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Port Alma Receiving Environment Monitoring Program Design Report

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Port Alma Receiving Environment Monitoring Program Design Report

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Synopsis: **A report which describes the design of the receiving environment monitoring program (REMP) at the Port of Rockhampton. This REMP design document specifically considers the potential impacts of dredging and offshore placement of dredged material on receiving environments.**

REVISION/CHECKING HISTORY

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Executive Summary

Port Alma Shipping Terminal is located 62km east of Rockhampton on the southern tip of the Fitzroy River delta and is operated by Gladstone Ports Corporation (GPC). The port has undertaken maintenance dredging in 2000, 2009 (23,000 m^3) and most recently in 2011 (40,000 m^3). Campaigns generally last a matter of days. The effects of maintenance dredging and dredged material disposal have not been investigated within this area to date.

GPC initiated the development of a receiving environment monitoring program (REMP) for the Port of Rockhampton (PoR). This REMP Design Report provides contextual information regarding the proposed activity (maintenance dredging), the receiving environment and the recommended design of the REMP. The aim of this REMP design document is to document procedures to monitor, identify, and describe potential impacts of dredging and dredged material disposal activities on ecological receptors within the receiving waters of the study area and meet the requirements of the Environmental Authority (EA EPPR00570813, sp. condition G8). Condition G9 of the EA requires a copy of the REMP to be submitted to the Department of Environment and Heritage Protection, and any comments incorporated.

Condition G8 of the EA requires:

a) Significant sensitive receptors in the PoR to be identified and mapped

b) Environmental aspects and potential impacts to be identified

c) All contaminant releases to be monitored

d) Methods for collection and analysis of samples (incl. specific areas to be monitored, times and durations) to be described.

e) That methods for data analysis and responding to results are described, to ensure compliance

f) Assessment of long-term ecological impacts associated with dredging

g) Reporting intervals to be specified

h) A review of environmental performance to be conducted after each dredge campaign.

As per Schedule 1 of the *Environmental Protection (Water) Policy 2009* (EPP Water 2009) Water, the study area falls into the slightly disturbed level of protection (Level 2), for which corresponding WQOs have been derived. 'Level 1' (high ecological/ conservation value) occur in the estuarine sections of Horrigan Creek located south of the study area, and freshwater streams that drain into Connor Creek.

Key ecological assets near the dredge area and the Dredged Material Placement Area (DMPA) include intertidal habitats (mangroves, saltpan, intertidal flats and seagrass), benthic macroinvertebrates, fish, shellfish, shorebirds, marine megafauna, and coral reefs. These communities exist within the Fitzroy River Delta (Queensland's largest catchment) and experience pulsed disturbances associated with quasi-annual flooding. The Fitzroy River has a major influence on the sedimentary, physical, and biological environments here and must be considered in the development of the any monitoring program.

Dredging can affect receiving environments through a range of mechanisms. Key impacting processes relevant to the activity include removal of benthos during dredging, burial of benthic fauna during placement of dredged material, and possible indirect water quality impacts associated with the creation of turbid plumes during dredging and material placement. The scale of these impacts depend on the rate, depth, and period of burial, dredged material attributes, similarity of the dredged material to the receiving habitat, the sensitivity and nature of the receiving habitat, and the community composition at the receiving site.

Benthic macroinvertebrates are the preferred indicators in monitoring studies of this nature, as they are within the zone of influence or potential impact (dredged material placement and plumes generated from dredge loading), are known to be reliable indicators in the detection of dredged material impacts, and are meaningful from an ecological and social-economic perspective. Disadvantages of monitoring macroinvertebrates include the large numbers of samples needed to account for natural variability (temporally and in communities), and that identification requires expert knowledge.

Preliminary modelling was undertaken and shows that turbid plumes could extend some distance (measured in kilometres) from the loading and placement sites. This modelled information was used to select appropriate nearfield test sites and control sites. Given the relatively short duration of the dredge campaign (days) and the small volume of material to be relocated, potential impacts to macroinvertebrate communities (if measureable) would be most likely to occur:

- On the DMPA
- Directly adjacent to the DMPA
- Within the channel to be dredged
- Directly adjacent to the channel to be dredged.

To test for differences in macroinvertebrate communities at these locations before and after dredging, multiple control locations would be required to account for spatial variation in control communities and broad-scale environmental changes. Given the potentially large influence of the Fitzroy River, a control location that is closer to the river mouth than putative impact sites would be important to separate the influence of flood discharge from dredging impact. In order to contextualise potential flood impacts, and better understand spatial environmental variability, the sampling design should include control locations that are more distant to the Fitzroy River mouth.

Sample locations should attempt to reduce environmental variation as much as possible. This would include choosing sites with similar bed-shear forces and particle size distributions, and from similar depths. Based on similarities in these benthic parameters, the potential plume influence the potential influence of the Fitzroy River and the most likely putative impacts a sampling design has been recommended. It is possible that other disturbances associated with the operation of the channel (e.g. sediment remobilisation by vessel wake, disturbance of the bed by propellers etc.) could have a confounding influence on benthic fauna communities, which not be readily separated from dredging and placement effects.

At a minimum, sampling frequency should include a “before” event sampled within two weeks prior to dredging and an “after” event, conducted two weeks after the cessation of dredging. Additional sampling events before and after the dredging would also allow examination of temporal variability and recovery. Additional events prior to, and after dredging would also reduce the chances of accidentally confusing temporal variation (random changes in communities over time) with dredging impacts. Initially, a pilot study should be conducted to examine the existing variability among locations and between treatments to determine the adequacy of the proposed design and level of replication.

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1 Introduction

1.1 Background

Port Alma Shipping Terminal (PAST) is located 62km east of Rockhampton on the southern tip of the Fitzroy River delta (Figure 1-1). PAST is located within the Port of Rockhampton (PoR), and is operated by Gladstone Ports Corporation (GPC).

PoR is a natural deep water harbour that can accommodate vessels of up to 180 metres in length. The Port has two berths for general cargo and one dolphin berth for handling of bulk liquids. Storage lands totalling 140 hectares are available away from the Port at Bajool, approximately 20 kilometres from the Port on the Bruce highway.

The Port currently imports ammonium nitrate, explosives, petroleum products, general and break bulk cargoes. Exports include ammonium nitrate, tallow, explosives, general and break bulk cargoes. Dredging is carried out on an 'as needs' basis, with previous campaigns in 2000, 2009 and 2011 (Section 3.1).

GPC initiated the development of a receiving environment monitoring program (REMP) for the Port of Rockhampton. This REMP Design Report provides contextual information regarding the proposed activity (maintenance dredging), the receiving environment and the recommended design of the REMP.

1.2 Aims and Objectives

1.2.1 Aim of the REMP

The monitoring program seeks to understand the intensity and extent of potential impacts related to maintenance dredging at PoR in order to protect the environmental value of the surrounding environment and assist GPC to meet the requirements of condition G8 of their Environmental Authority (EA EPPR00570813).

Condition G9 of the EA requires a copy of the REMP to be submitted to the Department of Environment and Heritage Protection, and any comments incorporated. Condition G8 of the EA requires:

a) Significant sensitive receptors in the PoR to be identified and mapped

b) Environmental aspects and potential impacts to be identified

c) All contaminant releases to be monitored

d) Methods for collection and analysis of samples (incl. specific areas to be monitored, times and durations) to be described.

e) That methods for data analysis and responding to results are described, to ensure compliance

f) Assessment of long-term ecological impacts associated with dredging

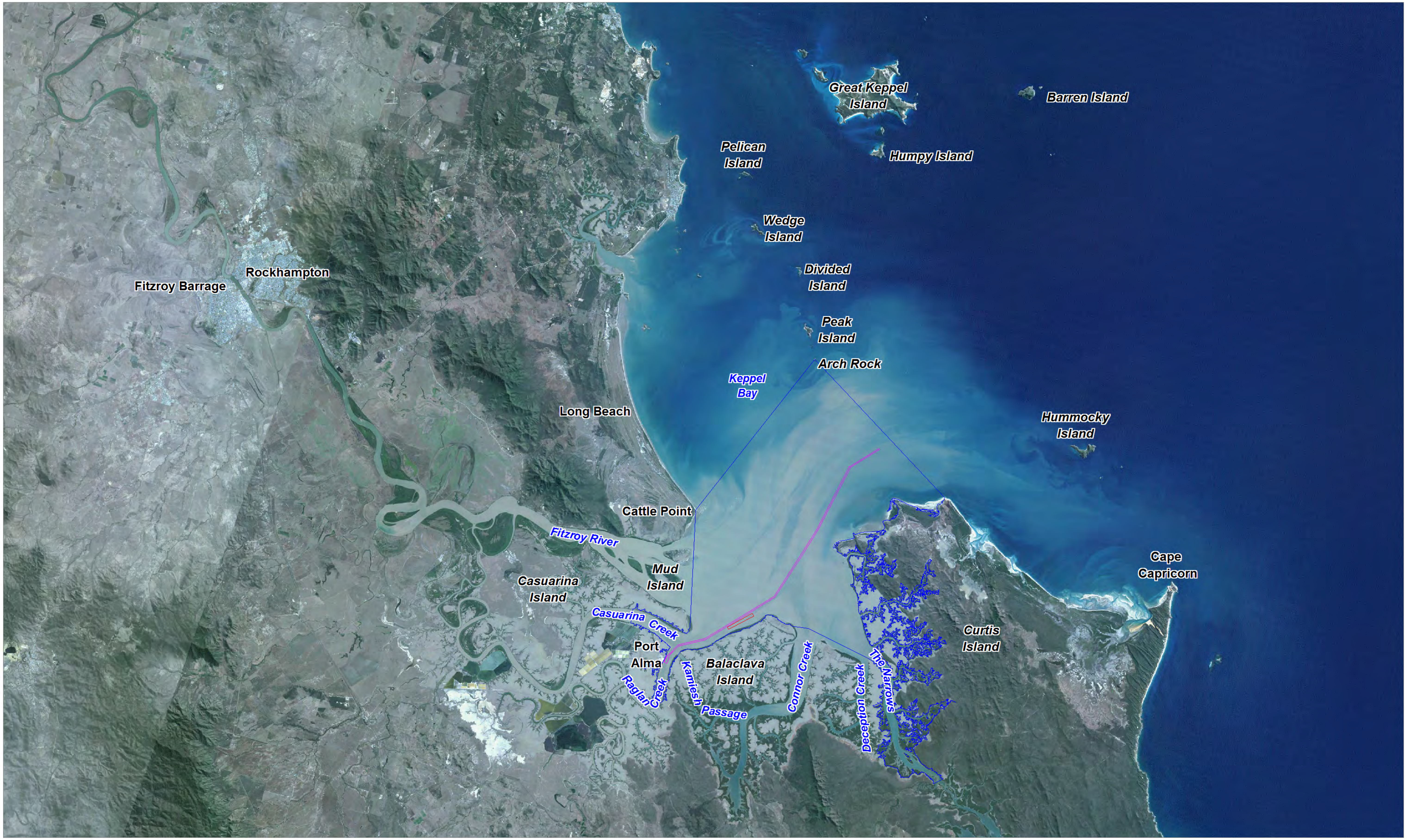
g) Reporting intervals to be specified

h) A review of environmental performance to be conducted after each dredge campaign.

1.2.2 Aim and Objectives of the REMP Design Report

The aim of this REMP design document is to document procedures to monitor, identify, and describe potential impacts of dredging and dredged material placement activities on ecological receptors within the receiving waters of the study area. The specific objectives of this REMP are to:

- Identity environmental values of waterways within the receiving environments and determine the water quality objectives to protect or enhance those environmental values.
- Undertake modelling to determine potential areas affected by turbid plumes generated by maintenance dredging activities.
- Develop a biological monitoring program which will monitor aquatic macroinvertebrate communities prior to the commencement of dredging operations. The information collected will be used to inform management of the impact of dredging activities, and to assess the level of impact to aquatic flora and fauna during dredging.



LEGEND

- Port of Rockhampton Limits
- Channel Extent (digitised)
- DMPA

Title:

Locality Plan

Figure: 1-1

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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1.3 Study Approach

When developing a monitoring program, it is important that the management aims (and associated hypotheses) are clearly defined, and that the program has been designed to specifically test the hypotheses. The present monitoring program design involves the following steps:

(1) Define the primary management aims of the monitoring program

(2) Identify the environmental values to be protected

(3) Examine potential dredging impacts via numerical modelling

(4) Establish testable hypotheses

(5) Select relevant, measurable and cost-effective indicators, and field and laboratory methods

(6) Develop an understanding of environmental conditions that may influence natural variability and require consideration in the experimental design

(7) Develop a monitoring program design (i.e. site selection and frequency etc.) that takes into account the above components

(8) Implement a pilot study to test the monitoring program design, and to make an initial assessment of historical impacts.

The present report describes the findings of investigations inclusive of steps one through to seven. A separate report has been prepared by BMT WBM (2015) which outlines the findings of a pilot study investigation (step 8).

1.4 Terminology and Acronyms

ANOVA	Analysis of Variance
BACI	Before/ After, Control/Impact monitoring design
DAFF	Department of Agriculture Forestry and Fisheries
DEHP	Department of Environment and Heritage Protection
DMPA	Dredged Material Placement Area
DNPRSR	Department of National Parks, Recreation, Sport and Racing
ECIFF	East Coast Inshore Fin Fishery
ENSO	El Niño Southern Oscillation
EPBC Act	*Environmental Protection and Biodiversity Conservation Act 1999*
ERMP	Ecosystem Research and Monitoring Program
GAWB	Gladstone Area Water Board
GBRWHA	Great Barrier Reef World Heritage Area
GPC	Gladstone Ports Corporation
LAT	Lowest Astronomical Tide
MBACI	Multiple Before/ After, Control/ Impact monitoring design (temporally

ANOVA	Analysis of Variance
NAGD	National Assessment Guidelines for Dredging
NC Act	*Nature Conservation Act 1999*
nMDS	non-metric multidimensional scaling ordination (graph or plot)
PAST	Port Alma Shipping Terminal
PCIMP	Port Curtis Integrated Monitoring Program
PoR	Port of Rockhampton
PSD	Particle Size Distribution
SMART	Simple, Measurable, Accessible, Relevant, Timely
TOC	Total Organic Carbon
TSS	Total Suspended Solids
WQO	Water Quality Objective

2 Description of the Receiving Waters

2.1 Environmental Values (EVs)

The study area is located at the mouth of the Fitzroy River and includes subtidal waters surrounding Balaclava Island. As per ANZECC/ARMCANZ (2000), water quality objectives for a waterway can be determined by first identifying the EVs for a particular catchment area. EVs have previously been established for the Fitzroy River catchment (which includes the mouth of the Alligator Creek and Port Alma, and waters south of Balaclava Island including southern portions of Connor Creek; Figure 2-1) and Capricorn-Curtis Coast region (which includes waters north of Alligator Creek and waters west and north of Balaclava Island; Figure 2-2) under Schedule 1 of the EPP Water.

Under Schedule 1 of the *Environmental Protection (Water) Policy 2009* (EPP Water 2009), all subtidal waters within the study area are classified as Enclosed waters/lower estuary, whereas intertidal portions of Balaclava Island and along the coast of the Narrows and north-west Curtis Island are classified as Middle estuary (Figure 2-1, Figure 2-2).

The EVs established for the relevant estuarine section of the study area includes the protection of the following:

- **Aquatic ecosystems** - The intrinsic value of aquatic ecosystems, habitat and wildlife in waterways and riparian areas
- **Human consumer of aquatic foods** - health of humans consuming aquatic foods — such as fish, crustaceans and shellfish (other than oysters) from natural waterways
- **Secondary recreation** - health of humans during recreation which involves indirect contact and a low probability of water being swallowed — e.g. wading, boating, rowing and fishing
- **Visual recreation** - amenity of waterways for recreation which does not involve any contact with water — e.g. walking and picnicking adjacent to a waterway
- **Industrial Use** - Suitability of water supply for industrial use, e.g. food, beverage, paper, petroleum and power industries, mining and minerals refining/processing
- **Cultural and spiritual values** - indigenous and non-indigenous cultural heritage — e.g. custodial, spiritual, cultural and traditional heritage, hunting, gathering and ritual responsibilities; symbols, landmarks and icons (such as waterways, turtles and frogs); and lifestyles (such as agriculture and fishing).

2.2 Water Quality Objectives

Based on the identified environmental values for the study area, water quality objectives (WQO's) can be derived which aim to protect the environmental values.

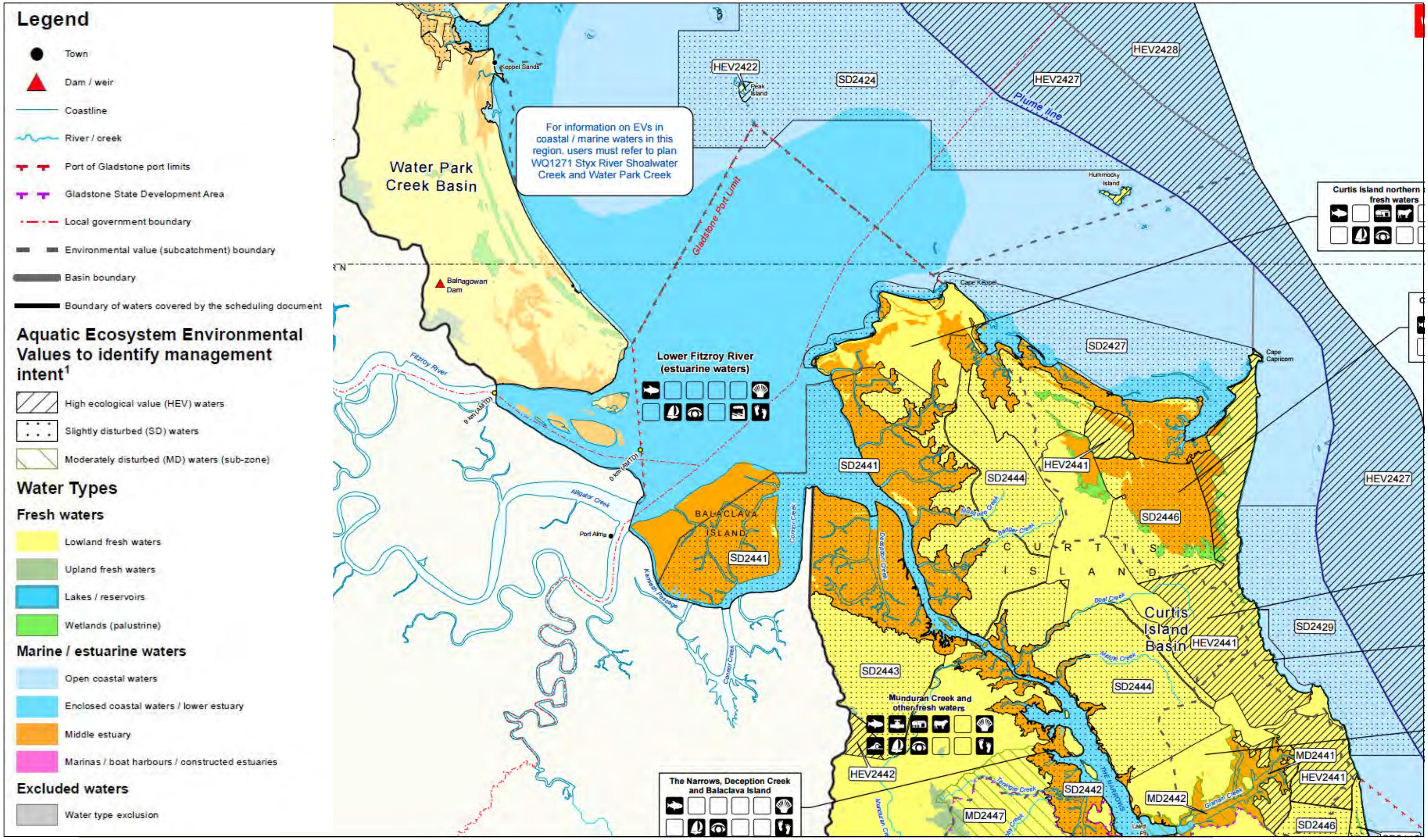


Figure 2-1 Capricorn-Curtis Coast region sub-plan (EPP Water)

BMT WBM

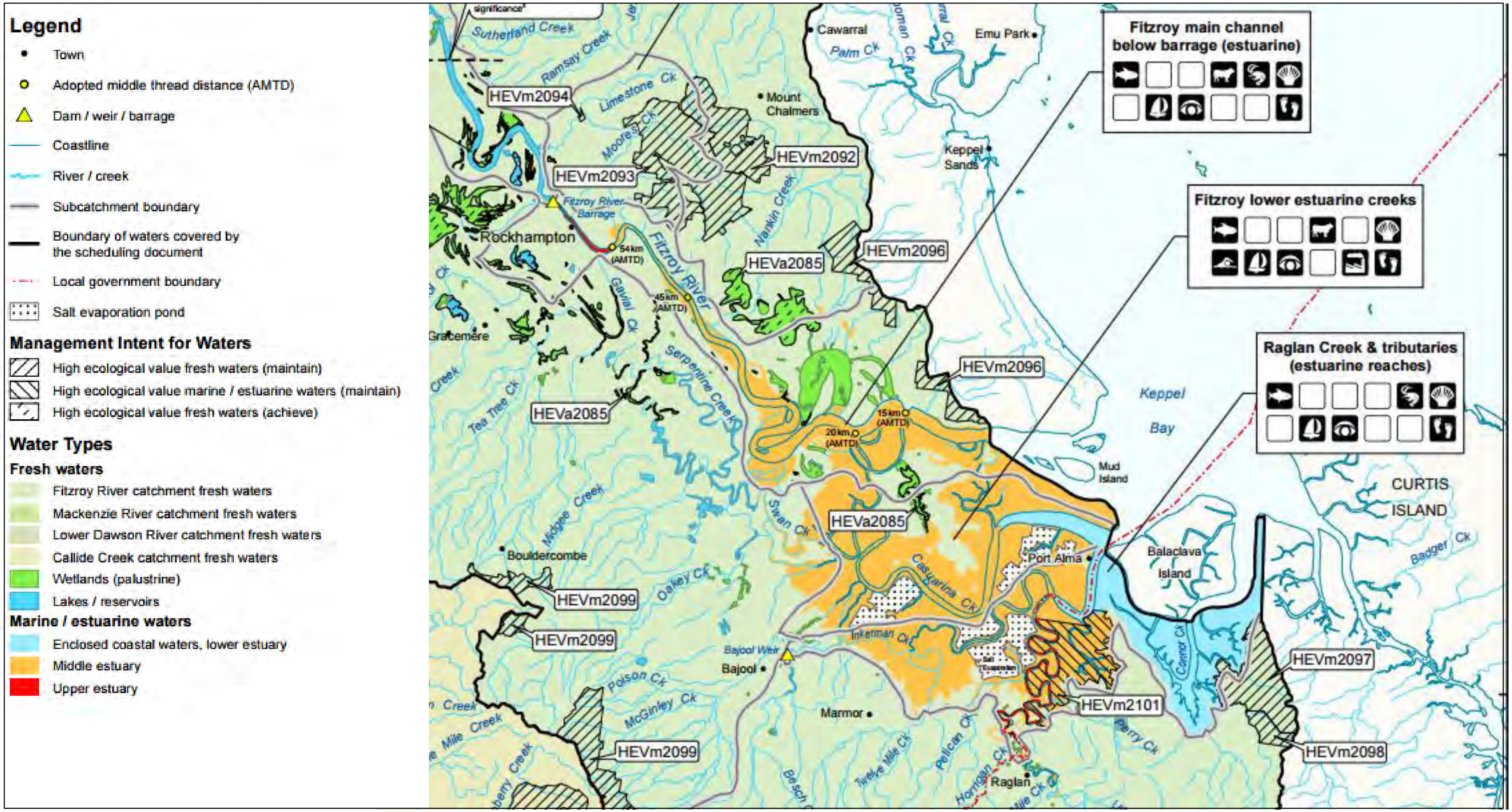


Figure 2-2 Fitzroy sub-plan (EPP Water)

In regard to the protection of the aquatic ecosystem EVs, there are three possible levels of protection required depending on the current state of the waterway. As per ANZECC/ARMCANZ (2000), these three levels are:

- **Level 1 (high ecological/conservation value ecosystems)** - effectively unmodified or other highly valued systems, typically (but not always) occurring in national parks, conservation reserves or in remote and/or inaccessible locations.
- **Level 2 (slightly-moderately disturbed ecosystems)** - ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained.
- **Level 3 (highly disturbed ecosystems)** - measurably degraded ecosystems of lower ecological value. Examples of highly disturbed systems would be some shipping ports and sections of harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive horticulture.

As per Schedule 1 of the EPP Water, the study area falls into the slightly disturbed level of protection (Level 2), for which corresponding WQOs have been derived. ‘Level 1’ (high ecological/ conservation value) occur in the estuarine sections of Horrigan Creek located south of the study area, and freshwater streams that drain into Connor Creek.

WQOs are provided in the Schedule 1 documents.

2.3 Ecological Assets and Sensitive Receptors

Key sensitive environmental receptors and ecological assets near the dredge and placement area include:

- Intertidal habitats, including mangroves, saltpan and intertidal flats and seagrass
- Benthic macroinvertebrate communities
- Fish communities
- Shorebird communities
- Marine megafauna species
- Coral habitats.

2.3.1 Intertidal Habitats and Seagrass

In 2008, the area of intertidal wetland within the Port Alma region was estimated at approximately 450 km^2. Mangroves are reported to cover 194 km^2 of this intertidal wetland vegetation with nine mangrove species reported to occur in the area (Duke *et al*. 2003, GAWB 2008; Stokes and Bucher 2012). The most widespread mangrove forests were found to occur predominantly along Connor Creek and The Narrows, in the lower Fitzroy River region (GAWB 2008).

Saltmarsh and saltpan communities are estimated to cover over half of the intertidal wetland within the Port Alma (~254 km^2). Two species of saltmarsh have been recorded in the Port Alma region

(Eberhard 2012) and the largest area of saltmarsh occurred near Casuarina Creek, Inkerman Creek, Raglan Creek and Connor Creek (GAWB, 2008).

Of the 30 seagrass species in Australia, seven species are found predominantly in shallow sheltered waters of Port Curtis and Port Alma. Historical mapping and monitoring of seagrasses in the Port Alma area, including outside the mouth of the Fitzroy River, did not detect large areas of seagrass habitat (York and Smith 2013) and seagrass has not been observed in the Port Alma area in recent monitoring (M. Rasheed, James Cook University pers. comm.).

The distribution of intertidal wetlands in the Port Alma region is reported to have remained relatively stable over the years. The distribution of mangroves increased in the Fitzroy River estuary between the 1940s and 1999 (Duke *et al.* 2003), however, a gradual loss of intertidal wetland vegetation cover was observed between 1986 and 2002 are reportedly linked to clearing for agricultural activities and urban development in coastal areas (Dekker *et al.*, 2005). More recent information on the intertidal wetlands of Port Alma is limited, with many studies focusing on site small, targeted areas and project specific sites.

2.3.2 Soft Sediment Benthic Fauna

A series of deep muddy tidal channels and sand bars are located close to the mouth of the Fitzroy estuary. Some channels appear to be infilling, whereas others exhibit erosional characteristics (Ryan *et al*. 2006). Low density muddy sediments appear in the sub-bottom profiles in the vicinity of Port Alma, within the main tidal channels of the Fitzroy River mouth (Ryan *et al*. 2006).

Ryan *et al.* (2006) suggest that most of the Fitzroy River mud accumulates in the mouth of the Fitzroy River, and a buoyant plume transfers the remainder offshore and to the north. Sands accumulate in the south of Keppel Bay and are transported onshore by tidal currents. The swing basin area for ship access in Port Alma is reported to be a predominantly mud substrate (Ryan 2007).

There are no published data describing soft-sediment communities (infauna or epifauna) in Port Alma but surveys undertaken elsewhere within Port Curtis suggest that macroinvertebrate communities generally consist of gastropods, bivalves, crustaceans, polychaetes, sponges and ascidians (Rasheed et al., 2003; GHD 2009; BMT WBM 2012a).

2.3.3 Fish and Shellfish Communities

The Fitzroy estuary, Raglan Creek and north Curtis Island are declared Fish Habitat Areas. The Fitzroy estuary hosts nine fish habitat types, including mangrove-lined waterways, mudflats, marshes and wetlands (Eberhard 2012). The diversity of habitats and extensive area create a regionally significant fish breeding area (Sheaves *et al.* 2014), and one of Queensland's most significant commercial sources of mudcrab (DNPRSP 2014). The mouth of the Fitzroy River supports the spawning of barramundi and threadfin (king and blue) and is an important area for commercial and recreational fisheries (Eberhard 2012; DNPRSP 2014). The green sawfish has also been recorded in the area (Eberhard 2012) and is listed as vulnerable under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Commercial catch data for 2013 from catch grids R29 and R30 (Figure 2-3) show that the bulk of species collected (by weight) include banana prawns, mud crabs, barramundi, sharks, mullet, and threadfin salmon (data from DAFF 2014). Grid R30 has a higher proportion of mud crab, fewer banana prawns, and more threadfin than grid R29. Reef fish and live coral collections constitute a much larger proportion of the catch in R29 due to the inclusion of the Keppel reefs. Net fishing (as a part of the East Coast Inshore Fin Fishery [ECIFF]) comprises the largest tonnage of catch from the grids Figure 2-4. The crab pot fishery is dominated by mud crab, and the beam trawl is made up primarily of banana prawns, with small contributions of greasy and coral prawns, squid, and mantis shrimp.

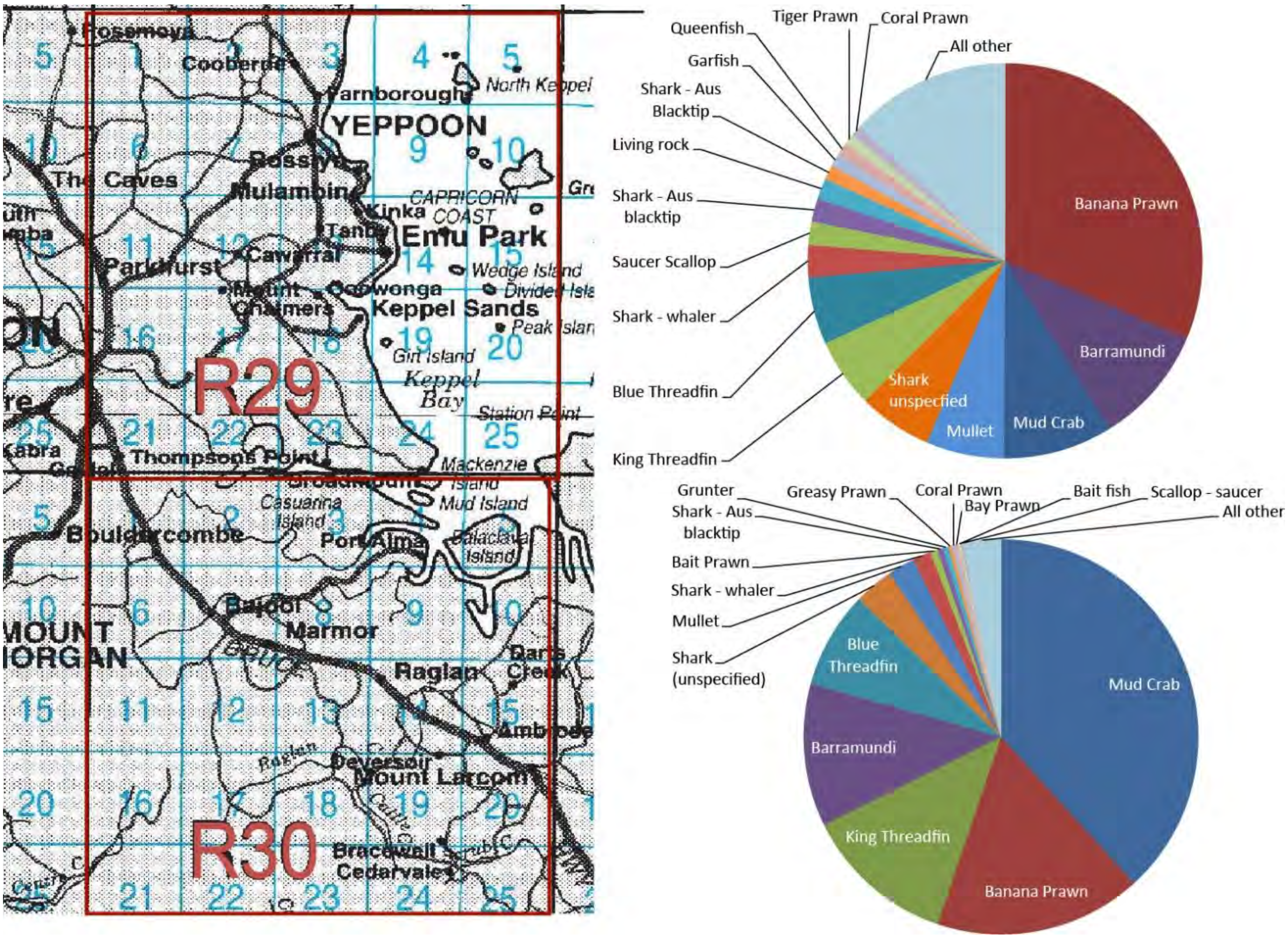


Figure 2-3 Locations of catch grids R29 and R30, and species composition

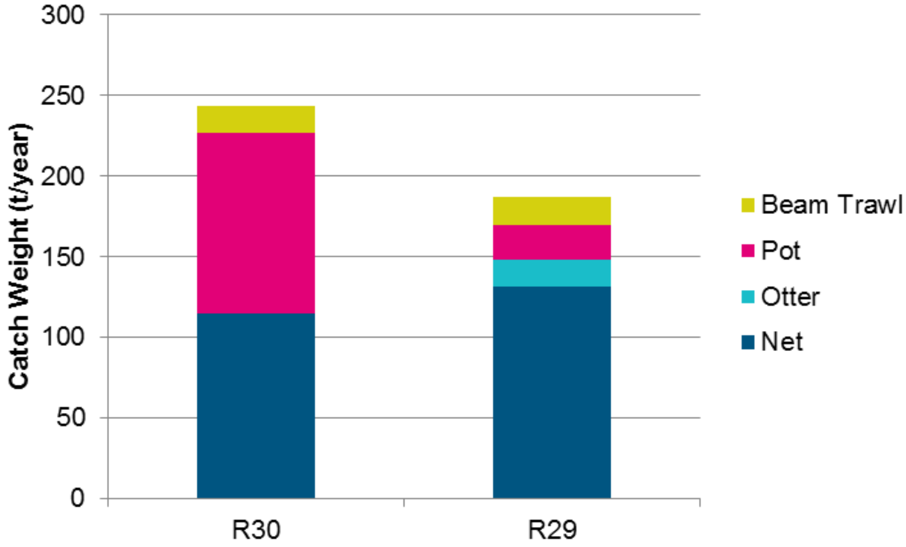


Figure 2-4 Catch tonnage for commercial grids R29 and R30 for four gear types

2.3.4 Marine Megafauna

Six species of marine turtles are known to occur in the Port Curtis and Port Alma regions including loggerhead, green, hawksbill, flatback, olive Ridley and leatherback turtles. Four of these species are found in the Fitzroy estuary (loggerhead, green, hawksbill and flatback) (Eberhard 2012), but boat-based surveys in 2010 and 2011 only observed green turtles in Port Alma (GHD 2011). Peak Island at the northern limit of Port Alma represents a key breeding habitat for flatback turtles and is the second largest nesting areas in eastern Australia (Limpus *et al.* 2013). All turtle species are listed species under the EPBC Act and *Nature Conservation Act 1992* (NC Act). Of the four species that are known to inhabit the PoR, all are considered Vulnerable except loggerhead turtles, which are listed as Endangered.

Three species of inshore dolphins have been recorded inhabiting Port Curtis and Port Alma and include Australian snubfin (*Orcaella heinsohni*), Indo-Pacific humpback (*Sousa chinensis chinensis*) and the inshore bottlenose dolphin (Cagnazzi 2013). The Fitzroy estuary supports the three inshore dolphin species, all of which are reported to be found in small groups (Cagnazzi 2013). All three dolphins are listed as migratory under the EPBC Act and the snubfin and Indo-Pacific humpback dolphins are listed as 'near threatened' under the Queensland NC Act.

Grech and Marsh's (2007) model of the relative density of dugongs across the Great Barrier Reef World Heritage Area (GBRWHA) maps dugong management units within the Port Alma region as medium conservation value for areas along the north west coast of Curtis Island and low conservation value for the remaining areas including the Fitzroy River delta and Fitzroy estuary (GHD 2009). The lower Fitzroy estuary accommodates a low number of dugongs due to the turbid waters limiting seagrass habitat. The seagrass meadows of Rodd's Bay and Port Curtis appear to be a significant transit zone for dugongs moving between central and south-east Queensland (Sobtzick *et al.* 2013). Estuarine crocodiles are also found in the Fitzroy River delta.

2.3.5 Shorebirds

Migratory shorebird monitoring conducted between Port Alma and Rodd's Peninsula found 62% of shorebirds surveyed were recorded in the Fitzroy River delta and north Curtis Island area (IMEMS 2013). Several embayments and the mouth of the Fitzroy River provides regionally significant foraging habitat for shorebirds (IMEMS 2013). The red-necked stint, curlew sandpiper, bar-tailed godwit, greater sand plover appear to show a preference for the Fitzroy River delta and evidence suggests it is an important stop over site for these species and others on northward migration. The survey also indicates the whimbrel, lesser sand Plover and sanderling are most common on north Curtis Island (IMEMS 2013).

A 2014 study of the same survey series of migratory shorebird monitoring recorded 15 species at north Curtis Island and 16 species in the Fitzroy estuary (Wildlife Unlimited 2014). The foraging density was observed at 1.5 birds/ha throughout the Fitzroy estuary and north Curtis Island area, an increase from the 2013 survey of 1.3 birds/ha.

In addition to playing a significant role as a stopover for migratory shorebirds, the Fitzroy River delta appears to be an important location for non-breeding shorebirds birds with high numbers recorded during winter months (IMEMS 2013).

The wetlands of the Fitzroy River delta also support a large number and wide variety of coastal birds, including magpie geese, sharp-tailed sandpiper, grey teal, plumed whistling-duck and black-winged stilt (Eberhard 2012).

2.3.6 Coral Reefs

The closest significant coral reef communities to Port Alma are located at Peak Island which are approximately 25 km north-east of the port facilities (BMT WBM 2013). Extensive coral reef communities can be found in the northern parts of Keppel Bay, with occasional corals and soft corals found on hard substrates such as rock shelves, around the northern tip of Curtis Island (BMT WBM unpublished).

2.3.7 Sensitive Receptors Relevant to Dredging and Material Placement

Selection of sensitive receptors for monitoring is discussed in the context of potential modelled dredge impacts (Section 3) in Section 4.1.

2.4 Key Ecosystem Drivers

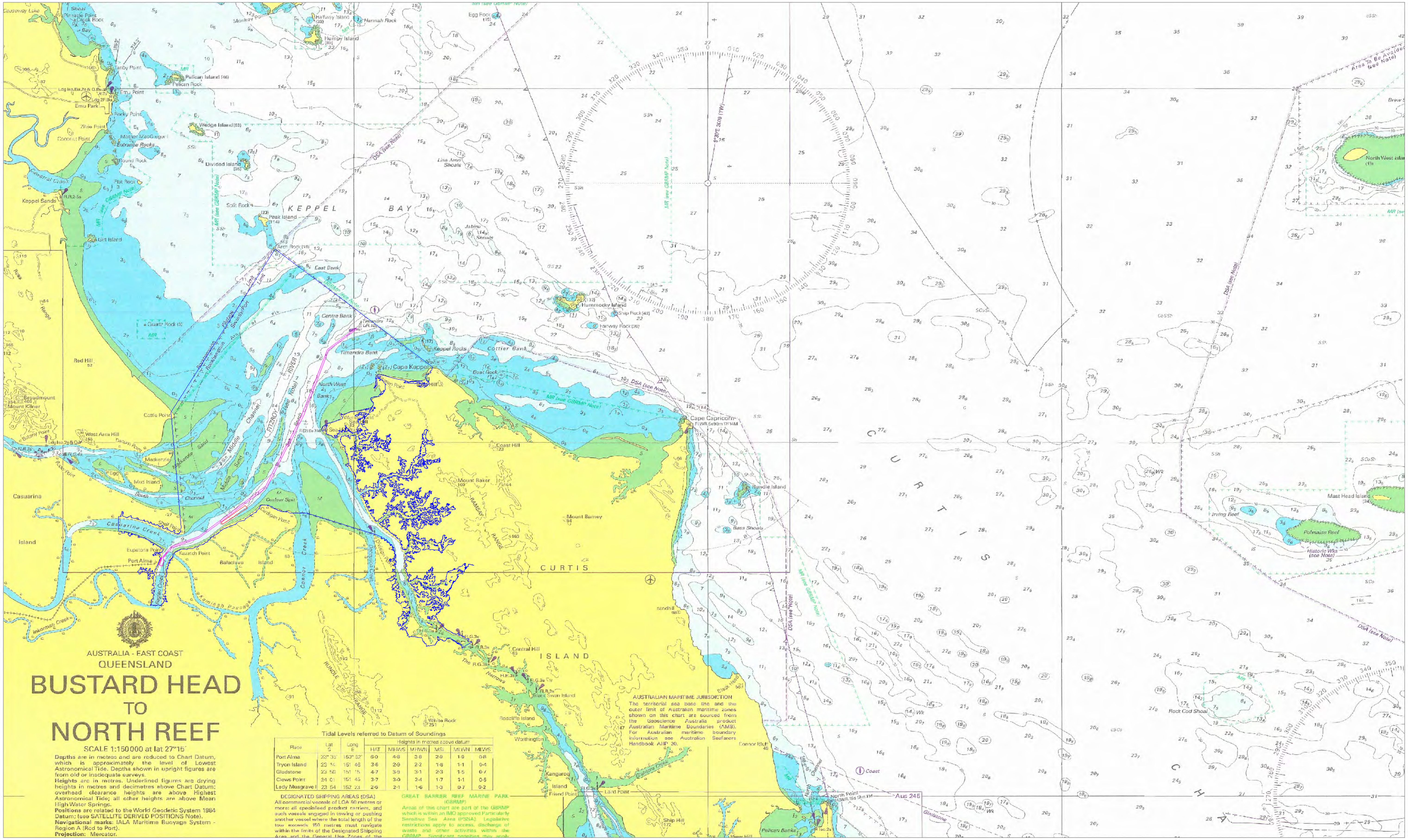
2.4.1 Bathymetry

Medium-resolution digital bathymetry is available for parts of Port Alma, with the remainder available from Australian Hydrographic Chart (Figure 2-5).

The main channel of the Fitzroy River bifurcates at the river mouth where several large mangrove Islands have formed on recently deposited sediment banks (Ryan *et al.* 2009). The northernmost channel divides again, becoming less prominent as it meets the large sediment banks offshore from Long Beach. Channels exiting from the mouth of the Fitzroy are relatively deep (>10 m in places). These run parallel to several other channels, one of which forms the main shipping channel into PAST, which is maintained (dredged) to a depth of 7.0 m below Lowest Astronomical Tide (LAT).

There are three large coastal creeks (Casuarina, Raglan-Inkerman and Connor Creeks) that all exit into Keppel Bay in close proximity to the Fitzroy River mouth. Large deposits of sediment are found at various places between these channels (Ryan *et al.* 2009).

The Fitzroy River channel extends beyond its present location along a paleo-channel northwards then eastwards from the present Fitzroy River mouth, around Curtis Island and finishes between Northwest Island and Douglas Shoal (Figure 2-6). This channel and associated abandoned channels originated during former glacial periods when sea levels were lower than today, with the most recent glacial maximum being approximately 10,000 years before present. Within the limits of Port Alma, these paleo-channels are less distinctive and have become filled with other sediments through time. Near the mouth of the Fitzroy River, a veneer of modern sediment (dominated by mud) covers most of the area, with coarser material found in some of the natural channels as a result of tidal and riverine flow (Ryan *et al.* 2009).



LEGEND

Port of Rockhampton Limits

Channel Extent (digitised)

DMPA

Title:

Bathymetry of Port Alma and Surrounding Region

Figure

2-5

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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2.4.2 Sediment and Sedimentation

The present distribution of sediment within the study area has been described by Ryan *et al.* (2009) and is a result of the delivery of sediment, hydrodynamic forces such as waves and currents, and the underlying geology.

The interpolations provided by Ryan *et al.* (2009) show that the inshore sediments surrounding Port Alma are dominated by mud and have very small proportions of gravel (Figure 2-7A, B). Sediments northeast of Cattle Point have much lower mud and gravel fractions and are dominated instead by sands. Grab samples of the beds surrounding Cattle Point show they are composed primarily of muddy sand. Multi-beam imagery and grab sampling of the banks north of Curtis Island (Ryan *et al*. 2006) shows that they are mobile beds of sediment with high calcium carbonate concentrations (derived from coral, molluscs, algae and foraminifera) that are moving around Curtis Island in a north-west direction. Sediments with the lowest calcium carbonate concentration also occur in the inshore sediments surrounding Port Alma, where total organic carbon (TOC) is high (Figure 2-7C, D).

Ryan *et al.* (2006; 2009) suggest that terrigenous sediments are delivered to Keppel Bay via the Fitzroy River and other creeks, while calcium carbonate sediments are introduced from offshore by bed-load transport. Banks to the north of the Fitzroy River mouth, with exposure to northerly and easterly winds, are composed of relatively well-sorted sands, as waves resuspend the mud fraction out of this material and transport it northwards, or alternatively, it settles further inside the estuary in relatively quiescent areas forming mud banks. Strong riverine flows and relatively large tides (up to 5.4 m amplitude) prevent fine sediments from settling in the channels, which are instead dominated by sands and gravels.

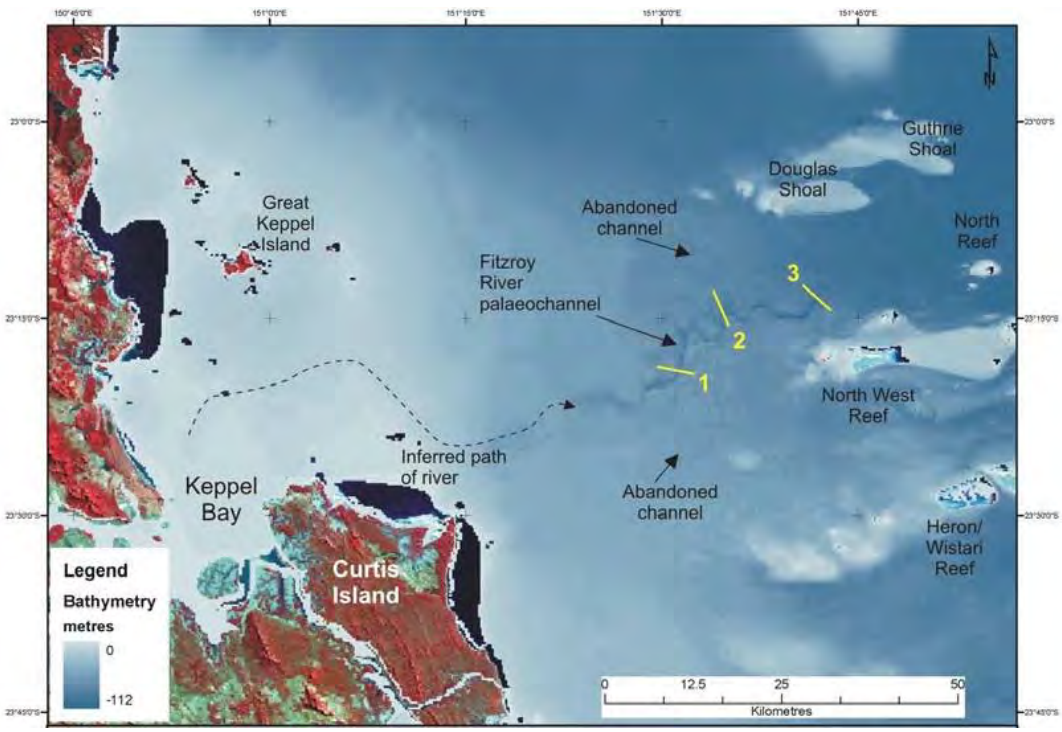


Figure 2-6 Fitzroy River paleo-channel (from Ryan *et al.* 2009)

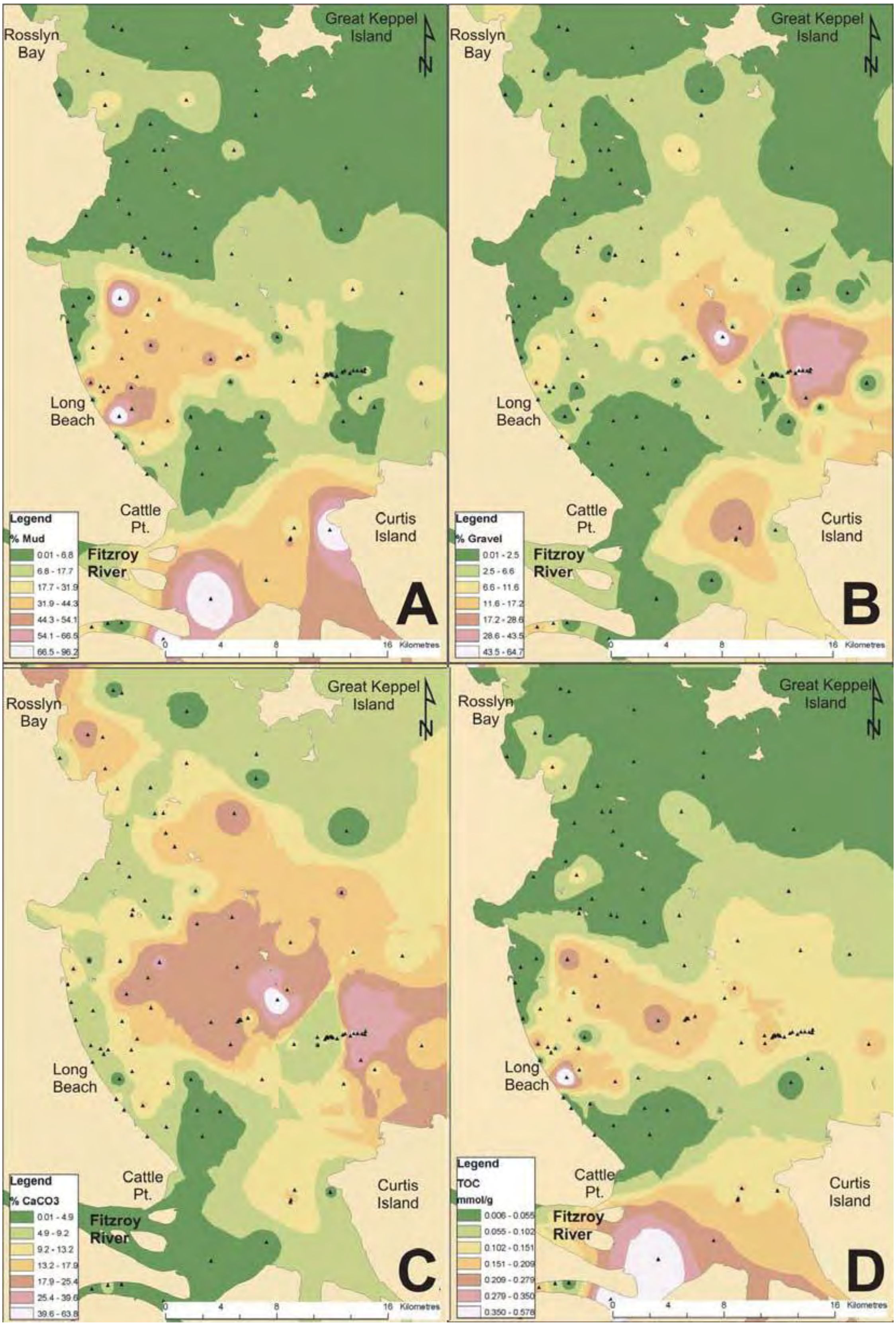


Figure 2-7 Interpolated distributions of mud (A); gravel (B); calcium carbonate (C); and total organic carbon (D), modified from Ryan *et al.* (2009).

Ryan *et al*. (2006) performed a cluster analysis on the sediment data from Keppel Bay based on similarities and differences in grain size, sorting and concentrations of calcium carbonate, TOC and feldspar. Sediments in the southern part of Keppel Bay near the Fitzroy River mouth were composed of a similar class of sediments (Figure 2-8). These sediments were comprised primarily of very poorly-sorted fine sand, with very fine silt (mud) and medium sand. This class coincided with low calcium carbonate concentrations and high concentrations, forming a distinct sediment class, different to others in further north in Keppel Bay.

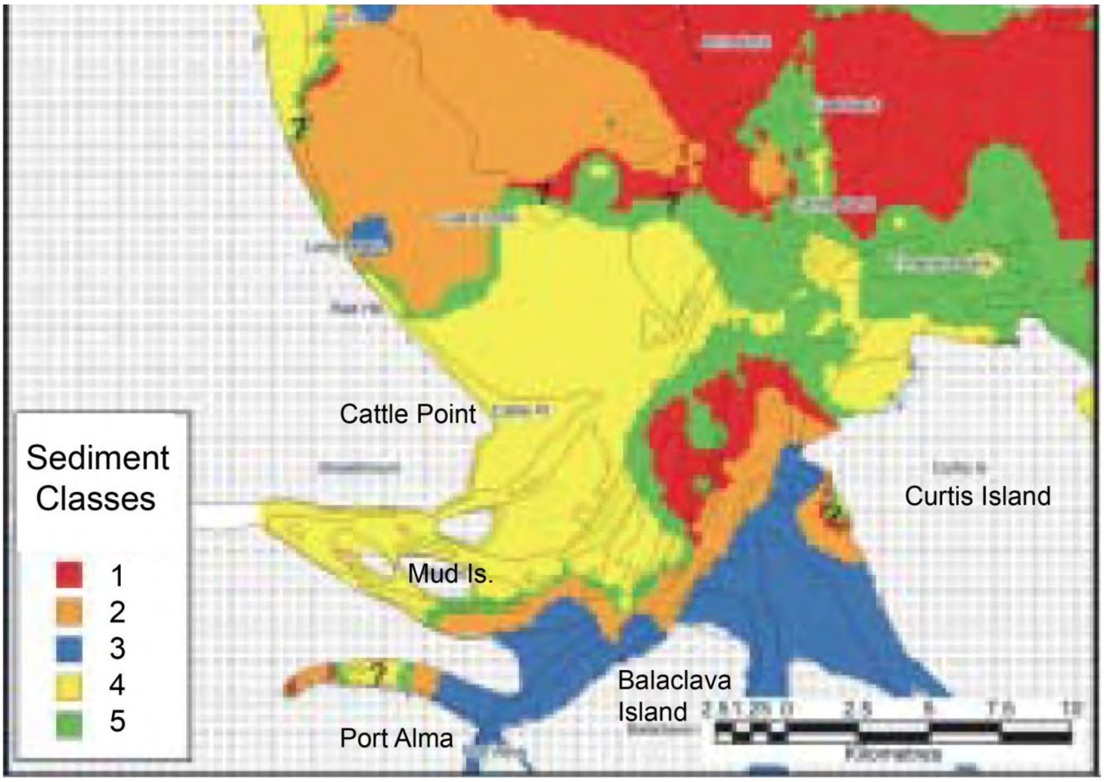


Figure 2-8 Interpolated distributions of sediment isoclasses, modified from Ryan *et al*. (2006)

The distribution and structure of intertidal wetlands is greatly influenced by geomorphological processes operating over a range of timescales. Changes to sedimentary processes associated with coastal development have resulted in substantial increases in mangrove colonisation in the wider Fitzroy River and Gladstone region (Duke *et al.* 2003). The most notable changes observed in the Port Alma was the formation of new mangrove islands in the Fitzroy River estuary in the 1960s (Duke *et al.* 2003).

2.4.3 Tidal Currents

Keppel Bay is a macro-tidal environment with a tidal range of approximately 5.4 m. This leads to relatively strong tidal velocities, which are highest near the mouth of the Fitzroy River and along scour points such as river beds. Examples of tidal vectors for peak ebb and flood tides during the modelling period are shown in Figure 2-9. During spring tides, maximum tidal velocities of 1.8 m/sec are predicted.

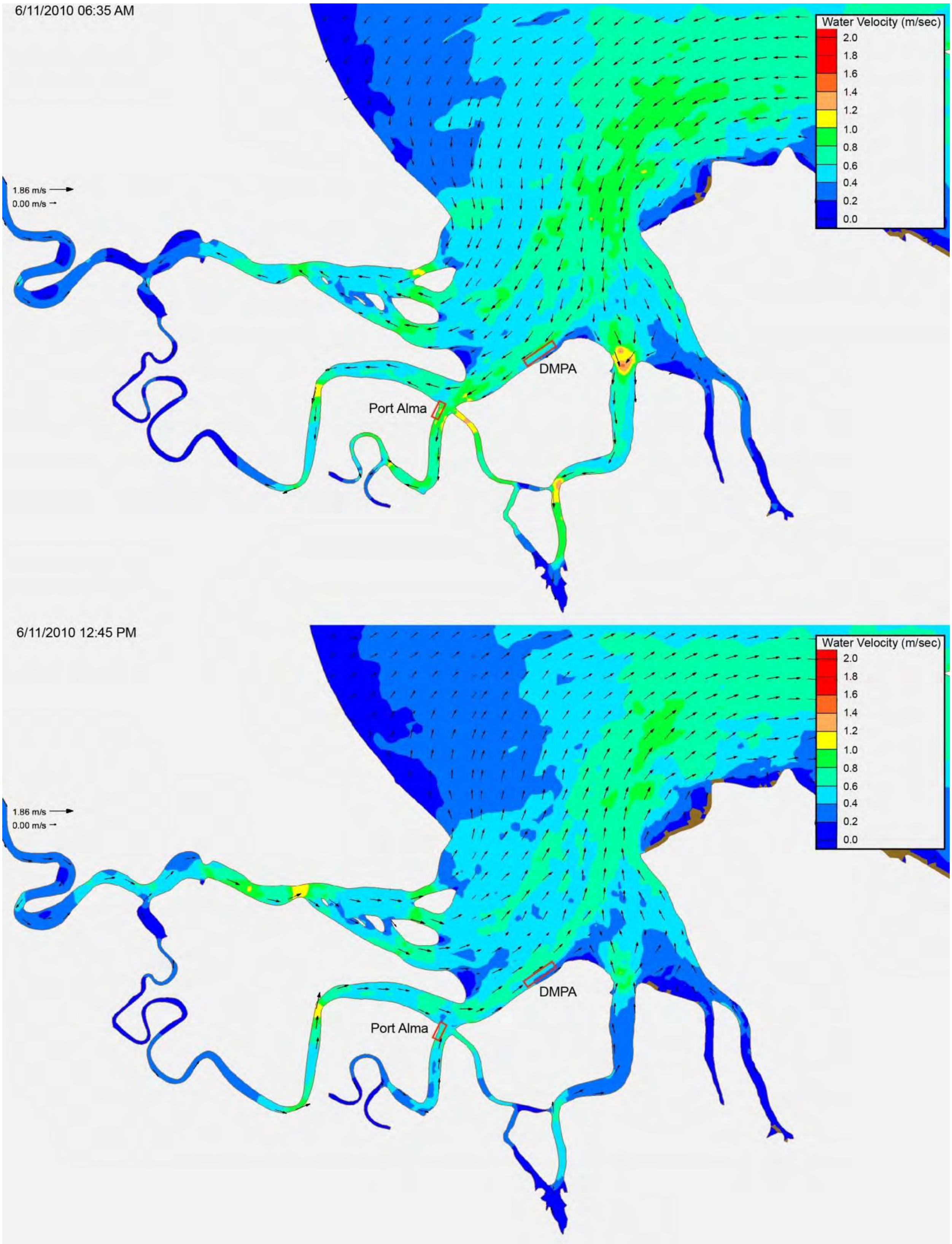


Figure 2-9 Peak modelled flood (above) and ebb (below) tidal vectors during the simulation period (5-8 November 2010). The approximate location of the dredge area at Port Alma and the DMPA are shown as red boxes.

Figure 2-9 shows that the areas with the fastest flow occur over relatively small distances at pinch points: where two channels coverge, at channel bottlenecks, and around channel bends. There are also broader areas of high flow within the entrance channels to Port Alma and through the Fitzroy River channel extending out and around the north-west extent of Curtis Island. The approximate positioning of the berthing pocket at Port Alma and the DMPA on Figure 2-9 show that water velocities of between 0.4 and 1.2 m/sec are encountered in these locations.

The Fitzroy River channels Casuarina Creek, Raglan Creek and Connors Creek show similar flood tide velocities, while the Narrows and Deception Passage are generally more quiescent. Connors Creek can show lower ebb tide velocities than the other creeks with similar channel widths; however, it should be noted that velocities change depending on stage within the tidal cycle, and the length of the channel.

2.4.4 River Discharges

The Fitzroy River is the largest river catchment area in Queensland and is the second largest in Australia (144,000 km^2). Together with the Burdekin, they are the largest net sources of nutrients, sediments, and contaminants on the Great Barrier Reef.

Flow into the Fitzroy Delta is extremely episodic with high volume floods formed by intense summer rainfall events produced by monsoonal depressions and cyclones, and are linked to the longer-term El Niño Southern Oscillation (ENSO) changes (Devlin *et al*., 2001; Kelly and Wong, 1996). Flows into the estuary can be extremely variable among years, for example, peak flows in 1991 of 15,000 m^3/sec were two orders of magnitude lower (100x lower) the following year (Radke *et al.* 1996).

Under high flow conditions, the residence time of water within the estuary is low, reducing the potential for biogeochemical cycling, and resulting in large net exports of pollutants into the GBR lagoon (Radke *et al.* 2006). However, once peak flows have ceased, the lower Fitzroy estuary gradually approaches the salinity of seawater over approximately 100 days, allowing riverine discharges to be transformed and deposited within the expanding delta (Radke *et al.* 1996).

Freshwater and turbid flood plumes can also have disastrous consequences for coral reefs in the vicinity of Keppel Bay. Floods in 2010 created freshwater plumes that caused 40-100% coral mortality at reefs up to 12 km offshore (Jones and Berkelmans, 2014).

3 Description of the Activity and Potential Impacts

3.1 Previous Dredging

Maintenance dredging is carried out within declared navigation channels and berth pockets at the Port of Rockhampton as shown in Figure 3-1. Maintenance dredging has been carried in 2000, 2009 and most recently in 2011. The 2009 and 2011 maintenance dredging campaigns have taken less than a week to conduct where dredged volumes consisted of 23,000 m^2 and 40,000 m^2 of material, respectively. In the most recent maintenance dredging campaign (February 2011), material was removed from the berth pocket and from the port-side (southern side) of the entrance channel, in the final approach to the Port (Figure 3-1). Dredging was performed over three days during this campaign.

There are several other spoil grounds marked on navigation charts, however the existing the Dredge Material Placement Area (DMPA) has been used for the last two maintenance dredging campaigns (Gordon Dwane GPC pers. comm. December 2014).

3.2 Potential Impacting Processes

Dredged material placement represents a form of disturbance, albeit a disturbance type that may lead to impacts outside the bounds of natural variability. The response of benthic macroinvertebrate communities to dredged material placement disturbance can vary from place to place, and over time (Wildish and Thomas, 1985; Jones, 1986; Toumazis, 1995; Roberts *et al*., 1998; Roberts and Forrest, 1999). Several factors can influence the initial level of impact and longer-term recovery processes, including (after Smith and Rule, 2001):

- Level and scale of initial impact
- Dredged material attributes (i.e. sediment grain size, organic matter content) and similarity to receiving habitat
- Receiving habitat
- Community composition at the receiving site
- Depth of deposition
- Period of burial
- The chemical composition of dredged material
- Adaptations of different taxa to a dynamic sedimentary environment.

The following is a discussion on the main potential impacts associated with dredged material placement in the context of the PoR DMPA and surrounding areas.

3.2.1 Impacts Due to Burial

Initially, the major impact of dredged material placement on benthic macroinvertebrate is through sediment burial. Many species of benthic macrofauna are capable of vertical migration through overlying sediment (e.g. reviewed by Maurer *et al*. 1986; Roberts *et al*. 1998). In dynamic sedimentary environments like the study area, many species are likely to have adaptations allowing rapid vertical migration through the sediment column (e.g. Smith and Rule 2001).

It would be expected that mortality resulting from smothering (i.e. due to low dissolved oxygen/starvation) would occur if dredged material was applied at rates exceeding the ability of any taxa to vertically migrate (e.g. Roberts *et al*., 1998). Environmental monitoring at the East Banks DMPA in Port Curtis (BMT WBM 2012a) showed that the placement of “clean” maintenance material had no quantifiable negative effect on communities within and adjacent to the DMPA. However, the large volumes of capital material did reduce abundance and richness within the DMPA.

3.2.2 Toxicity Impacts

The National Assessment Guidelines for Dredging (NAGD 2009) specifies concentration limits for toxicants, metals, and nutrients for dredged material to prevent toxic and hypoxic impacts to benthic communities during dredging and material placement. These guideline values are based on ecotoxicity experiments from over 350 publications worldwide, and apply to most species. Only ‘clean’ material that meets relevant guidelines and processes set out in NAGD (2009) can be placed at sea. On this basis, toxic effects to biota are not expected as a result of dredged material placement.

3.2.3 Changes to Bed Sediments

3.2.3.1 On-site Impacts

Changes in grain-size can occur in response to dredged material placement, depending on the nature of the dredged material to be placed, subsequent changes in seabed height at the DMPA, and the hydrodynamic environment of the site. DMPA’s elsewhere in Queensland consist of coarser material than the surrounding sediment, particularly in adjacent deeper waters. This occurs because the DMPA is subject to low to moderate levels of bed sheer-stress, which winnows out the finer material from the shallower sections, leaving the coarser material behind on the DMPA. Silts then preferentially settle out in the deeper waters immediately adjacent to the DMPA, and gradually decrease in concentration along a depth contour with distance away from it. Therefore, in the case of high energy DMPAs where there the DMPA is significantly elevated, sediment characteristics usually vary greatly depending on proximity to the DMPA. The differences in grain size between the PoR DMPA and surrounding sediments will be affected by the similarities of the placed material to the existing material, the differential in seabed heights and the hydrodynamic regime.

A popular view is that changes in sediment type can cause changes to community composition and species richness (e.g. Ahn and Choi 1998). For example, sediment grain size may be important to some echinoid and polychaete larvae, which have been demonstrated to not settle or delay metamorphosis until exposed to sand, or in some cases, muddy sand (Snelgrove and Butman 1994). However, interactions between the sediment and benthic macrofauna are much more complex than shifts in sediment grain size and faunal abundance.

Organic matter is thought to have a greater influence on benthic communities than sediment grain size alone. Organic matter in sediments is a dominant source of food for deposit feeders and indirectly (through resuspension) for suspension feeders (Snelgrove and Butman 1994). Deposit feeders and scavengers, are often the most abundant taxa in tropical near shore environments. Natural variation in the supply of organics is thought to be an important control in these detrital-based ecosystems, with community structure fluctuating in response to changes in organic loads. Furthermore, the type of organic or detrital matter is also thought to be an important control, with some species showing affinities to fresh carbon over aged detritus within the sediment, leading to differences in vertical distribution of taxa within the sediment (Snelgrove and Butman 1994).

Whether or not particle size distributions, and the type of organic matter they contain, will change substantially at the PoR DMPA will depend on the prevailing hydrodynamic conditions, such as flow and bed-shear stress, and on the nature of the material within the channels to be dredged. Given the extensive broad-scale heterogeneity in grain size (BMT WBM 2015), the relatively protected DMPA location, and the relatively small volume of material (see Section 3.3.1) the potential for large changes in grain size pre- and post-dredging on the DMPA and in adjacent areas is less than other high-energy DMPA's elsewhere in Queensland.

3.2.3.2 Near-field Impacts

The slope of the existing DMPA is generally flat (see Section 2.4.1) with the exception of the batter slope along the northern DMPA margin, nearing the channel. Therefore, it is unlikely that slumping would lead to significant effects to benthic fauna in adjacent areas.

Dredged material may also be resuspended and transported from the DMPA to adjacent areas by waves, currents or flood pulses. The likelihood and degree of impacts to adjacent environments is dependent on:

- Disturbance regime. Storms events are regular and significant factors controlling sediment movements and bed stability. During extreme weather events, currents and waves can remobilise and redistribute sediments throughout the near shore zone, including both the DMPA and adjacent areas. Pulsed river flows during these events represent a key source of fine sediments to near shore areas, and can also lead to resuspension of bed sediments. The distribution of sediment within Keppel Bay and its response to these drivers are discussed further in Section 2.4.
- Bed sheer stress and sediment grain size. The stability of the bed is a function of sediment grain size, with fine sediments tending to be more easily resuspended than coarser sediments. The sediments within the study area, including the DMPA and the dredged channel, are predominantly silty muds (Ryan *et al*. 2006; 2009), with some areas of shell grit.
- Presence of sensitive receptor sites in adjacent areas. The study area has high background turbidity and therefore no seagrass meadows, corals or other sensitive receptors are present. The benthic communities found here are comprised of species that can tolerate high turbidity and sediment deposition (BMT WBM unpublished).

On the basis of the above, there is a low likelihood that placed sediments would cause major changes to habitat conditions and biota in adjacent areas.

3.2.4 Turbid Plume Impacts

Dredging and material placement activities generate a plume of turbid water that would extend into areas outside the DMPA and channel. Silt from these plumes can deposit on sensitive receptors and also reduce the light available to communities that depend on it, such as corals and seagrasses. Contaminants associated with sediments can also impact surrounding biota once it is remobilised. Dredge plumes have not been monitored or tracked quantitatively at Port Alma; however, plumes generated by dredging at Port Curtis and from material placement at East Banks have been monitored and modelled extensively by BMT WBM.

Based on past turbid plume monitoring at the East Banks DMPA (BMT WBM 2012b), suspended sediment concentrations can rapidly (within 2 hrs) return to background levels after placement. Plumes associated with loading (dredging) can be much more persistent if they involve fine sediments, and hydrodynamic forces at the site are strong. The material to be dredged at Port Alma is made up primarily of fines (silt and mud) and is similar to that monitored in Jacobs Channel within Port Curtis. Assumptions regarding the dredged material properties and source rates used to model dredging activities in Jacobs Channel have been adopted within the present numerical modelling (see Section 3.3.1).

During extreme rainfall events, very high turbidity values can occur (i.e. >1,000 NTU at the Fitzroy Barrage [BMT WBM unpublished], grading down to approximately 50 NTU at Pelican Island in Keppel Bay [Schaffelke, *et al.* 2008]). High turbidity can be generated from a combination of catchment runoff, and by wave and tidal resuspension. The Fitzroy River is the largest contributor of suspended sediment to the study area, with smaller concentrations coming from surrounding creeks and rivers (see Section 2.4.4). Consequently, benthic macroinvertebrates communities are unlikely to be comprised of a large number of species that are highly sensitive to short term increases in turbidity (i.e. suspended sediments).

3.3 Areas Potentially Affected

3.3.1 Schematisation and Modelling

Based on this limited information a schematised three day dredging campaign was modelled to investigate the likely behaviour of the plumes generated by future maintenance dredging campaigns in Port Alma. Concentrations of Total Suspended Solids (TSS) were modelled using BMT WBM's TUFLOW-FV software (http://www.tuflow.com/Tuflow%20FV.aspx). Plume source terms (kg/s of sediment) used in the modelling were adopted from past modelling of maintenance dredging campaigns in Port Curtis. Such source terms have been validated against field data in Port Curtis. It has been assumed that the sediments and dredging operations within Port Alma will be similar to those within Jacobs Channel.

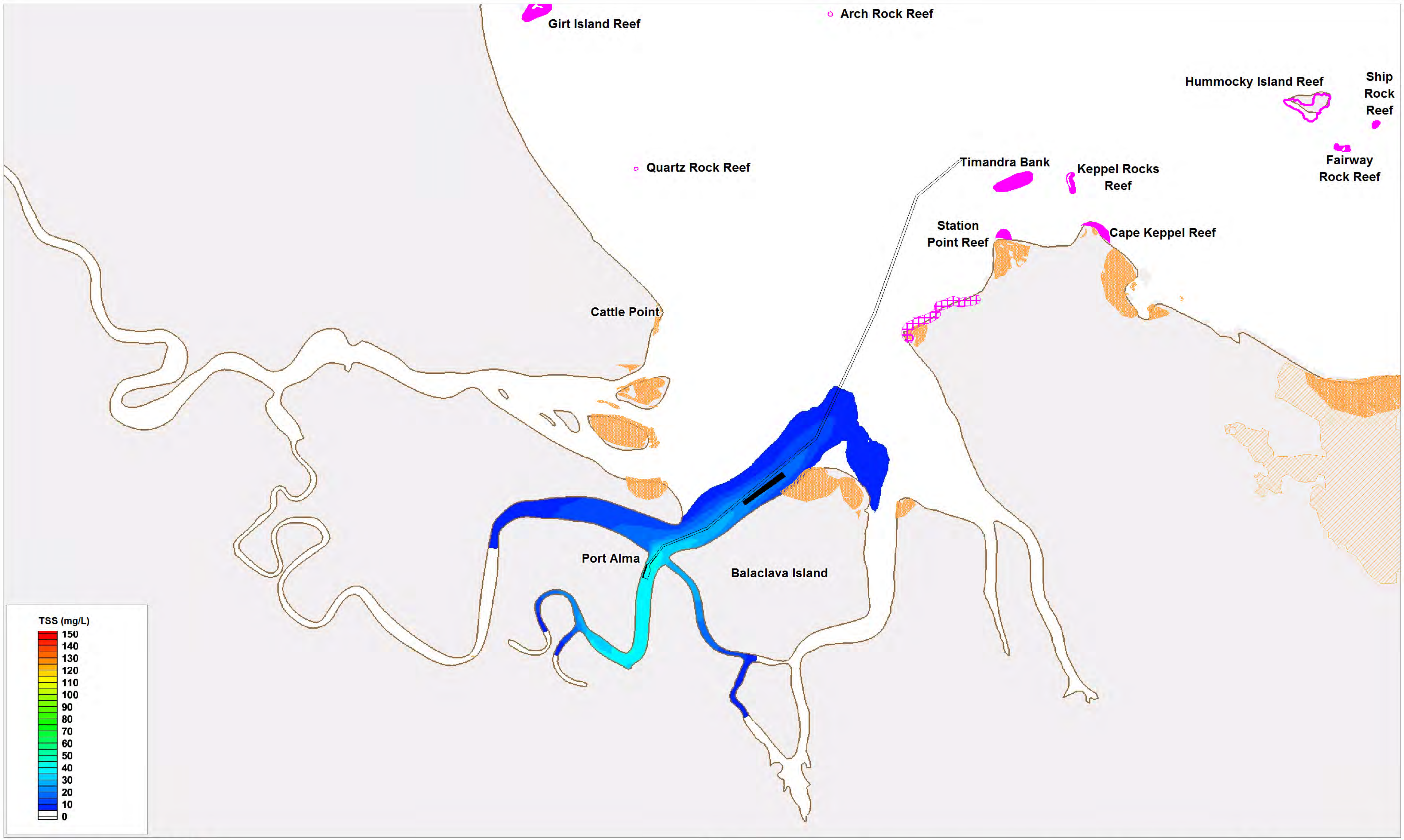
The modelling period included three days of dredging by the dredger *Brisbane* running continuously and cycling every three hours, dredging and placing a total of 34,320 m^2. The dredging period was then followed by four days of additional simulation where the dredge related sediments were available for resuspension and redistribution. The modelled dredging occurred during a spring tide when the suspended dredge related sediments had the greatest potential to travel within the prevailing currents beyond the dredge footprint. The TSS concentrations exceeded 50% of the time during the seven day simulation are shown in the 50th percentile exceedance plot (Figure 3-1) while the 95th percentile exceedance plot shows the TSS concentration that is exceeded 5% of the time, i.e. rarely (Figure 3-2).

3.3.2 Limitations

The hydrodynamic model has not been calibrated with measured tidal velocity data within Port Alma. Also, fine-scale bathymetry data was not available west of Balaclava Island, so contours for the model bathymetry were digitised from nautical charts. Despite these limitations, the modelling is sufficient to form an understanding of the general behaviour and extents of the dredge plumes used when designing a monitoring program. If data to verify the tidal currents was available along with more detailed information regarding past dredging campaigns and the local bathymetry then the modelling could be fine-tuned and the likely dredge plumes assessed in greater detail.

3.3.3 Modelling Results

Figure 3-1 and Figure 3-2 show the extent of the plumes, the location of the areas to be dredged and the DMPA. Also shown are the positions of important shorebird roosting sites, turtle habitats, and coral reefs. The extents of the dredge plumes generated during both dredging and material placement operations do not extend to any of the sensitive receptors (as defined in Section 2.3) at significant concentrations.



LEGEND

- Dredge Loading and Placement Areas
- Channel Extent (digitised)
- Recorded Turtle Nesting Beaches (DEHP 2013)
- Reef Extent
- Important Shorebird Roosts (IMEMS 2013)
- Major Shorebird Feeding Habitat (IMEMS 2013)

Title:
50th Percentile Plume Exceedance and Sensitive Receptors

Figure: 3-1

Rev: A

N 0 2.5 5km
Approx. Scale

BMT WBM
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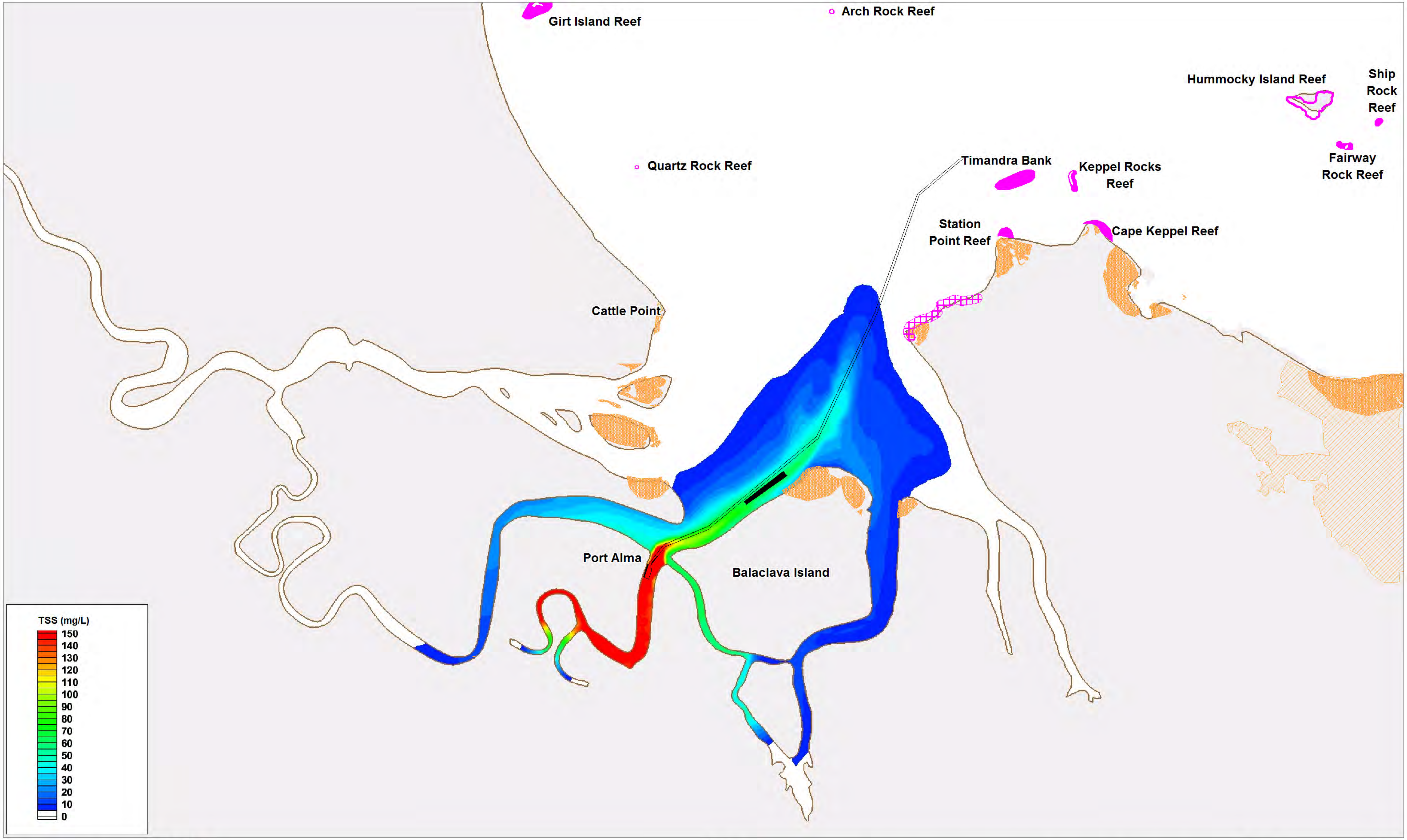

LEGEND

- Dredge Loading and Placement Areas
- Channel Extent (digitised)
- Recorded Turtle Nesting Beaches (DEHP 2013)
- Reef Extent
- Important Shorebird Roosts (IMEMS 2013)
- Major Shorebird Feeding Habitat (IMEMS 2013)

Title:
95th Percentile Plume Exceedance and Sensitive Receptors

Figure 3-2

Rev: A

N 0 2.5 5km
Approx. Scale

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4 Monitoring Program Design

4.1 Indicators

4.1.1 Selection Framework

In selecting condition and condition driver indicators, principles of the SMART framework (UNDP 2009) were considered. The SMART framework is divided in to the following five criteria:

- Simple (easily interpreted and monitored)
- Measurable (statistically verifiable, reproducible and show trends)
- Accessible (regularly monitored, cost effective and consistent)
- Relevant (directly address issues or agreed objectives)
- Timely (provide early warning of potential problems).

Table 4-1 presents indicator groups that are directly relevant to the quantifying impacts to marine environment as a result of dredging and dredged material placement. The indicator groups considered in this assessment were selected on the basis that they are representative of:

- The key ecological assets and sensitive receptors occurring in the Port Alma area, as summarised in Section 2; or
- The physical and physio-chemical environmental drivers likely to be affected by dredging or dredged material placement (e.g. changes to water quality, sediment properties etc.); or
- Aquatic ecosystem condition indicators.

Each of the indicator groups were assessed in accordance with the SMART criteria listed above.

4.1.2 Indicator Groups

Marine Plants

Seagrass meadows are not well developed in the Port Alma area, most likely due to high turbidity and fluvial discharges from the Fitzroy River. Any seagrass meadows are likely to be restricted to shallow protected tidal banks, is expected to vary over time in response to changes in ambient water quality (water clarity) conditions. No seagrass has been observed in recent broad-scale surveys (Rasheed). Given the lack of seagrass in the vicinity of the dredged area and DMPA, it is unlikely to be affected by port operations and on this basis would not represent a reliable indicator.

Mangroves and saltmarsh occur directly adjacent to the dredge site, and are also near the DMPA. Mangroves and saltmarsh can be adversely affected by sediment burial, but typically at levels measured in 10s of centimetres to metres. Neither community is sensitive to increased water column turbidity. It would be expected that any sediment loading generated by dredging would have negligible effects on saltmarsh and mangrove habitats, and therefore, have limited value as indicators in this context.

Table 4-1 Pressure and condition indicators relevant to dredging and dredged material placement

Indicator Group	SMART Criteria Met	SMART Criteria Not Met
Physio-chemical Pressure/Driver		
Physio-chemical sediment properties	Meets all criteria	-
Toxicants in water column	Meets all criteria	-
Sediment resuspension/ deposition	Relevant to assessing impacts of: dredged material placement re-suspension and movement of sediment from DMPA	Difficult to accurately measure Results highly method dependent Can be expensive
Turbidity/suspended solid concentrations	Relevant to measuring impacts of plumes from dredging and material placement	Difficult to accurately measure turbidity generated by re-suspension of dredged material compared to native bed sediments
Ecological Condition		
Seagrass condition	Seagrass sensitive to changes in light and nutrients Robust indicator of long-term changes to turbidity	Seagrass meadows not recorded in Port Alma area Impact identification based on long-term trends (not timely)
Reef community condition	Corals are sensitive to changes in light and nutrients Robust indicator of long-term changes to turbidity	Coral reefs absent from PoR Impact identification based on long-term trends (not timely)
Saltmarsh/mangrove communities	Easily measured	Not highly sensitive to turbidity or sediment deposition Well represented along foreshore of Port Alma, but unlikely to be affected by dredged sediments Impact identification based on long-term trends (not timely)
Benthic macroinvertebrate communities	Represented at and adjacent to DMPA and dredge site Easy to quantify Sensitive to sediment burial, changes to sediments and turbidity Community structure reflects local conditions Well studied elsewhere	Requires specialist taxonomic expertise, and therefore expensive Impact identification based on long-term trends (not timely)
Benthic meiofauna communities	Represented at and adjacent to DMPA and dredge site Sensitive to sediment burial, changes to sediments and turbidity Community structure reflect local conditions	Requires specialist taxonomic expertise, and therefore expensive Ecology poorly known Impact identification based on long-term trends (not timely)
Demersal fish and shellfish	Represented at and adjacent to DMPA and dredge site Easy to quantify	Highly mobile – may not reflect local conditions Ecology/sensitivities poorly known Impact identification based on long-term trends (not timely)

Reef Associated Biota (including Corals)

The closest known reefs to the DMPA occur approximately 14 km away on the northern tip of Curtis Island. There is little information on the structure of communities on these reefs, although based on environmental conditions present here, it would be expected that reefs would be inhabited by species that are tolerant of periods of low light and sediment deposition. Field investigations at Cape Keppel Reef (BMT WBM unpublished) showed that communities were extremely simplified and consisted of occasional soft and hard coral taxa that are relatively resistant to turbidity.

Preliminary modelling undertaken in the present study (Section 3.3.3) indicates that sediment plumes generated by dredging or material placement would generally travel in a south-west to north-east direction, but were not predicted to make contact with reefs. The closest coral reefs to the DMPA are found 14 km to its north-east, and therefore, are unlikely to be affected. On this basis, monitoring of reefs and corals is not considered a priority in the context of assessing impacts of dredging and dredged material placement, but could provide useful for other general ecosystem monitoring programs relevant to GPC.

Benthic Fauna

Benthic macroinvertebrates are the preferred indicators in monitoring studies of this nature, as they:

- Are within the zone of influence or potential impact (i.e. smothering and changes in habitat conditions) with respect to dredged material placement and plumes generated from dredge loading;
- Are known to be reliable indicators in the detection of dredged material impacts; and
- Are meaningful from an ecological and social-economic perspective, as they represent food resources for most commercially significant species that occur in the study area and regulate a range of marine ecosystem processes.

Monitoring of macroinvertebrates also has two main disadvantages:

- Large numbers of samples need to be processed to account for natural variability in communities, in space and time, increasing costs of monitoring; and
- Identification of taxa and analysis of habitat properties requires expert knowledge, specialised equipment and laboratory facilities, and it time consuming.

The advantages of using benthic macroinvertebrates outweigh the disadvantages, and for this reason are preferred indicators for assessing impacts of dredging and dredged material placement (both in the DMPA and adjacent areas).

Fish and Prawns

Fish and prawns occur at and adjacent to the DMPA, and therefore, could be directly (and indirectly) affected by dredged material placement and associated turbid plumes. However, these groups are not optimal indicators for assessment of dredging and placement impacts as:

- They are highly mobile; therefore, patterns in community structure may not reflect local conditions
- Community structure can show great variation in space and time
- Ecology/sensitivities are poorly known for most species.

For this reason, fish and prawns are not considered to be the preferred indicators in the context of the present study.

4.2 Sampling Locations

Given the relatively short duration of the dredge campaign (less than 1 week) and the small volume of material to be relocated, potential impacts to macroinvertebrate communities (if measureable), would be most likely to occur:

- On the DMPA
- Directly adjacent to the DMPA
- Within the channel to be dredged
- Directly adjacent to the channel to be dredged.

To test for differences in macroinvertebrate communities at these locations before and after dredging, multiple control locations would be required to account for spatial variation in control communities and broad-scale environmental changes. Given the potentially large influence of the Fitzroy River (when in flood), a control location that is closer to the river mouth than putative impact sites would be important to separate the influence of flood discharge from dredging impact.

In order to contextualise potential flood impacts, and better understand spatial environmental variability, the sampling design should include another control location that is more distant to the Fitzroy River mouth. Without this location, it may be difficult to attribute potential effects of dredging and river discharge, under some circumstances.

Sample locations should attempt to reduce environmental variation (variation not attributable to treatment, i.e. dredging activities) as much as possible. This would include choosing sites with similar bed-shear forces and particle size distributions, and from similar depths. Based on similarities in these benthic parameters, the potential plume influence (Figure 3-1 and Figure 3-2), the potential influence of the Fitzroy River (Section 1), and the most likely putative impacts (listed above), the sampling design shown in Figure 4-1 is recommended. Sampling locations are:

- In-channel (direct dredge loading impact)
- Near-field impact (indirect dredge loading)
- DMPA impact (direct material placement impact)
- Near-field impact (indirect DMPA placement)
- Control North (more affected by Fitzroy River discharge)
- Control South (less affected by Fitzroy River discharge).

LEGEND

- In-Channel
- Near-field Impact (Loading)
- DMPA Impact
- Near-field Impact (DMPA)
- Control North
- Control South
- Dredge Area (Loading)
- Channel Extent (digitised)
- DMPA

Title:
Sampling Design

N

0 1.5 3km

Approx. Scale

Figure
4-1

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4.3 Sampling Frequency

Sampling frequency should include a “before” event sampled within two weeks prior to dredging and an “after” event, conducted two weeks after the cessation of dredging. This should occur at intervals that coincide with dredging campaigns, e.g. every five years. GPC may wish to consider additional sampling events before and after the dredging to examine temporal variability and recovery, should there be any evidence of impacts. If adopted, additional sampling events could take place three months before and three months after dredging. Additional events prior to, and after dredging would also reduce the chances of accidentally confusing temporal variation (random changes in communities over time) with dredging impacts.

Initially, a pilot study will be conducted to examine the existing variability among locations and between treatments to determine the adequacy of the proposed design and level of replication.

4.4 Sampling Methodology

At each location, three sites with five replicates will be taken to examine spatial variability within and among locations and sites.

Samples will be taken with a large van Veen grab (0.14 m^2 gape) which collects approximately 20 L of sediment and sediment will be sieved through a 0.5 mm sieve. During an earlier pilot study, very few animals were collected (many zero counts) using a smaller grab (0.028 m^2 gape) using a 1 mm sieve. Samples will be preserved in 10% formalin and stained with Rose Bengal. Particle size distribution (PSD) samples will also be collected using a small van Veen to quantify grain size at each location.

4.5 Laboratory Analysis

Animals in the sieved (0.5 mm fraction) will be separated from detrital and inorganic material using an illuminated Magilamp. Fauna will be identified (using binocular and dissecting microscope techniques) to the lowest practical taxonomic level (which in most cases will be morpho-species level, but higher taxonomic levels in difficult to identify taxa), and subsequently transferred to 70% ethanol solution.

Sediment samples will be sent to ALS laboratories for PSD analysis. Sediments will be passed through a series of Australian standard sieves identifying particle size down to 75 µm in order to estimate the proportion of material within the size categories; silt (<0.075 mm), sand (0.075-2.36 mm), and gravel (2.36-63 mm).

4.6 Data Analysis and Reporting

Data analysis for the pilot study will be limited to investigating differences among sites, locations and treatments within one sampling period only. Investigations involving temporal replication could be undertaken on the monitoring data once pre- and post-dredging data has been acquired.

Table 4-2 is a list of biological metrics that should be calculated from the benthic macroinvertebrate data. Also shown in the table are expected responses of indicators to environmental stress. A summary of statistical analyses techniques that should be used is provided below.

Table 4-2 Macroinvertebrate-based metrics and indicators

Metric/test	How tested	Response to environmental stress	Reference
Number of taxa (taxonomic richness *S*)	ANOVA - comparison of mean number of taxa between control and test locations and sites	Reduced relative to controls at high stress levels (i.e. burial due to dumping, removal by dredging) Potential increase in abundance of some taxa in areas indirectly affected by plumes	Stephenson *et al*. (1978) Jones and Candy (1981) Poiner and Kennedy (1984)
Abundance of individuals (*N*)	As for *S*	As for *S*	As for *S*
Margalef's species richness (d)	As for *S*	As for *S*	As for *S*
Pielou's evenness (J')	As for *S*	As for *S*	Warwick (1996)
Average phylogenetic distinctness (Delta+)	As for *S*	As for *S*	Clarke and Warwick (2001a)
	Funnel plot of expected and observed Delta+ and *S*	Significant departure from simulated 'expected' average Delta+ scores based on permutations	Clarke and Warwick (2001a)
Number of rare and common species	Geometric abundance curves	Small number of rare taxa Assemblage comprised of a small number of common taxa	Gray and Pearson (1982)
	K dominance curves	Small number of rare taxa Shallow curve gradient	Lambshead *et al.* (1983)
Heterogeneity in assemblages (similarity) within locations	Relative dispersion index	High variation between sites relative to variation within control locations	Warwick and Clarke (1993)
Similarity in assemblages	n-MDS	Assemblages at test locations highly dissimilar to control	Clarke and Warwick (2001b)
	ANOSIM	Significant difference between control and test location	Clarke and Warwick (2001b)

Statistical tests will include:

- **ANOVA -** Analysis of variance (ANOVA) tests will be used to test for differences in univariate measures of community structure (species richness [S], abundance [n], Margalef's species richness [d], and Pielou's evenness [J']) using ANOVA with location treated as a fixed factor and sites nested within locations. Asymmetrical ANOVA will be used to investigate differences between controls and the DMPA.
- **Power Investigations -** The percentage contribution of the residual variance to total variance from the ANOVAs should be used in power analyses following the formulae and methods of Snedecore and Cochrane (1989). Critical values from the F distribution for α= 0.05 and β= 0.9 should be used in all cases. Effect size curves should be developed to show the relationship between effect size (proportional reduction) and sampling sizes using the global residual variance for each univariate response.

- **Variance Metrics -** Several studies have demonstrated that assemblages are more heterogeneous in disturbed compared to undisturbed environments. In addition to ANOVA, descriptive statistics should be generated to determine whether the test locations had more variable taxa richness and abundance than control locations. The dispersion coefficient (variance/ mean) and the coefficient of variation (standard deviation*100/ mean) shall be calculated for taxonomic richness, total abundance and the percentages of fines to explore patterns in variability.
- **K-dominance curves** (Lambshead *et al*. 1983), in which the species are ranked in order of dominance on the x-axis (logarithmic scale) with percentage dominance on the y-axis (cumulative scale), shall be constructed.
- **Multivariate analysis:** Differences in assemblages of macrobenthic fauna shall be examined using multivariate procedures described by Clarke (1993). For all analyses, raw data should be initially transformed (Log_{x+1}) and a similarity matrix generated using the Bray-Curtis measure of similarity. The similarity matrix will be used to construct:
  - Non-metric multidimensional scaling (nMDS) ordinations (Clarke 1993, Clarke and Ainsworth 1993).
  - Analysis of Similarity (ANOSIM), which will be used to assess variation in assemblages among locations and sites within locations. Separate tests should be done for the DMPA and DMPA nearfield locations versus controls, and the channel and near-field channel versus controls.

4.7 Conclusions

Based on SMART criteria, likely impacts, and the presence of sensitive receptors in the PoR, biological monitoring should include benthic macroinvertebrate communities using the recommended spatial design and analyses. Given the small volumes of material to be dredged, the infrequent nature of dredging, and the severity of natural disturbance events, the impacts of dredging and dredged material placement may be very slight. The sampling design and frequency may require adjustment depending on the findings of a pilot study and/ or subsequent monitoring events.

Sediment testing should be conducted in accordance with the NAGD (2009) on a five-yearly basis, coincident with dredging campaigns, and in association with water quality monitoring. Water quality monitoring including grab samples and dredge plume mapping should be used to investigate model predictions regarding the behaviour and intensity of dredge plumes, and the concentrations of toxicants in the water column.

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