to the study area.

Table 3-3 Metal and metalloid concentrations (mg/kg) in sediments collected from Fisherman Islands and Whyte Island, 2014

Location and site		Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Fishman Islands	1	5.3	<0.1	18	7.2	5.6	0.03	7.9	30
	2	9	<0.1	32	27	11	0.09	20	74
	3	7.7	<0.1	30	26	14	0.08	16	64
	4	7.1	<0.1	26	18	11	0.05	14	52
	5	2.8	<0.1	5.7	1.6	1.4	<0.01	4	11
	6	8.6	<0.1	28	29	9.8	0.05	18	75
	8	8.1	<0.1	22	26	8.8	0.06	14	86
	10	6	<0.1	25	14	8.3	0.05	11	46
	11	6.9	<0.1	19	8.2	6.8	0.03	8.4	32
	13	5.7	<0.1	36	18	9.1	0.04	19	58
	14	11	<0.1	42	20	13	0.05	21	66
	15	7.6	<0.1	27	12	8.1	0.05	14	49
	16	5.2	<0.1	30	16	9.8	0.06	14	68
	17	8.5	<0.1	20	8.9	5.2	0.04	11	35
	18	6.3	<0.1	16	6.3	4.3	0.04	8	32
	19	7.8	<0.1	37	17	10	0.05	18	62
	20	3.2	<0.1	11	5	2.9	0.02	5.6	19
	22	11	<0.1	25	18	13	0.06	15	51
	23	1.8	<0.1	7.2	12	2.4	0.02	3.4	11
Whyte Island	24	4.3	<0.1	28	30	13	0.13	17	58
	25	7.9	<0.1	23	21	17	0.08	13	66
	26	5.5	<0.1	28	28	13	0.12	13	96

1 - Pink shading denotes samples greater than or equal to ISGQ trigger value (ANZECC & ARMCNAZ 2000)

Table 3-4 Nutrient concentrations (mg/kg) in sediments collected from Fisherman Islands and Whyte Island, 2014

Location	Site	TN	TKN	Nitrate	Nitrite	TP
Fisherman Islands	1	630	630	0.8	<0.1	410
	2	4080	4080	<0.1	<0.1	780
	3	6320	6320	<0.1	<0.1	1100
	4	3830	3830	0.1	<0.1	760
	5	1480	1480	<0.1	<0.1	150
	6	9670	9670	<0.1	<0.1	1000
	8	9000	9000	<0.1	0.2	1000
	10	3060	3060	<0.1	0.1	670
	11	1370	1370	<0.1	<0.1	570
	13	1790	1790	<0.1	<0.1	540
	14	1900	1900	<0.1	<0.1	790
	15	1470	1470	<0.1	<0.1	620
	16	6890	6890	<0.1	<0.1	610
	17	1440	1440	<0.1	<0.1	340
	18	1620	1620	<0.1	<0.1	320
	19	3260	3260	<0.1	<0.1	680
	20	1510	1510	<0.1	<0.1	250
	22	10800	10800	<0.1	<0.1	1300
	23	76	76	0.2	0.1	210
Whyte Island	24	7600	7600	<0.1	0.1	680
	25	12600	12600	<0.1	0.1	1300
	26	8450	8450	<0.1	0.2	1200

Table 3-5 TPH and BTEX concentrations (mg/kg) in sediments collected from Fisherman Islands and Whyte Island, 2014

Location	Site	Total Petroleum Hydrocarbons[1]					BTEX					
		C6-C9	C10-14	C15-28	C29-36	TPH[2]	Benzene	Toluene	Ethyl Benzene	m+p xylenes	o-xylene	Total BTEX
Fisherman Islands	1	<10	<10	<50	<50	60	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	2	<20	<20	220	250	490	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4
	3	<20	<20	210	210	440	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4
	4	<10	12	110	130	251	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	5	<10	<10	<50	<50	60	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	6	<20	<20	400	390	810	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4
	8	<20	31	440	450	931	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4
	10	<10	17	170	130	322	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	11	<10	<10	94	93	197	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	13	<10	10	110	86	211	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	14	<10	<10	83	78	171	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	15	<10	<10	<50	63	98	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	16	<20	<20	300	310	630	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4
	17	<10	15	150	150	320	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	18	<10	<10	110	95	215	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	19	<10	<10	87	80	177	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	20	<10	<10	100	75	185	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
	22	<40	<40	500	310	830	<0.8	<0.8	<0.8	<1.6	<0.8	<4.8
	23	<10	36	130	100	271	<0.2	<0.2	<0.2	<0.4	<0.2	<1.2
Whyte Island	24	<20	31	290	320	651	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4
	25	<20	38	780	550	1378	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4
	26	<20	34	590	630	1264	<0.4	<0.4	<0.4	<0.8	<0.4	<2.4

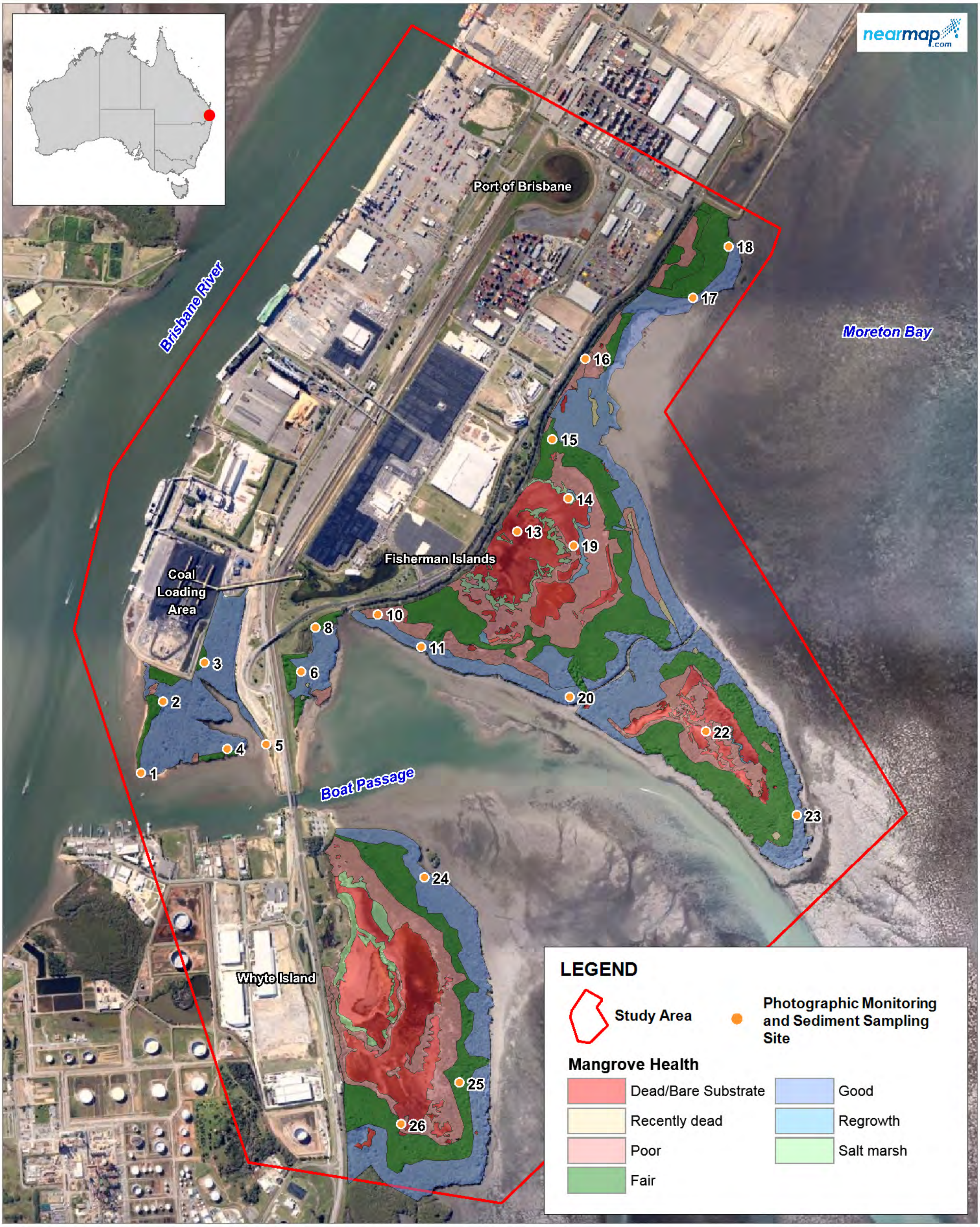
1 - Pink shading denotes samples greater than or equal to NAGD Screening Level (DEWHA 2009)
2- TPH was determined by adding the concentrations of each fraction. Where results include values less than the laboratory limit of reporting, those values less than the laboratory limit of reporting were halved (Environment Australia 2002)

Table 3-6 Organo-chlorine concentrations (mg/kg) in sediments collected from Fisherman Islands and Whyte Island, 2014[1,2]

Parameter	Fisherman Island																			Whyte Island		
	1	2	3	4	5	6	8	10	11	13	14	15	16	17	18	19	20	22	23	24	25	26
Aldrin	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
alpha-BHC	<2	<4	<4	<2	<2	<8	<8	<2	<2	<2	<2	<2	<8	<2	<2	<2	<2	<8	<2	<8	<8	<8
beta-BHC	<2	<4	<4	<2	<2	<8	<8	<2	<2	<2	<2	<2	<8	<2	<2	<2	<2	<8	<2	<8	<8	<8
gamma-BHC (Lindane)	<2	<4	<4	<2	<2	<8	<8	<2	<2	<2	<2	<2	<8	<2	<2	<2	<2	<8	<2	<8	<8	<8
delta-BHC	<2	<4	<4	<2	<2	<8	<8	<2	<2	<2	<2	<2	<8	<2	<2	<2	<2	<8	<2	<8	<8	<8
cis-Chlordane	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
trans-Chlordane	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
p,p'-DDD	<10	<20	<20	<10	<10	<40	<40	<10	<10	<10	<10	<10	<40	<10	<10	<10	<10	<40	<10	<40	<40	<40
p,p'-DDE	<1	8	4	2	<1	5	<4	<1	<1	<1	<1	<1	<4	<1	<1	1	<1	<4	<1	<4	<4	<4
p,p'-DDT	<10	<20	<20	<10	<10	<40	<40	<10	<10	<10	<10	<10	<40	<10	<10	<10	<10	<40	<10	<40	<40	<40
Dieldrin	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
alpha-Endosulfan	<2	<4	<4	<2	<2	<8	<8	<2	<2	<2	<2	<2	<8	<2	<2	<2	<2	<8	<2	<8	<8	<8
beta-Endosulfan	<2	<4	<4	<2	<2	<8	<8	<2	<2	<2	<2	<2	<8	<2	<2	<2	<2	<8	<2	<8	<8	<8
Endosulfan Sulphate	<10	<20	<20	<10	<10	<40	<40	<10	<10	<10	<10	<10	<40	<10	<10	<10	<10	<40	<10	<40	<40	<40
Endrin	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
Endrin ketone	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
Endrin aldehyde	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
Heptachlor	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
Heptachlor epoxide	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
Hexachlorobenzene	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4
Methoxychlor	<5	<10	<10	<5	<5	<20	<20	<5	<5	<5	<5	<5	<20	<5	<5	<5	<5	<20	<5	<20	<20	<20
Oxychlordane*	<1	<2	<2	<1	<1	<4	<4	<1	<1	<1	<1	<1	<4	<1	<1	<1	<1	<4	<1	<4	<4	<4

1 - Blue shading denotes samples potentially greater than or equal to ISGQ trigger value (ANZECC & ARMCNAZ 2000), though uncertain due to inadequate laboratory 'Limit of Reporting'

2 – Pink shading denotes samples greater than or equal to ISGQ trigger value (ANZECC & ARMCNAZ 2000)



Title:

Location of Sediment Sampling Sites in Relation to Mangrove Condition Categories

Figure: **3-16**

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4 Discussion

4.1 Patterns in Community Structure

The mangrove forests (mangals) of the study area were floristically similar to other locations on the west coast Moreton Bay (Dowling 1986; Abal *et al.* 1998). Consistent with other coastal (non-riverine) environments on the south-eastern Queensland coast, remnant and regenerating mangals in the study are were numerically dominated by *Avicennia marina. Avicennia marina* is particularly tolerant of saline waters compared to other mangrove species, which represents a competitive advantage allowing it to dominate in more saline coastal environments.

Ceriops tagal var. *australis* co-dominated with *Avicennia marina* in places, most notably on the landward margin of the south-western sector of Fisherman Islands. Aziz and Kahn (2001) found that *Ceriops tagal* had a salinity tolerance approaching that of *Avicennia marina,* which allows it to co-dominate in these saline coastal environments.

Consistent with other estuaries on the south-eastern Queensland coast, remnant and regenerating saltmarsh in the study are was numerically dominated by *Sarcocornia quinqueflora, Sesuvium portulacastrum, Enchylaena tomentosa, Suaeda australis* and *Suaeda arbusculoides*. Saltmarsh vegetation was largely restricted to a narrow fringe at both Fisherman Islands and Whyte Island, located between a large area classified as 'dead mangroves/bare' and mangroves in poor condition. This 'dead mangroves/bare' category includes both disturbed and undisturbed saltpan/saltmarsh and areas that once supported mangrove forest (see Section 4.2.1).

Saltmarsh is particularly vulnerable to sea level rise, clearing and mangrove invasion, and is now listed as a Vulnerable Ecological Community under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*. There is presently insufficient information to determine long-term trends in saltmarsh communities within the study area. However, given that saltmarsh is restricted to a small fringe between dead and degraded mangroves, there is a need for further work to determine key drivers and its long term viability.

4.2 Patterns in Mangrove Health

4.2.1 Long term Context

WBM has investigated historical patterns in mangrove distribution and extent at Fisherman Islands in a series of reports, most notably WBM (1998) and WBM (2000). Key historical trends in mangrove distribution and extent recorded by WBM (1998; 2000) are summarised in Table 4-1. Note that WBM (1998) only mapped mangrove changes at Fisherman Islands and Bishop Island, and historical aerial photography for Whyte Island (presented in WBM 1998) has been inspected in the present study.

Aerial photography from 1972 shows that bare substrate (possibly including saltmarsh vegetation and/or saltpan) was present on Whyte Island to the east and west of the present day Port Drive. This area of bare substrate is still present today, and was mapped in the present study as 'dead mangrove/bare' category. By 1978, Port Drive had been constructed, and this area of bare substrate had been extensively disturbed, and had also significantly increased in extent to the east of this 'remnant' bare substrate. The 1987 aerial photograph shows that there was a further expansion in the area of bare substrate east of the 'new' substrate recorded in 1978. The results of the present study show that the extent of bare substrate/bare mangroves has significantly increased since this time.

The causes of the major changes in mangrove/bare substrate extent at Whyte Island have not been fully determined. Clearing and filling of 'remnant' saltpan/saltmarsh and mangroves as part of the construction of Port Drive appears to be a key driver of change between 1972 and 1978. Previous investigations by WBM (2002) suggested a potential linkage between mangrove health, and nutrient and contaminant (metals, TPH) concentrations at Whyte Island. The cause/s of mangrove loss since 1978 has not been explored in detail to date, but are considered in the following section.

Table 4-1 Historical changes in mangroves documented by WBM (2000) between 1972 and 1995

Year	Fisherman Islands	Whyte Island
1972	• Mangrove cover largely in-tact across Fisherman Islands • Patches of bare substrate/'saltmarsh' mapped east of present day Lucinda Drive (hereafter referred to as central saltpan), and in the eastern 'point' of Fisherman Islands	• Mangrove cover largely in-tact across Whyte Island • Bare substrate (either saltpan or saltmarsh) present immediately east and west of present day Port Drive
1978	• Clearing of mangroves along newly constructed Port Drive, resulting in isolation of mangroves on the Brisbane River side • Mangrove/saltpan/saltmarsh elsewhere largely unchanged from 1972	• Significant expansion of bare substrate to the east and west of the newly constructed Port Drive associated with infilling on remnant saltpan/saltmarsh and mangrove areas
1983	• Mangrove/saltpan/saltmarsh largely unchanged from 1978	No available imagery
1987	• Significant expansion in the area of 'bare substrate/saltmarsh' east and west of the present day Lucinda Drive, as a result of unconfined reclamation activities in the central saltpan area • Mangrove/saltpan/saltmarsh in eastern sector largely unchanged from 1972	• Further expansion of the extent of bare substrate to the east of the 'new' bare substrate area observed in 1978
1991	• Further reclamation of mangroves associated with port expansion works in the north-western section of Fisherman Islands • Mangrove/saltpan/saltmarsh in eastern sector largely unchanged from 1972	• Gross changes in mangroves and bare substrate not evident, but small-scale changes possible
1993-98	• Further reclamation of mangroves associated with port expansion works in the north-western section of Fisherman Islands • Mangrove/saltpan/saltmarsh in eastern sector largely unchanged from 1972	• Gross changes in mangroves and bare substrate since 1991 not evident, but small-scale changes possible

Historical changes to mangroves and bare substrate have been extensively mapped and described by WBM (2000). Aerial photography from 1972 shows that 'remnant' patches of bare substrate/'saltmarsh' occurred east of present day Lucinda Drive (hereafter referred to as central saltpan), and in the eastern 'point' of Fisherman Islands. Large losses in mangroves were coincident with the construction of Port Drive (1978). Port expansion works in the late 1980's resulted in (i) infilling of the remnant patches of bare substrate/'saltmarsh'; and (ii) reclamation/indirect impacts causing extensive losses in mangrove forest within and adjacent to port expansion footprint. Since the late 1990's there have been ongoing losses in mangroves (and increases in 'bare substrate') adjacent to the port expansion footprint, as well as an expansion of the 'remnant' bare substrate near the eastern tip of Fisherman Islands. These contemporary losses are not known to be a direct result of broad-scale clearing/reclamation, and potential causes are discussed in the following sections.

4.2.2 Contemporary Patterns

The general distribution and patterns of mangrove health at each location were broadly similar to those described in 2012, with each location broadly characterised as follows:

- *Fisherman Islands, Northern Section* – Mangroves were mostly in good or fair condition, although degraded mangrove areas were present adjacent to reclaimed lands on the landward margin of the northern section. Areas classified as poor or dead were typically affected by surface water ponding, a high occurrence of deformed pneumatophores and/or high epiphytic algae cover.
- *Fisherman Islands, Western Section* – The seaward margins were comprised of good quality mangrove forest. However, extensive areas of dead and poor condition mangroves were present in central/landward sectors. As discussed in Section 4.2.1, these bare and degraded areas once supported saltpan/saltmarsh and mangrove forest prior to port expansion works in the 1980's (WBM 1998; 2000).
- *Fisherman Islands, Eastern Section* – Extensive areas of good and fair condition mangroves were present, although the central region was dominated by 'dead/bare' areas and poor condition mangroves. A remnant patch of saltmarsh/saltpan was mapped by WBM (1998; 2000) based imagery from the 1970's and 1990's, which is coincident with the "dead/bare" category (i.e. this area appears to represent remnant saltpan/saltmarsh). It is not known whether there has been an actual change in extent of poor condition mangroves.
- *Fisherman Islands, Coal Loading Area* – The Coal Loading Area section of Fisherman Islands was in the healthiest condition, predominantly compromised of mangroves in good condition, with only small patches of dead or poor condition mangroves.
- *Whyte Island* – Half of Whyte Islands was classified as either dead or poor condition mangroves, encompassing the majority of the central and landward area. Mangroves in good and fair condition were restricted towards the outer seaward margin. As discussed in Section 4.2.1, these bare and degraded areas once supported saltpan/saltmarsh and mangrove forest prior to road construction works in the 1970's (WBM 1998; 2000).

While these broad patterns remained consistent, there was an evident decline in mangrove health across the study area since the previous survey. Key areas exhibiting a decline in mangrove health included (by category):

- *'Dead/bare'* – Patches of dead mangrove trees were mapped towards the outer seaward boundaries around Whyte Island and the eastern section of Fisherman Islands;
- *Recently dead* – New patches of recent dieback observed across Fishman Island, including the outer boundaries of the northern, western and eastern sections, as well as the Coal Loading Area; and
- *Poor* – An increase in the area of mangroves in poor condition across Fisherman Islands, including significant bands towards the eastern boundary of both the western and eastern sections, and areas on the outer boundary of the Coal Loading Area.

Recovery of mangroves (i.e. regrowth, and change in category from regrowth to good) was observed in small isolated areas. Some recovery was detected through the mapping component, however it was most evident through the photographic monitoring, specifically:

- Photographic monitoring detected increasing establishment of regrowth mangrove vegetation, marked by taller mangroves in good condition, at Sites 15 and 22 (western and eastern sections of Fisherman Islands, respectively). At Site 14 in the western section of Fisherman Islands, improved saltmarsh condition and extent was also recorded through the photographic monitoring.
- At the Fisherman Islands (eastern section), the area previously mapped as regrowth had become established and was mapped as good condition mangroves.

4.3 Processes Controlling Mangrove Health

The structure of mangrove and saltmarsh communities is governed by a range of complex, inter-related processes. Anthropogenic alterations to these processes can lead to changes to mangrove and saltmarsh condition and community structure. Declines in the condition or health of mangrove communities can be caused by numerous natural and anthropogenic factors, or by the cumulative effects of a combination of such factors, as discussed below.

4.3.1 Physical Processes and Flushing

Hydrological processes are a key driver of wetland health and vegetation community structure. Mangroves and saltmarshes are adapted to live in saline, waterlogged environments (Saenger et al. 1977), but tend to occupy different levels of the shoreline. Mangroves live between the mid-intertidal to Mean High Water Mark (MHWM), whereas saltmarshes typically occur above MHWM but below Mean High Water Spring (MHWS). Tidal processes are a key driver of these spatial patterns, and even small disruptions to these processes (including alterations to flushing) can result in major changes in community structure.

Disruptions to catchment hydrology and tidal processes can lead to alterations to drainage patterns and water ponding. Aside from the range of secondary effects occurring that are associated with ponding water and may contribute to poor mangrove health (i.e. reduced water quality, anoxic conditions, macroalgal mats, reduced benthic diversity and associated bioturbation etc.), water ponding alone can be detrimental to mangrove health. In this regard, prolonged water ponding can impair mangrove respiration by restricting gas exchange (i.e. reduced exposure to air), resulting in physiological stress and eventually mortality in severe cases (Field 2007).

It has also been hypothesised that water ponding in areas of mangrove dieback may be symptomatic of land subsistence; the 'sinking centre' hypothesis of Duke *et al.* (2010) and DEEDI (2011), In the absence of high resolution (accuracy ± 10-20 mm) bed elevation data from different time periods it is not possible to determine whether subsidence has occurred. However, available LiDAR data (see Appendix B) suggests that local topography, at least in the western and eastern sections of Fisherman Islands, would facilitate water ponding. At these locations, there are central areas of relatively low-lying land are surrounded by slightly elevated ground, such that drainage of rainfall and tidal overflow would likely be impeded.

Sedimentation can also lead to localised impacts to mangrove condition. Where new dieback and poor condition mangroves were mapped at the (eastern) Coal Loading Area, there was a substantial build-up of sand among the mangroves, potentially due to an increase in wave energy at the seaward edge of the mangrove community. This sand had buried pneumatophores, which can affect the respiratory activity of *Avicennia marina*. It may also act as a bund, which could pond water and interrupt tidal flow to/from the mangrove community.

These physical processes can lead to a range of secondary water quality effects, as described below.

4.3.2 Water Quality

To date, examination of potential causal factors as part of this monitoring program has concentrated on pore water salinity and sediment quality. Monitoring detected a strong association between pore water salinity and mangrove health in the period up to 2010, with higher pore water salinity recorded in degraded mangrove areas. While this trend has been less pronounced during the last two surveys, pore water salinity remained lowest within the 'good' mangrove health category compared to the comparatively degraded mangrove categories (i.e. fair to dead) at the same location.

It is hypothesised that differences in porewater salinity between good to degraded mangroves reflected differences in local elevation, drainage patterns, and degree of regular tidal inundation/flushing. The healthiest mangroves generally occur along the well flushed, seaward margins of mangrove forest, whereas dead mangroves and mangroves in poor condition were almost exclusively found landward of the mangrove fringe. As discussed above, several patches of 'dead/bare' and highly degraded mangroves were poorly drained (as evidenced by water ponding during low tide), which could lead to elevated porewater salinity. This would especially be the case during periods of low rainfall and/or high evaporation, and possibly during neap tide periods (refer Section 4.3.3 for discussion on droughts).

Over the last two monitoring surveys, sediment concentrations of nickel and *p,p'DDE* both exceeded toxicity trigger values in places; nickel in the area of dead mangroves at the Fisherman Islands western section, and *p,p'DDE* among good/fair mangroves at the Coal Loading Area. As mentioned previously (Section 3.4.2), the nickel exceedance recorded (21 mg/kg) is not particularly high and likely associated with similar nickel concentrations occurring naturally throughout the wider area. Furthermore, no association between *p,p'DDE* and mangrove health is suspected, given that elevated concentrations were not detected among the many other sampling sites located among mangroves of good/fair condition.

WBM (2002b) examined potential causes of mangrove dieback at Whyte Island, and identified heavy metals, TPH and high nutrients as potential stressors. The three sediment sampling sites currently at Whyte Island are located towards the outer seaward margin, in areas dominated by good/fair condition mangroves. There are few available contaminant data for degraded mangrove areas. This limitation with the monitoring program design precludes a meaningful assessment of potential linkages between mangrove health and contaminant concentrations.

4.3.3 Biological Interactions

Saltmarshes and mangroves compete for space near their lower and upper tidal range limits, respectively. Case studies elsewhere indicate that crustaceans (crabs, amphipods) can regulate the distribution of estuarine wetland plants through the consumption of plant propagules. The importance of biological interactions in regulating wetland communities would vary over a range of local spatial scales (measured in metres to 10's of metres).

Competition dynamics may change in response to changes in environmental conditions. For example, changes in tidal heights could favour mangroves to the detriment of saltmarsh species. Long term annual rainfall data (Appendix C) suggest that, like the rest of southeast Queensland and northern New South Wales, the study area has been experiencing its driest decade or two since records began. It is also unknown whether any long-term (measured in decades to centuries) changes in water levels (i.e. due to changes in tidal heights or rainfall) have resulted in changes to the distribution and extent of different wetland species.

4.4 Conclusions

The present study found that while mangrove forests across the Fisherman Islands and Whyte Island were mostly in good to fair condition, there were extensive areas of dead/bare areas and dying mangroves. There has been a steady decline in mangrove condition at Fisherman Islands and Whyte Island over the last two decades, particularly in landward margins which are considered most vulnerable to changes to hydrology.

Saltmarsh is restricted to a small fringe between dead and degraded mangroves. There is presently insufficient information to assess long term trends in saltmarsh extent and condition. Coastal saltmarsh is considered a Vulnerable Ecological Community under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*, and is considered particularly vulnerable to altered hydrology and invasion by mangroves.

Long term patterns in mangrove health and physical, chemical and biological drivers have not been fully explored to date. This should be a future focus on the mangrove monitoring program, in order to determine mitigation is practical or feasible. Given current trends, it is expected that there will be further mangrove degradation unless the effects of key stressors can be mitigated.

5 References

Abal, E. G., W. C. Dennison, and M. H. O'Donohue. (1998). Seagrasses and Mangroves in Moreton Bay. Pages 269-278 in I. R. Tibbetts, N. J. Hall, and W. C. Dennison, editors. Moreton Bay and Catchment. School of Marine Science, University of Queensland, Brisbane.

ANZECC & ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council, and Agriculture and Resource Management Council of Australian and New Zealand.

Aziz, I. and M. A. Khan. (2001). Experimental assessment of salinity tolerance of *Ceriops tagal* seedlings and saplings from the Indus delta, Pakistan. Aquatic Botany 70:259–268.

BMT WBM (2013) Port of Brisbane maintenance dredging – sediment quality report. Prepared for the Port of Brisbane by BMT WBM, Brisbane.

DEEDI (2011) Data collection protocol for mapping and monitoring mangrove communities in Queensland. Queensland Department of Employment, Economic Development and Innovation, Brisbane.

DEWHA (2009) National Assessment Guidelines for Dredging (NAGD). Australian Department of Environment, Water, Heritage and the Arts, Canberra.

DoE (1998) Draft Guidelines for the Assessment and Management of Contaminated Land in Queensland. Queensland Department of Environment, Brisbane.

Dowling, R. M. (1986). The mangrove vegetation of Moreton Bay. Queensland Botany Bulletin No. 6.

Duke, N., Haller, A., Brisbane, S., Wood, A., Rogers, B. (2010) 'Sinking Centres' in Moreton Bay mangroves – maps showing areas of unusual anoxic ponds and mangrove dieback in tidal wetlands of the bay area in 2003-08. Report to H & A, QPIF, DEEDI, Queensland. Revised version: 20 August 2010. School of Biological Sciences, The University of Queensland, Brisbane.

Field, C.D. (2007). Rehabilitation of mangrove ecosystems: an overview. Marine Pollution Bulletin, 37: 383-392.

FRC Environmental (2004) Fisherman Islands and Whyte Island Mangrove Health Assessment 2004. Prepared for the Port of Brisbane Pty Ltd by FRC Environmental, Wellington Point.

FRC Environmental (2006) Fisherman Islands and Whyte Island Mangrove Health Assessment 2006. Prepared for the Port of Brisbane Pty Ltd by FRC Environmental, Wellington Point.

FRC Environmental (2008a) Fisherman Islands and Whyte Island Mangrove Health Assessment: Volume 1. Prepared for the Port of Brisbane Pty Ltd by FRC Environmental, Wellington Point.

FRC Environmental (2008b) Fisherman Islands and Whyte Island Mangrove Health Assessment: Volume 2 - Appendices. Prepared for the Port of Brisbane Pty Ltd by FRC Environmental, Wellington Point.

FRC Environmental (2010) Fisherman Islands and Whyte Island Mangrove Health Assessment 2012. Prepared for the Port of Brisbane Pty Ltd by FRC Environmental, Wellington Point.

FRC Environmental (2012) Fisherman Islands and Whyte Island Mangrove Health Assessment 2012. Prepared for the Port of Brisbane Pty Ltd by FRC Environmental, Wellington Point.

McKee, K., Mendelssohn, I., Hester, M. (1998) Reexamination of pore water sulphide concentrations and redox potentials near the aerial roots of Rhizophora mangal and Avicennia germinans. American Journal of Botany 75(9): 1352-1359.

Reichelt, A., Jones, G. (1994) Trace metals and tracers of dredging activity in Cleveland Bay – field and laboratory studies. Australian Journal of Marine and Freshwater Research, 45:1237-1257.

Ward, I., Larcombe, P. (1996) A geochemical comparison of modern and Holocene sediments, north Queensland. Wetlands Australia, 15(1): 10-21.

WBM (2000) Assessment of the health, viability and sustainability of mangrove communities at Fisherman Islands. Prepared for Port of Brisbane Corporation by WBM Oceanics Australia, Brisbane.

WBM (2002a) Assessment of the health and viability of mangrove communities at Fisherman Islands. Prepared for Port of Brisbane Corporation by WBM Oceanics Australia, Brisbane.

WBM (2002b) Assessment of the health and viability of mangrove communities at Whyte Island. Prepared for Port of Brisbane Corporation by WBM Oceanics Australia, Brisbane.

Appendix A Photographic Monitoring Images - 2014

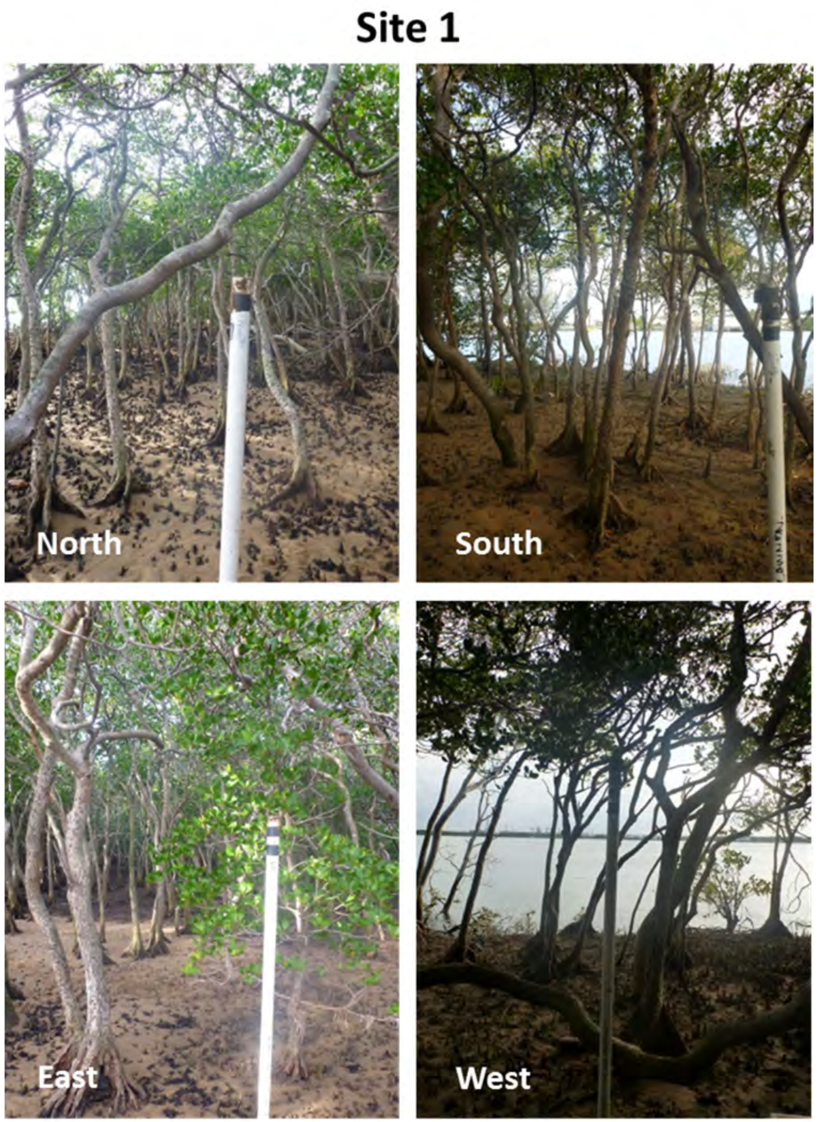

Figure A-1 Site 1 Photographic Monitoring, 2014

Figure A-2 Site 2 Photographic Monitoring, 2014

Photographic Monitoring Images - 2014

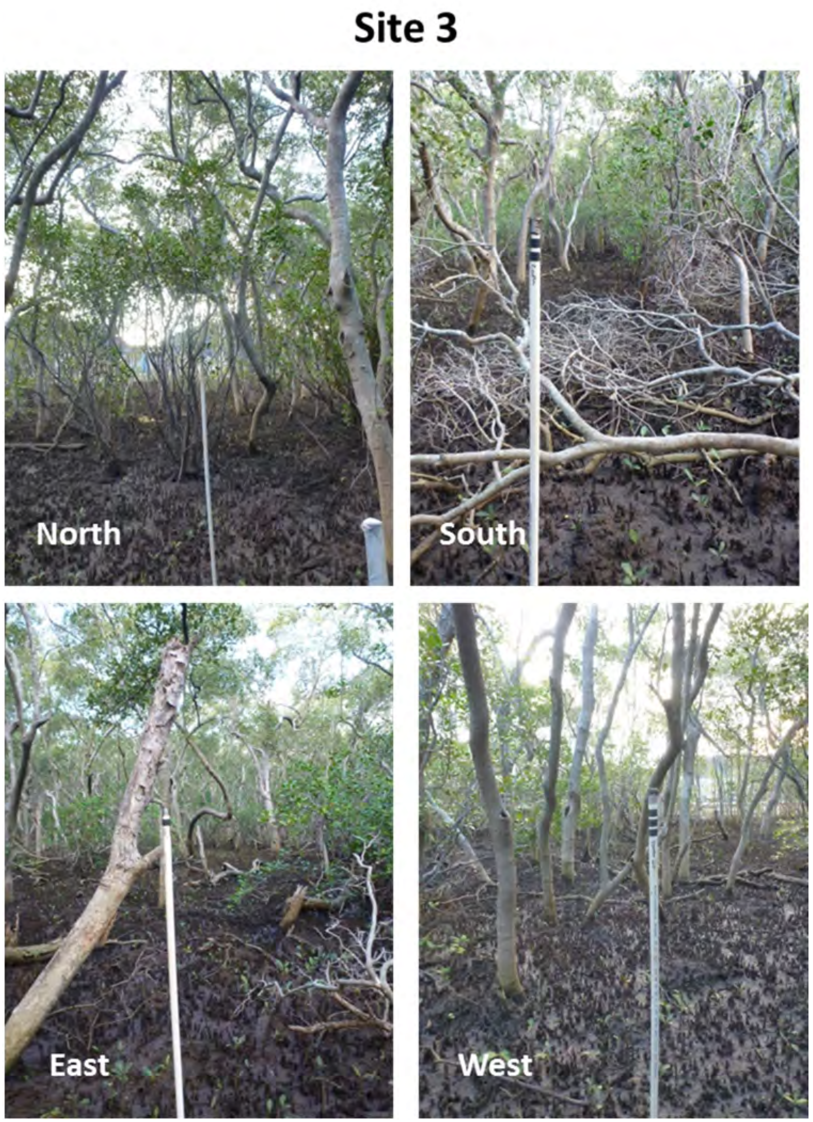

Figure A-3 Site 3 Photographic Monitoring, 2014

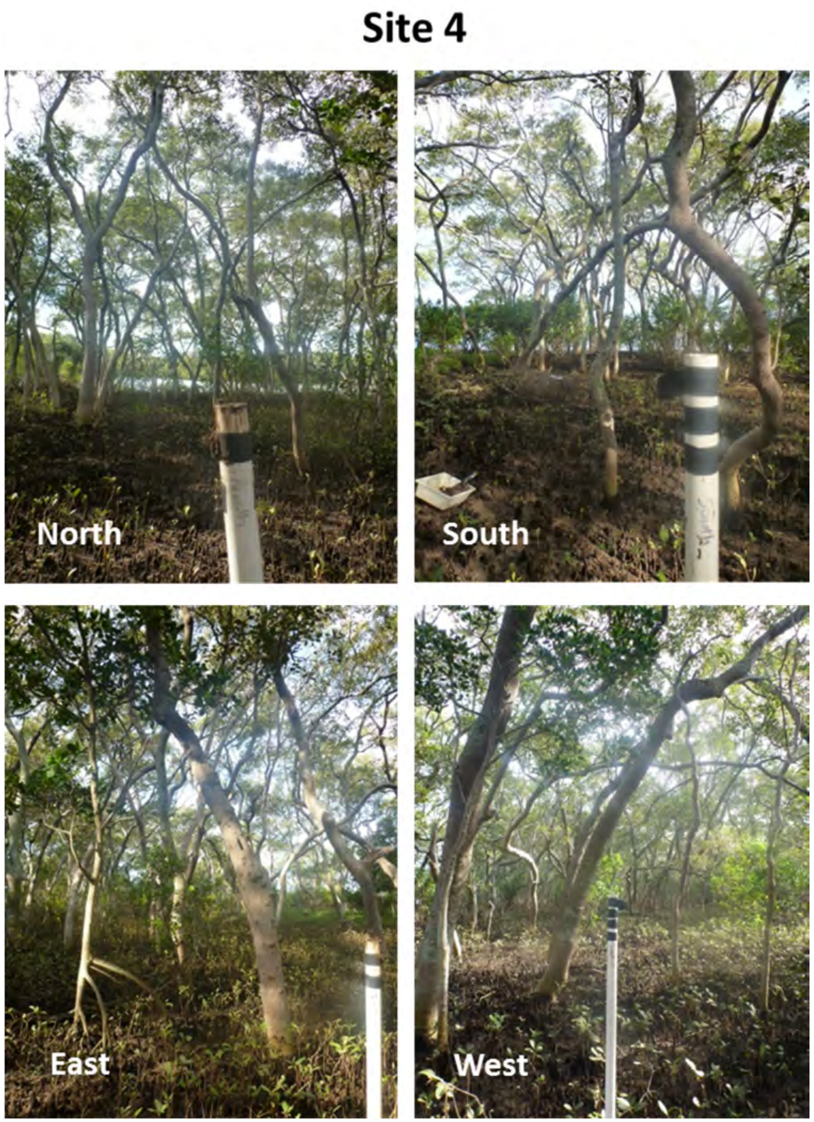

Figure A-4 Site 4 Photographic Monitoring, 2014

Figure A-5 Site 5 Photographic Monitoring, 2014

Figure A-6 Site 6 Photographic Monitoring, 2014

Site 8

Figure A-7 Site 8 Photographic Monitoring, 2014

Site 10

Figure A-8 Site 10 Photographic Monitoring, 2014

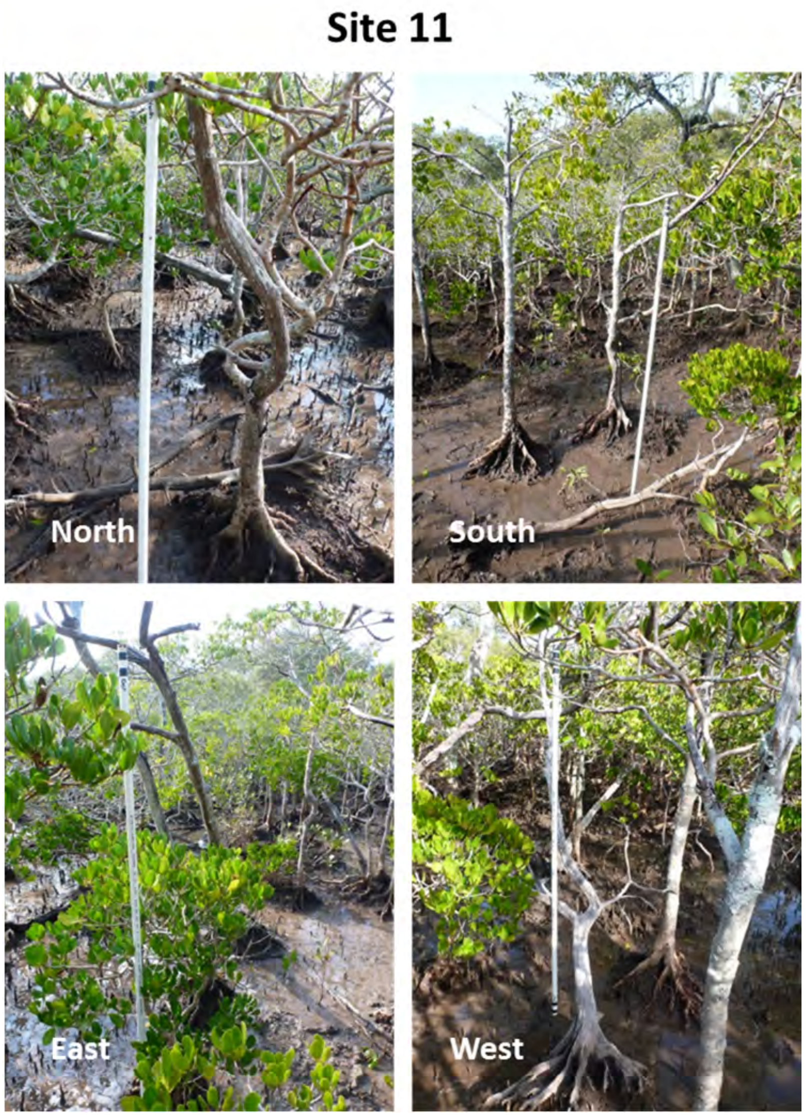

Figure A-9 Site 11 Photographic Monitoring, 2014

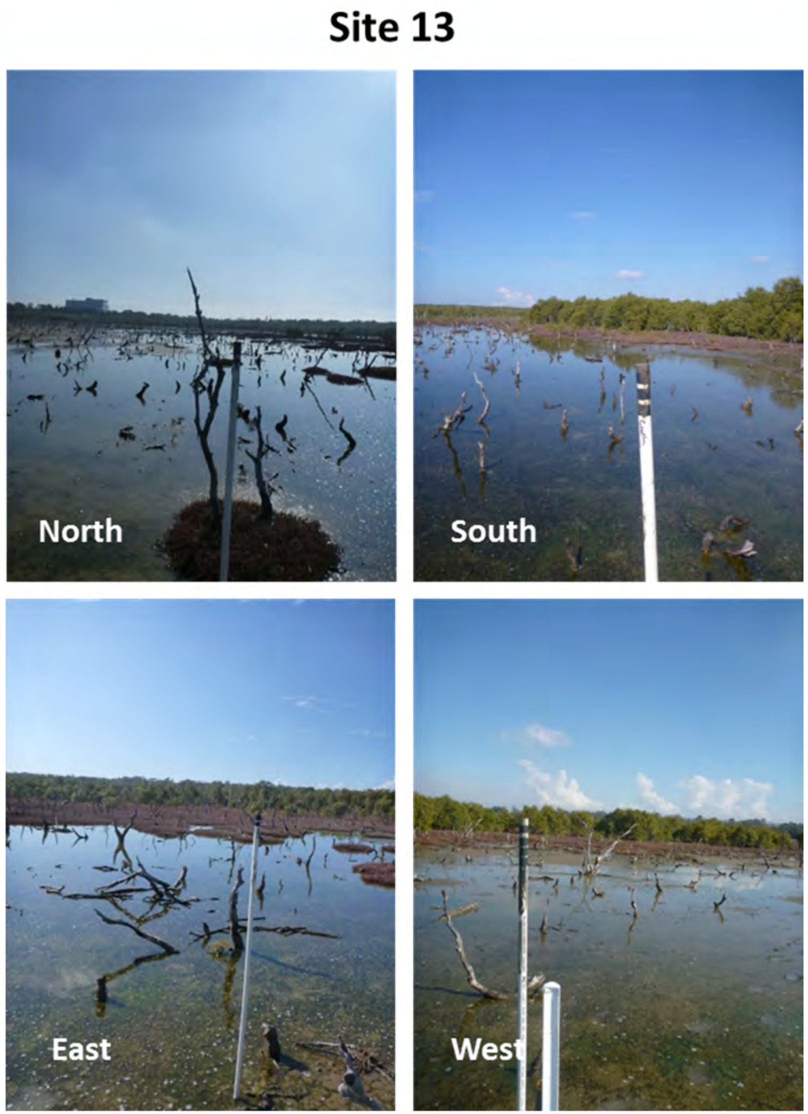

Figure A-10 Site 13 Photographic Monitoring, 2014

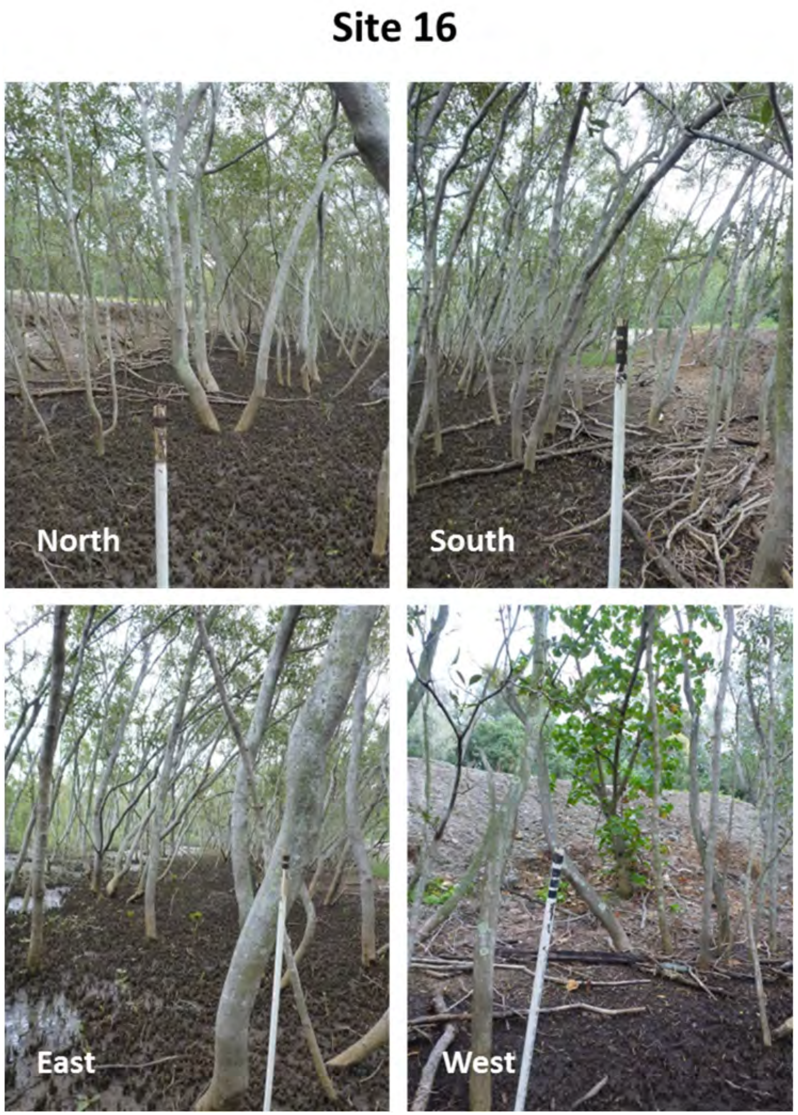

Figure A-11 Site 16 Photographic Monitoring, 2014

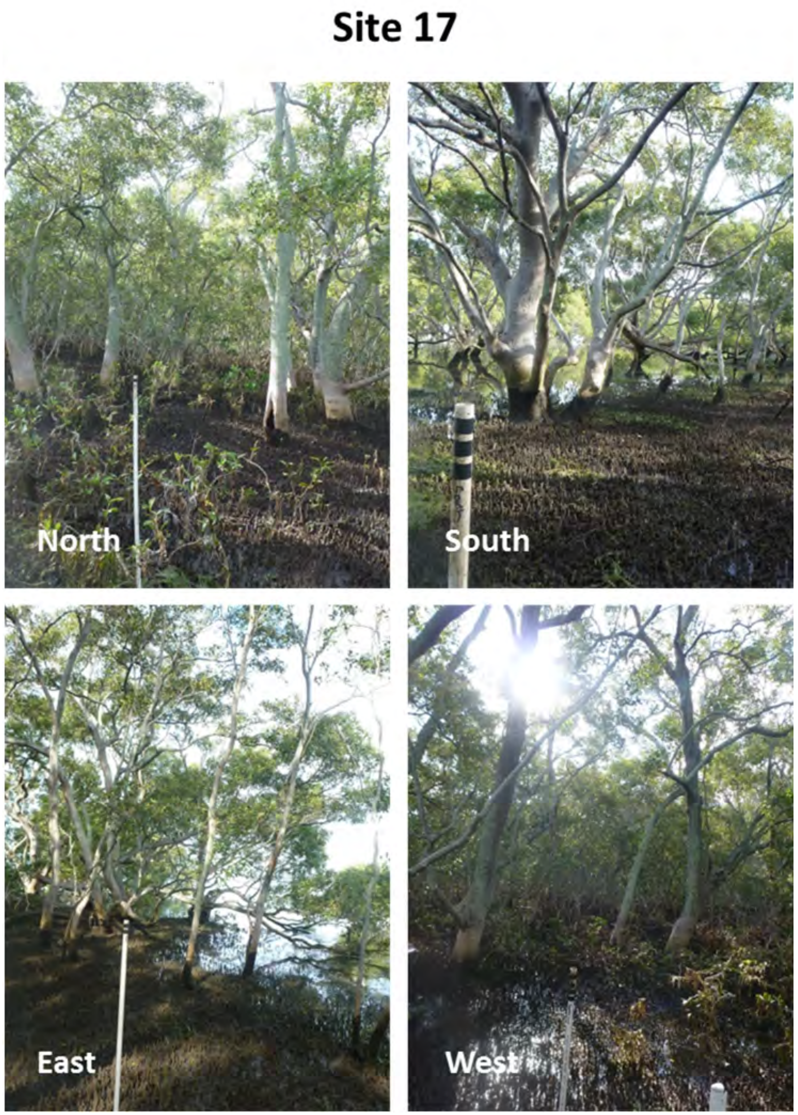

Figure A-12 Site 17 Photographic Monitoring, 2014

Site 18

Figure A-13 Site 18 Photographic Monitoring, 2014

Site 20

Figure A-14 Site 20 Photographic Monitoring, 2014

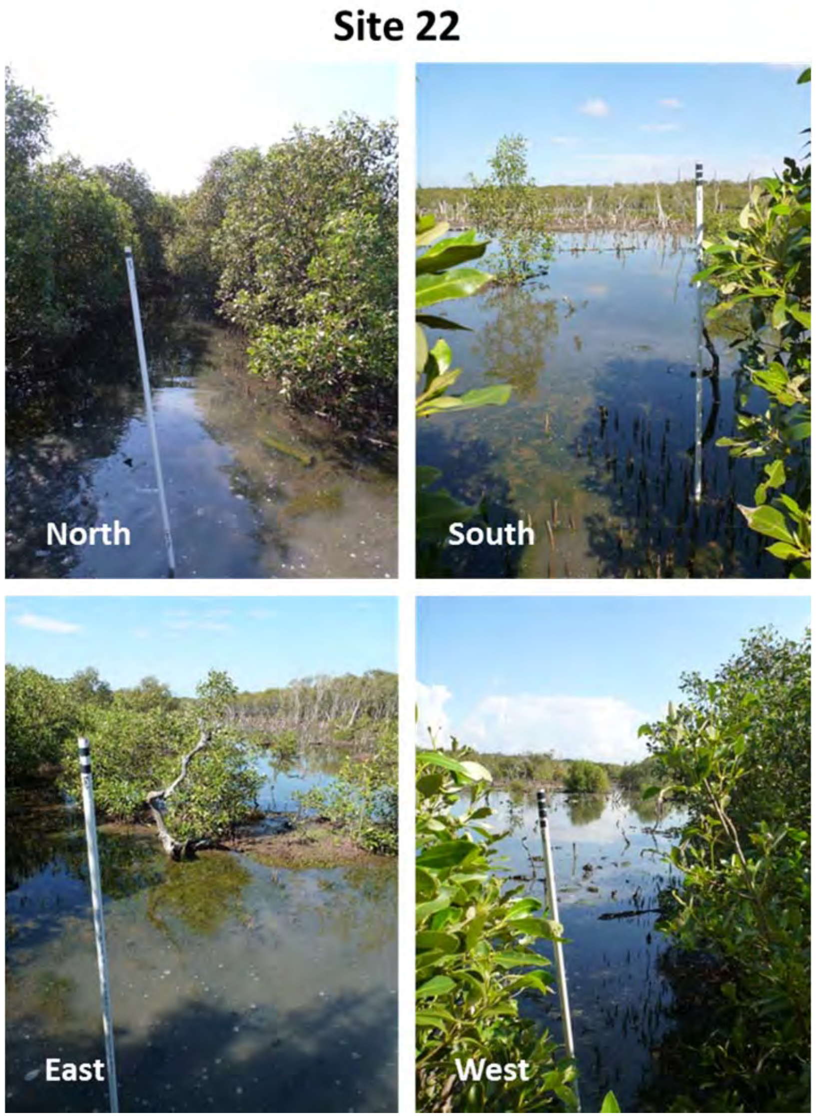

Figure A-15 Site 22 Photographic Monitoring, 2014

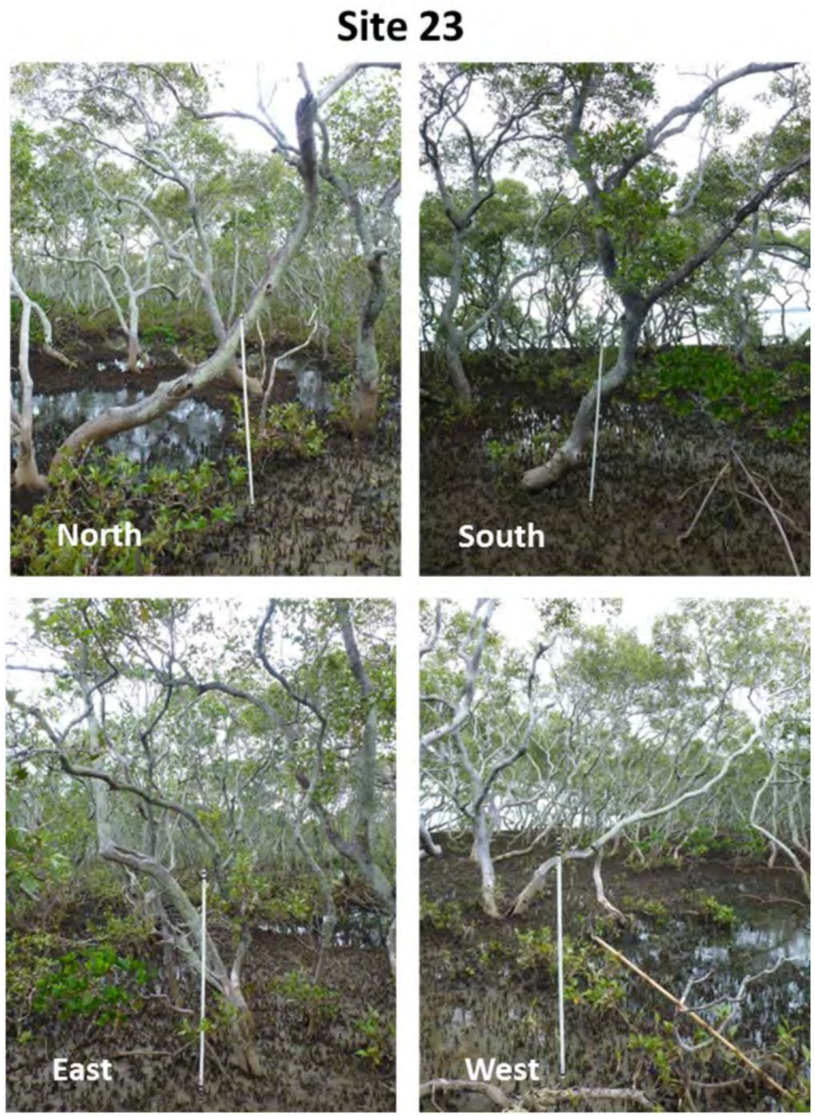

Figure A-16 Site 23 Photographic Monitoring, 2014

Site 14

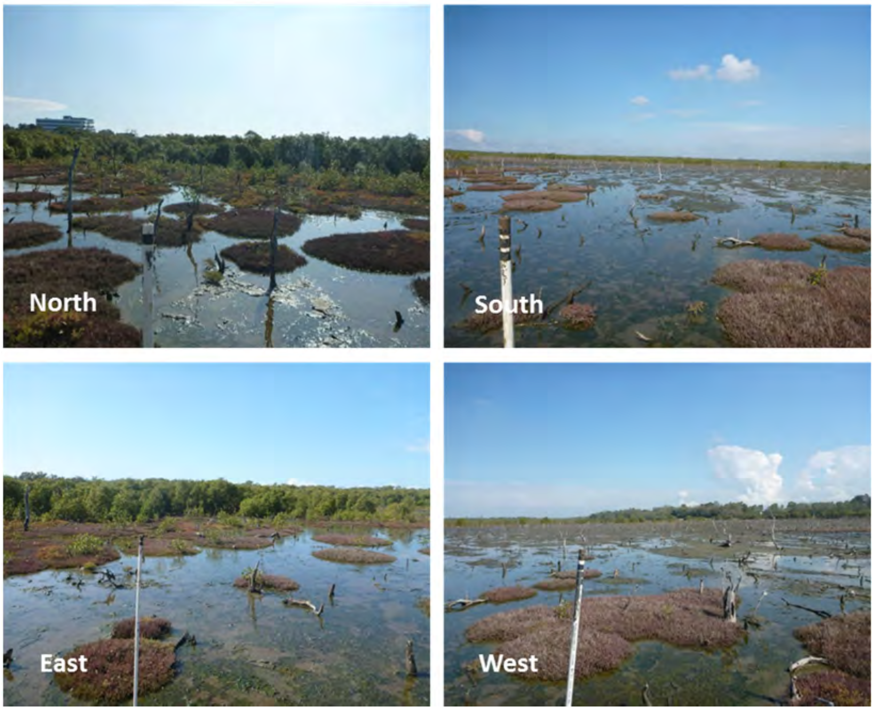

Figure A-17 Site 14 Photographic Monitoring, 2014

Site 15

Figure A-18 Site 15 Photographic Monitoring, 2014

Site 24

Figure A-19 Site 24 Photographic Monitoring, 2014

Site 25

Figure A-20 Site 25 Photographic Monitoring, 2014

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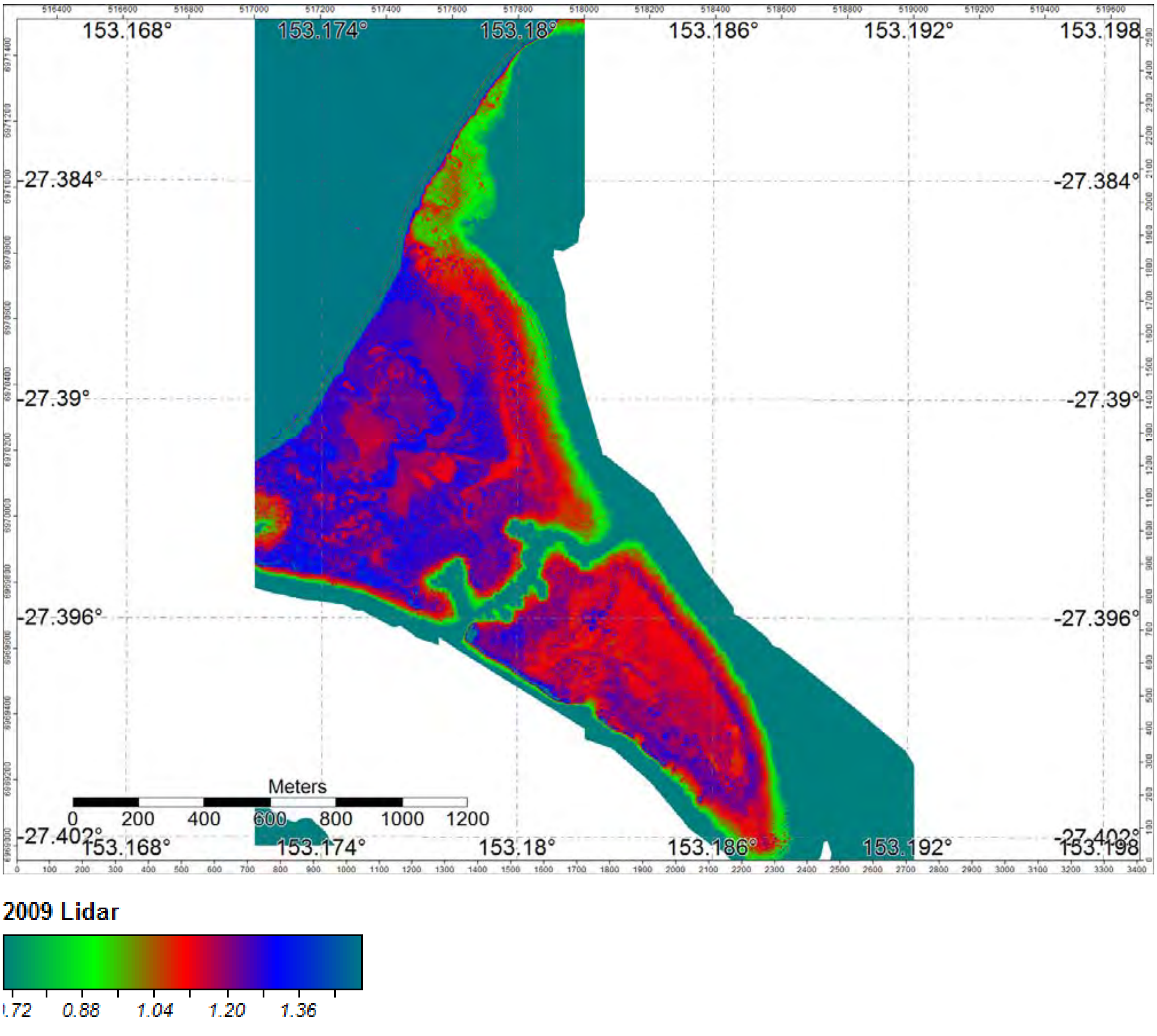
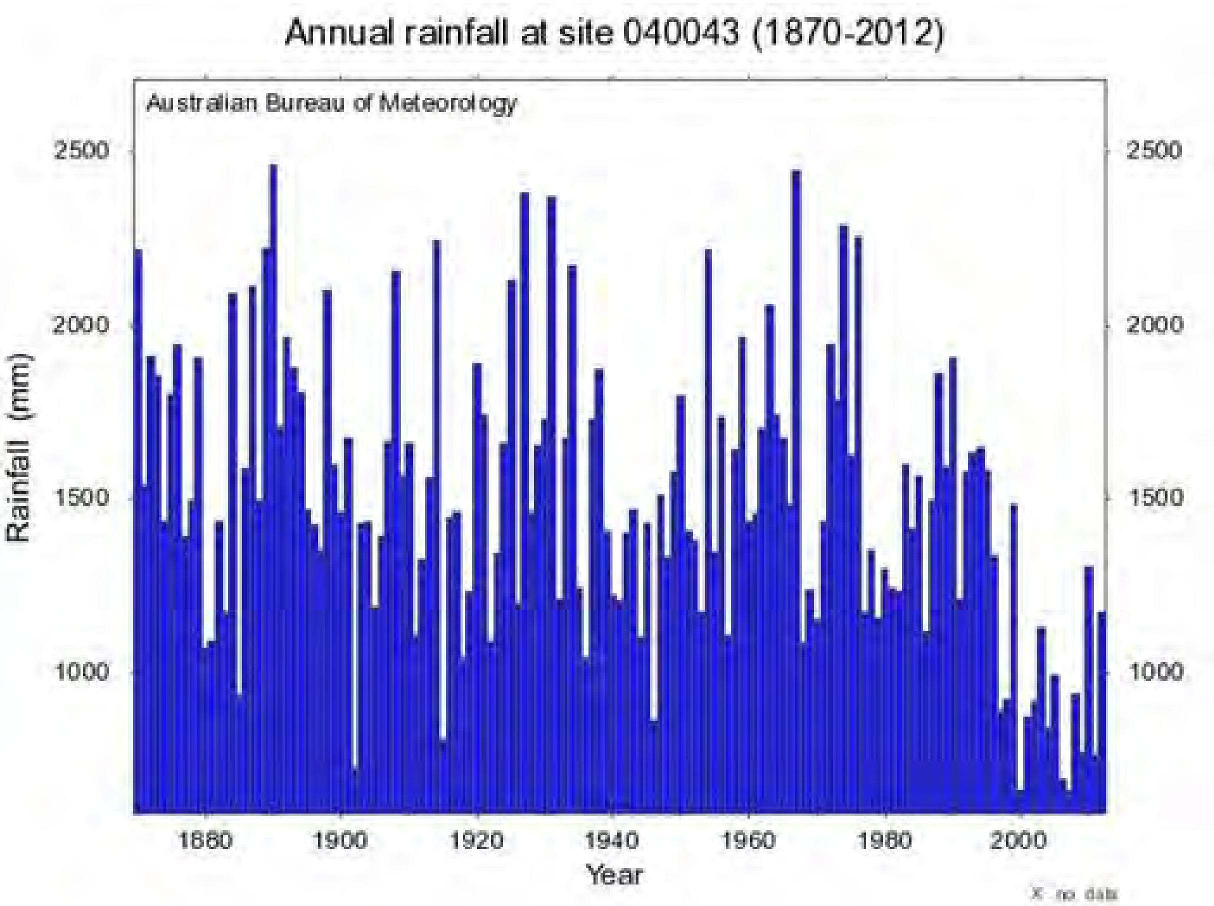
Figure A-21 Site 26 Photographic Monitoring, 2014

Appendix B Topography – 2009 LiDAR, Fisherman Islands



Appendix C Annual Rainfall at Moreton Bay Rain Gauge



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