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Port Alma Benthic Fauna Pilot Monitoring Program - Final Report

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Port Alma Benthic Fauna Pilot Monitoring Program - Final Report

Prepared for:	Gladstone Ports Corporation
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Document Control Sheet

BMT WBM Pty Ltd
Level 8, 200 Creek Street
Brisbane Qld 4000
Australia
PO Box 203, Spring Hill 4004

Tel: +61 7 3831 6744
Fax: + 61 7 3832 3627

ABN 54 010 830 421

www.bmtwbm.com.au

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Title:	Port Alma Benthic Fauna Pilot Monitoring Program - Final Report
Project Manager:	Darren Richardson
Author:	Darren Richardson
Client:	Gladstone Ports Corporation
Client Contact:	Gordon Dwane
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Synopsis: **A report outlining the findings of a pilot benthic fauna monitoring program undertaken at Port Alma in 2015.**

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Executive Summary

The Port of Rockhampton is operated by Gladstone Ports Corporation (GPC) and includes port facilities at Port Alma near the mouth of the Fitzroy River. The navigation channels and berth pockets are maintained by dredging, and dredged material is placed in an offshore dredged material placement area (DMPA) located near the port facilities.

GPC initiated the development of a receiving environment monitoring program (REMP) for the Port of Rockhampton (PoR). The present report outlines the findings of a pilot field investigation to develop and refine the REMP for the PoR for assessing the impacts of dredging and dredged material placement. The broad aim of this pilot study is to characterise spatial patterns in benthic macroinvertebrate assemblages at the PoR, in order to develop a Receiving Environment Monitoring Program for assessing impacts of dredging and dredged material disposal.

Sampling was carried out in January 2015 at a range of control and test locations. Test locations included the dredged channel, areas adjacent to the dredged channel, the dredged material placement area (DMPA) and areas adjacent to the DMPA. A van Veen grab sampler was used to sample benthic macroinvertebrates, which were identified and enumerated in the laboratory. Univariate and multivariate statistical techniques were adopted to compare trends in indicators among and within control and test locations.

A total of 2874 individuals were recorded in the present study. The catch was comprised of 144 taxa from 87 families, 13 classes and 11 phyla. The most abundant group were the polychaete worms (42% of individuals), followed by malacostracan crustaceans (27% of individuals), acorn worms (11% of individuals), nemertean worms (5% of individuals), ostracod seed shrimps (3% of individuals) and gastropod molluscs (2% of individuals).

Benthic communities within the study area were characterised by having the following attributes:

- Comprised exclusively of marine/estuarine species, with no freshwater species recorded
- Comprised exclusively of small opportunistic and/or mobile taxa
- Abundance dominated by a few taxa
- A large proportion of uncommon taxa (93% of taxa were recorded in one or two samples).

Fewer benthic macroinvertebrate taxa and individuals were recorded in the DMPA (39 taxa), channel (47 taxa) and areas immediately adjacent to the DMPA (30 taxa) compared to control locations (73 and 74 taxa). Benthic assemblages in the immediate environs of the channel (79 taxa) were not different from those recorded at control locations. The more depauperate communities observed in the test locations could reflect either: impacts from past dredging and dredged material placement activities, other anthropogenic influences (e.g. vessel traffic or trawling), experimental design artefacts, including differences in environmental conditions between control and test locations, and high levels of natural variability at various spatial scales (among locations, and among sites within locations). The simplification of communities in dredged channels has been observed in other Queensland ports; however, dredged material placement does not typically cause long term impacts to benthic communities (particularly outside the DMPA).

It is not possible to conclude with a high degree of certainty that observed differences in benthic fauna communities were a response to legacy impacts of past dredging and dredged material placement activities. The present pilot study represents a snap-shot in time, and impact detection needs to consider not only spatial differences in indicators (i.e. among and within treatments), but also the direction and magnitude of temporal changes observed at different spatial scales. It is recommended that future monitoring should, involve sampling before and after dredging (and material placement) to quantify impacts. Additional sampling events should only be considered if impacts are resolved, to assess recovery trajectories of assemblages. This should be undertaken at multiple treatments, locations and sites within and adjacent to the primary test site, as adopted in the present study.

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1 Introduction

1.1 Background

The Port of Rockhampton is located near the mouth of the Fitzroy River, adjacent to Balaclava Island (Figure 1-1). Port Alma's facilities are located within the Port of Rockhampton (PoR) and are operated by Gladstone Ports Corporation (GPC). The navigation channels and berth pockets are maintained by dredging, and dredged material is placed in a dredged material placement area (DMPA) located near the port facilities.

GPC initiated the development of a receiving environment monitoring program (REMP) for the Port of Rockhampton. A desk-top and modelling assessment was undertaken to facilitate the development of the REMP (BMT WBM (2015). BMT WBM (2015) provided recommendations regarding the development of the REMP, which included the development and implementation of a pilot benthic macroinvertebrate sampling program.

The present report outlines the findings of this pilot field investigation to develop and refine the REMP for the Port of Rockhampton. In accordance with BMT WBM (2015), the pilot study specifically considers spatial patterns in benthic macroinvertebrate communities as a means for developing a program to examine the potential effects of maintenance dredging and dredged material placement on benthic fauna communities.

1.2 Aims and Objectives

The broad aim of this pilot study is to characterise spatial patterns in benthic macroinvertebrate assemblages at the Port of Rockhampton, in order to develop a REMP for assessing impacts of dredging and dredged material placement. The specific objectives of this study area to:

- Characterise benthic macroinvertebrate community structure (diversity, richness, abundance, similarity) in areas previously affected by dredging and dredged material placement, and in adjacent areas affected by plumes and outside the influence of plumes
- Investigate any legacy effects of material placement on benthic fauna communities and sediments
- Provide recommendations regarding the design and implementation of the REMP, including spatial (site and sample) and temporal replication, and key considerations regarding confounding environmental influences.

1.3 Impact Hypothesis

Dredging and dredged material placement may affect benthic macroinvertebrates through the following mechanisms:

- Dredging will result in the direct loss of fauna in the dredging footprint.
- Dredged material placement will result in the smothering of most benthic flora and fauna within the DMPA. Depending on the depth of placed sediment, it is possible that some more mobile burrowing fauna will be able to migrate through the placed sediments.

- Dredging and dredged material placement will lead to sediment mobilisation, which could have either adverse (e.g. smothering) or beneficial (i.e. increase food resources) effects to benthic fauna in adjacent areas.
- Physical habitat conditions will be altered as a result of dredging and dredged material placement.

Benthic communities in dynamic coastal environments such as the Port Alma typically display relatively rapid recolonisation (measured in time scales of days to weeks) following dredged material placement (Newell *et al*. 1998). Recovery timeframes are typically longer, measured in months to 10s of months (see Newell *et al*. 1998; BMT WBM 2012).

Based on the above, it would be expected that past dredging and dredged material placement would manifest as:

- Lower diversity and/or abundance in benthic fauna communities, and altered benthic assemblage structure, within the loading site, DMPA and/or areas adjacent compared to background (e.g. Newell *et al*. 1998)
- Potentially higher levels of spatial heterogeneity in assemblage structure within loading site, DMPA and/or areas adjacent compared to background. Warwick and Clarke (2001) note that high variability in marine fauna assemblages structure can be a symptom of stress.

The impact hypothesis to be tested is:

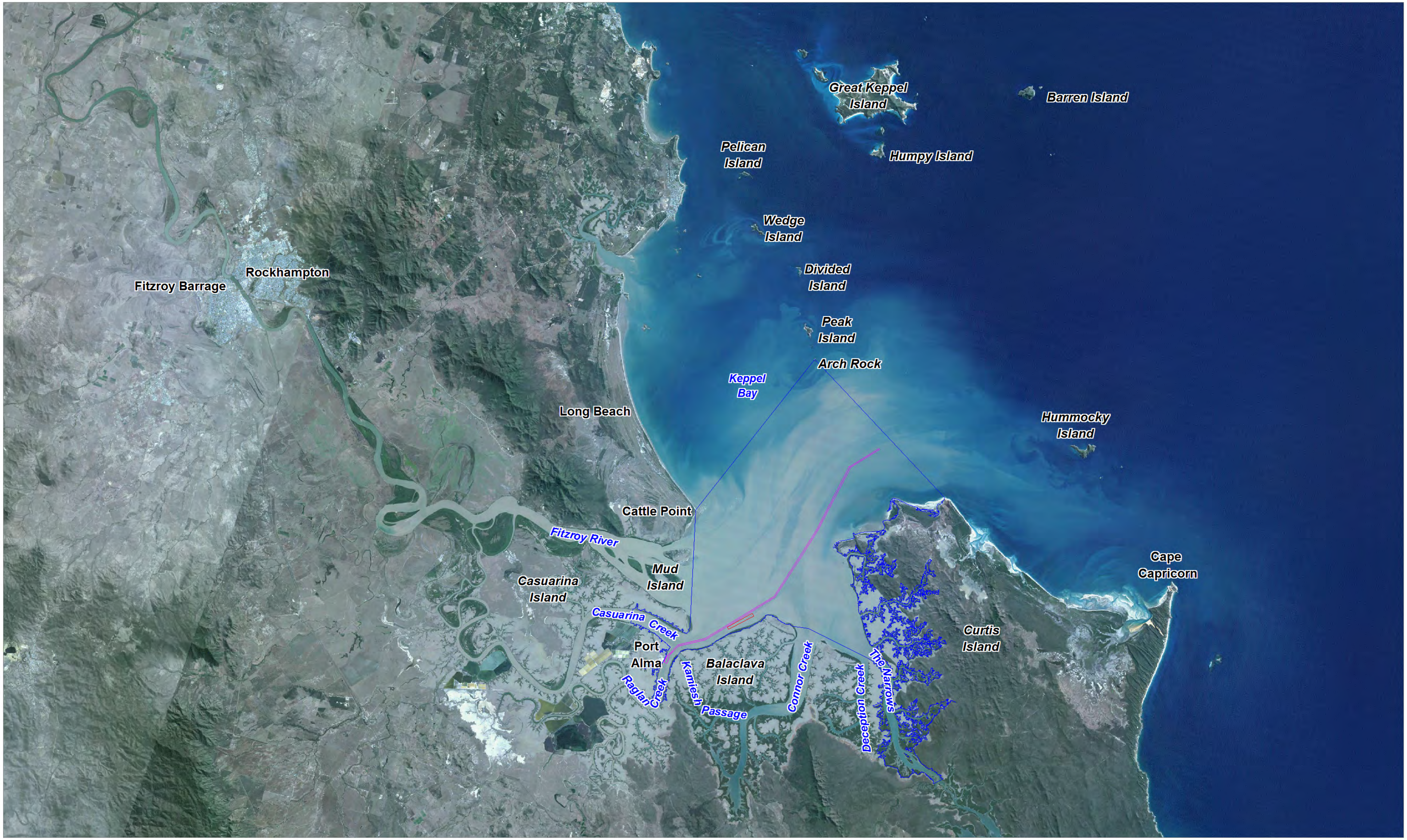
- *There are no differences in diversity, abundance or variability in assemblages between control and test locations (treatments), and differences are consistent among sites within locations.*

1.4 Study Area

The study area for this investigation includes subtidal waters adjacent to the mouth of the Fitzroy River. BMT WBM (2015) provides a description of the environmental setting of the study area, including currents, sediment types and marine ecological attributes. The investigation specifically focussed on declared navigation channels and the DMPA, as shown in Figure 1-1.

1.5 Terminology and Acronyms

ANOVA	Analysis of Variance
BACI	Before/ After, Control/Impact monitoring design
DMPA	Dredged Material Placement Area
ERMP	Ecosystem Research and Monitoring Program
GPC	Gladstone Ports Corporation
NAGD	National Assessment Guidelines for Dredging
nMDS	non-metric multidimensional scaling ordination (graph or plot)
PoR	Port of Rockhampton
PSD	Particle Size Distribution



LEGEND

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

Title:

Locality Plan

Figure

1-1

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Approx. Scale

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2 Methodology

2.1 Timing of Sampling

Sampling was undertaken on one occasion between 14 and 17 January 2015. Above average rainfall occurred in the summer months preceding sampling (i.e. February and March 2014), whereas the period May to December 2014 generally had below average rainfall (except August and September 2014). Average rainfall conditions were recorded in January 2015, and no major falls were recorded in the survey period.

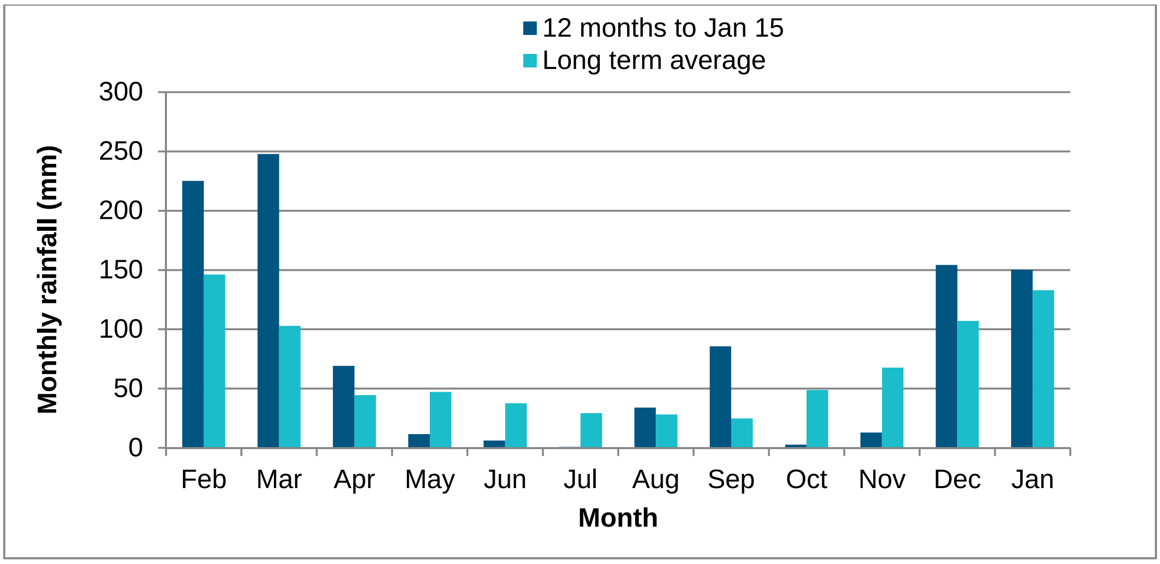
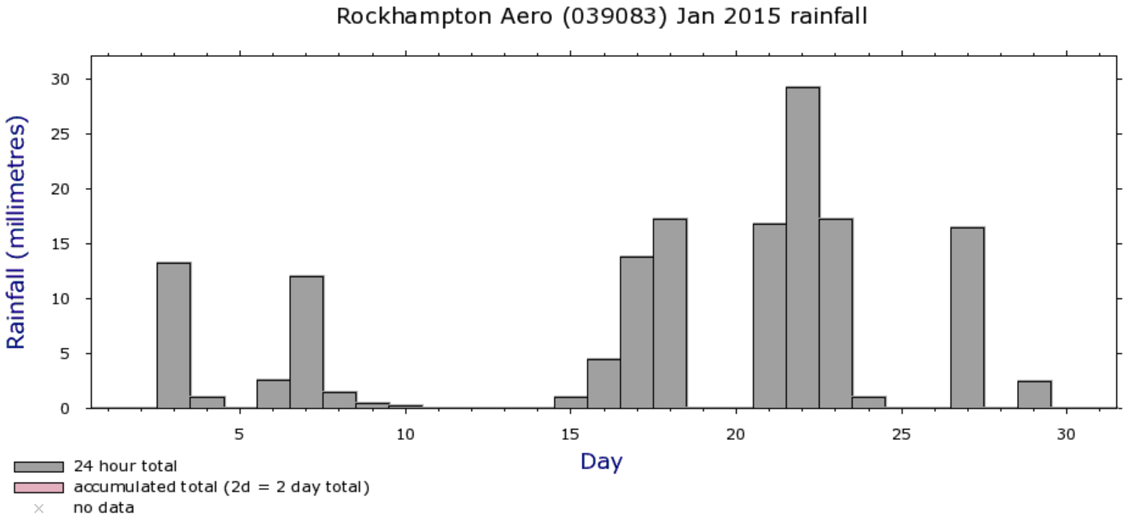


Figure 2-1 Monthly rainfall at Rockhampton airport (BOM Station 39083) – 12 month period leading up to and including January 2015 and long term average for the period 1939-2015



Note: Data may not have completed quality control.

Climate Data Online, Bureau of Meteorology
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Figure 2-2 Daily rainfall at Rockhampton airport (BOM Station 39083) January 2015

2.2 Sampling Design

A nested orthogonal design was adopted which included the following spatial scales of variability:

- Treatments - controls and the following four test treatments: DMPA, areas adjacent to the DMPA, in-channel, areas adjacent to the channel.
    - The DMPA treatment examined direct effects of material placement and these were located on the DMPA.
    - The near field impact (DMPA) treatment examined indirect impacts from material placement and these were located directly adjacent to the DMPA.
    - The in-channel treatment examined direct impacts of dredge loading and these were located within the dredge footprint of the 2010 campaign.
    - The near field impact (loading) treatment examined indirect impacts of dredge loading in the areas adjacent to the channel dredging footprint.
- Locations - all but the control treatment (two locations) were represented by one location
- Sites nested within locations - three haphazardly selected sites were sampled in each location
- Replicate samples within sites - five samples were collected in each site.

The position of treatments, locations and sites are shown in Figure 2-3. Site selection was informed by modelling and a review of existing information, as described in BMT WBM (2015).

2.3 Sampling and Enumeration

Benthic macroinvertebrates and sediment particle size distribution (PSD) samples were collected using a van Veen grab. Sampling was conducted from the research vessel *Rush*. Location and navigation to the sediment sampling locations was made possible using a real time differential Global Positioning System (dGPS) to provide position-fixing accuracy's of ±2m.

In several sites, sediments restricted the closure of the grab jaws, limiting the effective amount of sample collected. Casts that resulted in improper closure of the grab or incomplete samples were discarded, and the grab was deployed again in another location (within metres).

2.3.1 Sampling Methods

A total of five replicate benthic macroinvertebrate samples were collected from each site. Replicates were positioned haphazardly within sites and sampled with a large van Veen grab (0.1 m^2). Sample material was initially placed into individual 40 L plastic bins, and sediment depths were measured to ensure a complete sample had been collected. Sample material was then passed through a 0.5 mm mesh sieve with retained material transferred into individual containers for fixing in a buffered formalin (10%) solution of seawater.

At each location, one sediment sample was collected for PSD analysis. Sediment and any collected overlying waters were placed into a bin, where material was allowed to settle for up to an hour before 200-500 g of sample was extracted.

2.3.2 Laboratory Processing

Animals in the ≥1.0 mm fraction were separated from detrital and inorganic material using an illuminated Magilamp. Fauna were identified (using binocular and dissecting microscope techniques) to the lowest practical taxonomic level (which in most cases was morpho-species level, but higher taxonomic levels in difficult to identify taxa), and subsequently transferred to a 70% ethanol solution.

Sediment samples were sent to ALS Environmental Pty Ltd for PSD analysis. Sediments were passed through a series of Australian Standard sieves identifying particle size down to 75 µm in order to allow an estimation of the proportion of material within the size categories; silt (<0.075 mm), sand (0.075-2.36 mm), and gravel (2.36-63 mm).

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 Locations and Sites

Figure

2-3

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2.4 Statistical Analyses

Table 2-1 is a list of biological metrics calculated from the benthic macroinvertebrate data, and the statistical analyses used to test the impact hypotheses outlined in Section 1.3. Also shown in the table are expected responses of indicators to environmental stress. A description of the statistical analyses techniques is provided below.

Table 2-1 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)

2.4.1 Univariate Indices

ANOVA

Analysis of variance (ANOVA) tests were 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 was used to investigate differences between controls and the DMPA. This was done as a test case to compare the variability within and among control and impact locations to investigate the suitability of control locations. The asymmetrical ANOVA tests were carried out in accordance with procedures in Underwood (1991, 1992, 1994). Sums of squares were calculated using Number Cruncher Statistical Software (NCSS). Prior to analyses, the assumptions of ANOVA (Sokal and Rohlf 1995) were tested:

- The assumption that the variances of error terms are normal was tested using Shapiro-Wilk tests. For cases of non-normality, data were log (x + 1) transformed and Shapiro-Wilk tests were repeated on the transformed data. In all cases, transformations stabilised heterogeneous variances.
- To meet the ANOVA assumption that variances of sets of samples are equal, equality of variances F-tests were used to test for homogeneity of variances. Raw data were log transformed (x + 1) in cases where variances were heterogeneous. For comparisons between controls and test sites, significance was determined at the lower probability level of $p = 0.01$ on the untransformed data (Underwood 1981).

Power Investigations

The percentage contribution of the residual variance to total variance from the ANOVAs was used in power analyses following the formulae and methods of Snedecore and Cochrane (1989). Critical values from the F distribution for $\alpha = 0.05$ and $\beta = 0.9$ were used in all cases. Effect size curves (Section 3.3.2) show the relationship between effect size (proportional reduction) and sampling sizes using the global residual variance for each univariate response. In other words, the graph describes the magnitude of change that could be detected between two groups (e.g. locations) under different levels of sampling replication.

Variance Metrics

Several studies have demonstrated that assemblages are more heterogeneous in disturbed compared to undisturbed environments. In addition to ANOVA, descriptive statistics were 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) were calculated for taxonomic richness, total abundance and the percentages of fines to explore patterns in variability.

2.4.2 Graphical Descriptors

Plots of 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), were constructed for the totals of the 15 samples at each location (sites pooled). Furthermore, geometric abundance curves were calculated to assess variability in the distribution of rare and common species, based on procedures in Gray and Pearson (1982).

Scatter plots of taxonomic richness and phylogenetic distinctness (based on presence-absence data) were generated based on site-averaged data. Furthermore, confidence funnels for taxonomic distinctness were constructed (see Clarke & Warwick 2001b). In this approach, unaltered reference sites should fall within the 95% confidence limits in the funnel plot of taxonomic distinctness against species number, assuming that each site harbours species selected randomly (we used 10 000 random selections) from the regional species pool (i.e. the total master species list from this study). By contrast, anthropogenically altered sites should fall below the 95% confidence limits of the funnel plot (Warwick and Clarke 1998).

All data analyses were undertake using the software package Primer Version 6.

2.4.3 Multivariate Analyses

Differences in assemblages of macrobenthic fauna were examined using multivariate procedures described by Clarke (1993). For all analyses, raw data were initially transformed (Log x +1) and a similarity matrix was generated using the Bray-Curtis measure of similarity.

Spatial variation in the assemblages was presented graphically using non-metric multidimensional scaling (nMDS) ordinations (Clarke 1993; Clarke and Ainsworth 1993). Location averaged data were used in the analyses, and groupings produced by cluster analysis were superimposed on the ordination. A stress value was presented for the ordination as a measure of how well it satisfied all the conditions of its rank similarity matrix. This value is not indicative of any measure of environmental-stress, rather, a value of <0.1 indicates that the ordination has represented accurately the relationships among the samples, but values closer to 0.2 indicate that the ordination may have misrepresented the data in high dimensional space.

An analysis of similarity (ANOSIM) was used to assess variation in assemblages among locations and sites within locations. Separate tests were done for the DMPA and DMPA nearfield locations versus controls, and the channel and near-field channel versus controls.

All multivariate analyses were done using the software package Primer Version 6.

3 Results

3.1 Sediment Particle Size Distribution

Particle size distributions (PSD) among each of the sites showed that fines (mud and silt) dominated the composition of surficial seabed sediments (Figure 3-1). Most treatments had similar PSDs; however, Control North located at the mouth of the Fitzroy River had the most sand, and one of the channel sites (CH In B) contained a sample with gravel. No cobble was recorded.

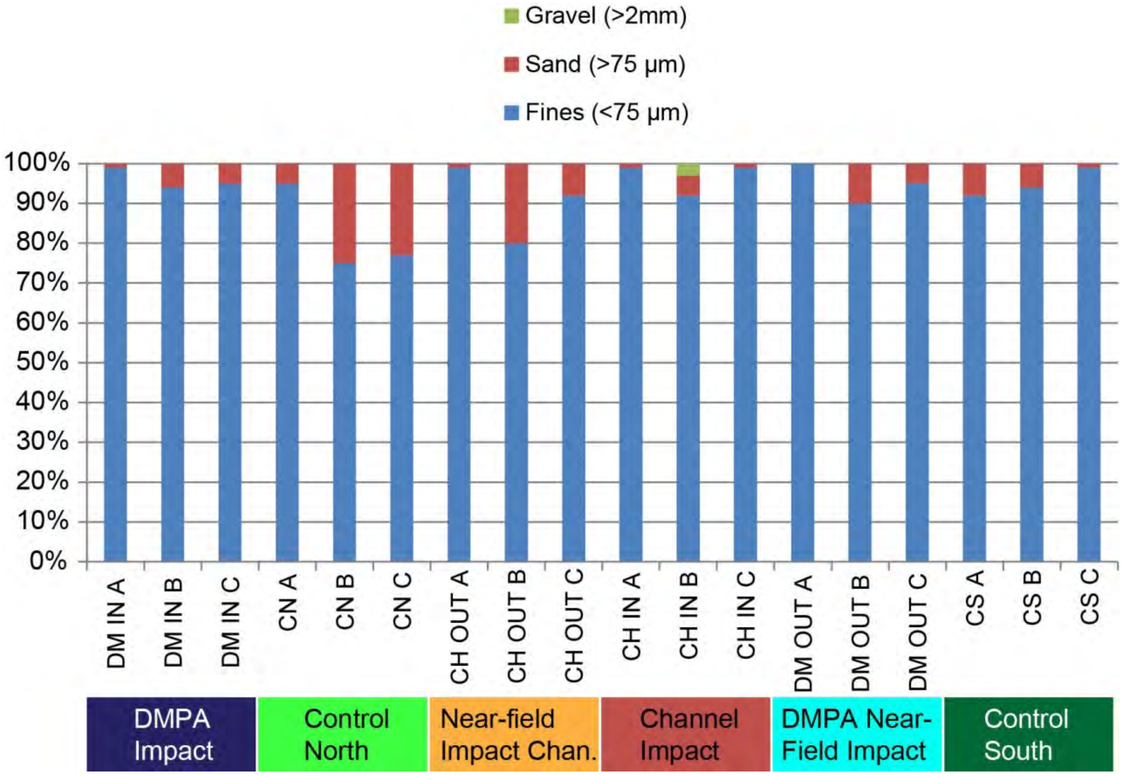

Figure 3-1 Particle Size Distributions for each site, grouped by treatment

3.2 Taxonomic Composition

A total of 2874 individuals were recorded in the present study. The catch was comprised of 144 taxa from 87 families, 13 classes and 11 phyla. The most abundant group were the polychaete worms (42% of individuals), followed by malacostracan crustaceans (27% of individuals), acorn worms (11% of individuals), nemertean worms (5% of individuals), ostracod seed shrimps (3% of individuals) and gastropod molluscs (2% of individuals).

Table 3-1 lists the most abundant taxa recorded in grab samples, contributing >1% of the total catch. The six most abundant species comprised 44% of the total catch: the deposit-feeding polychaete worm *Paraprionospio* sp. (13% of individuals), the acorn worm *Glossobalanus* sp (10.8% of individuals), an amphipod (6.3% of individuals), a decapod shrimp (6.2% of individuals), the deposit-feeding polychaete *Terebellides* sp (4.2% of individuals) and the predatory polychaete worm *Onuphis* sp (3.8% of individuals).

Table 3-1 Benthic fauna taxa contributing greater than 1% of catch

Taxa	Family	Order	Class	Phylum	% of total	Total
Paraprionospio sp	Spionidae	Spionida	Polychaeta	Annelida	13.1	377
Glossobalanus sp	Ptychoderidae	Ptychoderidae	Enteropneusta	Hemichordata	10.8	309
Amphipod 1	.	Amphipoda	Malacostraca	Crustacea	6.3	182
Decapod shrimp 1	.	Decapoda	Malacostraca	Crustacea	6.2	177
Terebellides sp	Trichobranchidae	Terebellida	Polychaeta	Annelida	4.2	121
Onuphis sp	Onuphidae	Eunicida	Polychaeta	Annelida	3.8	110
Mysid 1	Mysidae	Mysidacea	Malacostraca	Crustacea	3.3	96
Ostracoda 1	.	.	Ostracoda	Crustacea	3.1	89
Capitellidae 1	Capitellidae	Scolecida	Polychaeta	Annelida	3.0	86
Nemertean 1	.	.	.	Nemertea	2.3	67
Nemertean 2	.	.	.	Nemertea	2.1	60
Ancistrosyllis sp	Pilargiidae	Phyllodocida	Polychaeta	Annelida	2.0	57
Nassarius sp 1	Nassariidae	Neogastropoda	Gastropoda	Mollusca	1.9	55
Caragobius rubristriatus	Gobiidae	Perciformes	Actinopterygii	Chordata	1.8	53
Listriolobus sp	Echiuridae	Echiurida	Echiuroidea	Echiura	1.8	52
Nereididae 1	Nereididae	Phyllodocida	Polychaeta	Annelida	1.8	51
Ophelina sp	Opheliidae	Scolecida	Polychaeta	Annelida	1.5	42
Nuculana darwini	Nuculidae	Nuculoida	Bivalvia	Mollusca	1.4	41
Glycera sp 1	Glyceridae	Phyllodocida	Polychaeta	Annelida	1.4	39
Apseudes sp 3	Apseudidae	Tanaidacea	Malacostraca	Crustacea	1.1	33
Decapod shrimp 4	.	Decapoda	Malacostraca	Crustacea	1.1	33
Theora lata	Semelidae	Veneroida	Bivalvia	Mollusca	1.1	32
Boccardia sp	Spionidae	Spionida	Polychaeta	Annelida	1.0	29

Most taxa captured were uncommon (Figure 3-2), with 28% of taxa represented as singletons (i.e. one individual) and 12% of taxa represented by two individuals (11). Furthermore, 55% of taxa were recorded at one (36% of taxa) or two (19% of taxa) sites (Figure 3-2). As shown in Figure 3-3, there was a positive relationship between species distribution (i.e. number of sites recorded) and species abundance, indicating that abundant species were also widely distributed across the study area. The most notable exception to this was the acorn worm *Glossobalanus* sp., which was recorded at only three sites but comprised 10.8% of the catch. All other abundant taxa (i.e. taxa represented by >52 individuals) were recorded at eight or more of the 18 sites sampled.

None of the specimens identified to species were declared marine pests listed by NIMPIS (2009).

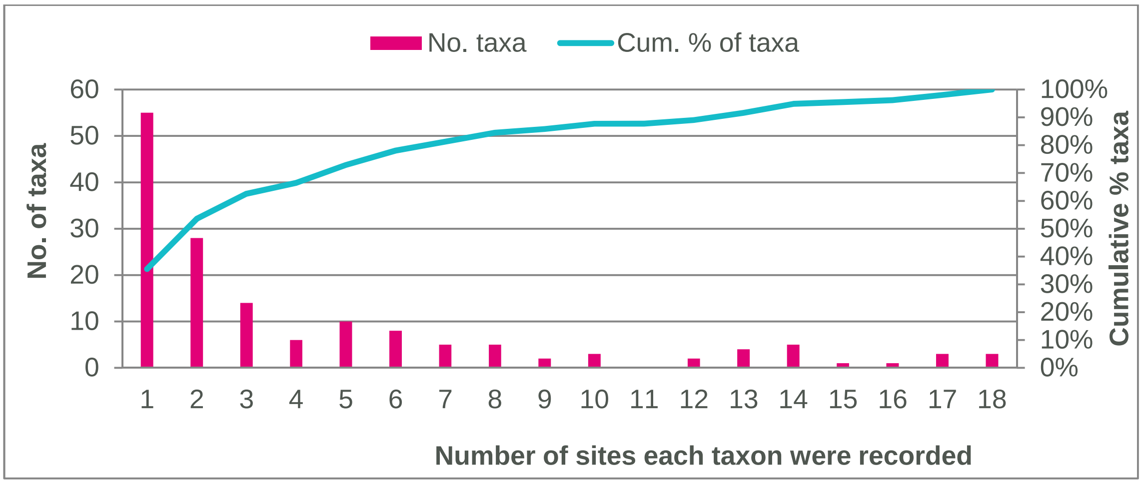

Figure 3-2 Number of sites each taxon were recorded

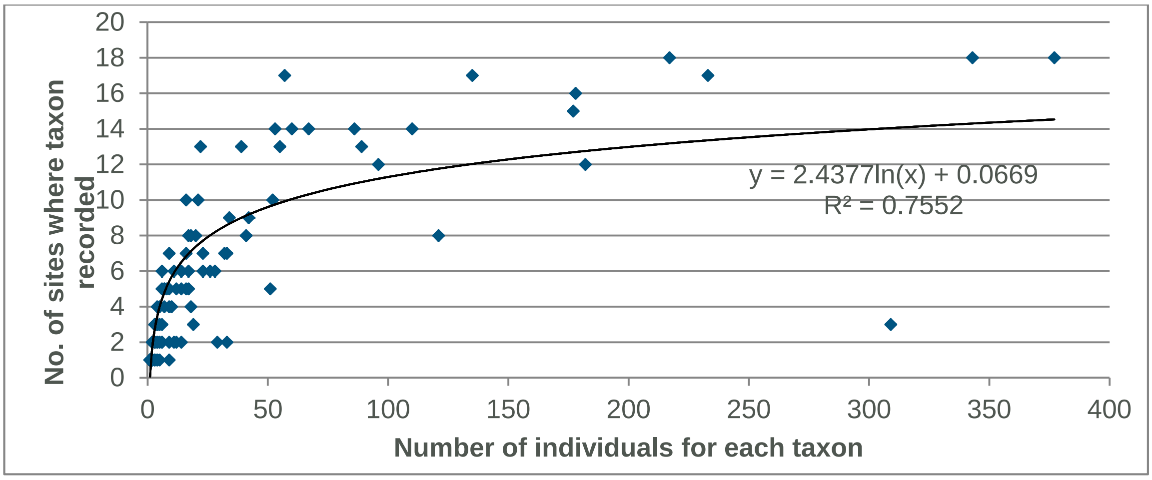

Figure 3-3 Number of sites and individuals for each taxon

3.3 Analysis of Assemblages

3.3.1 Distribution Plots for Species Abundance and Taxonomic Distinctness

Figure 3-4 presents geometric abundance curves for each location (sites pooled). The curves show the number of species represented by a single individual (class 1), 2-3 individuals (class 2), 4-7 (class 3), 8-15 individuals (class 4) and so on. Locations that have stressed assemblages tend to have fewer rare species (i.e. classes 1-3) and a larger number of abundant species, and the curves tends to have a mode that is positioned to the middle or right side of the plot (Gray and Pearson 1982). While the near field channel and near-field DMPA locations had fewer singletons than control locations, Figure 3-4 shows that the curves for each location were similar, with rare species dominating and the mode of the curves located to the left side of the plot. These results do not suggest that the test locations had assemblages that were markedly different to control locations.

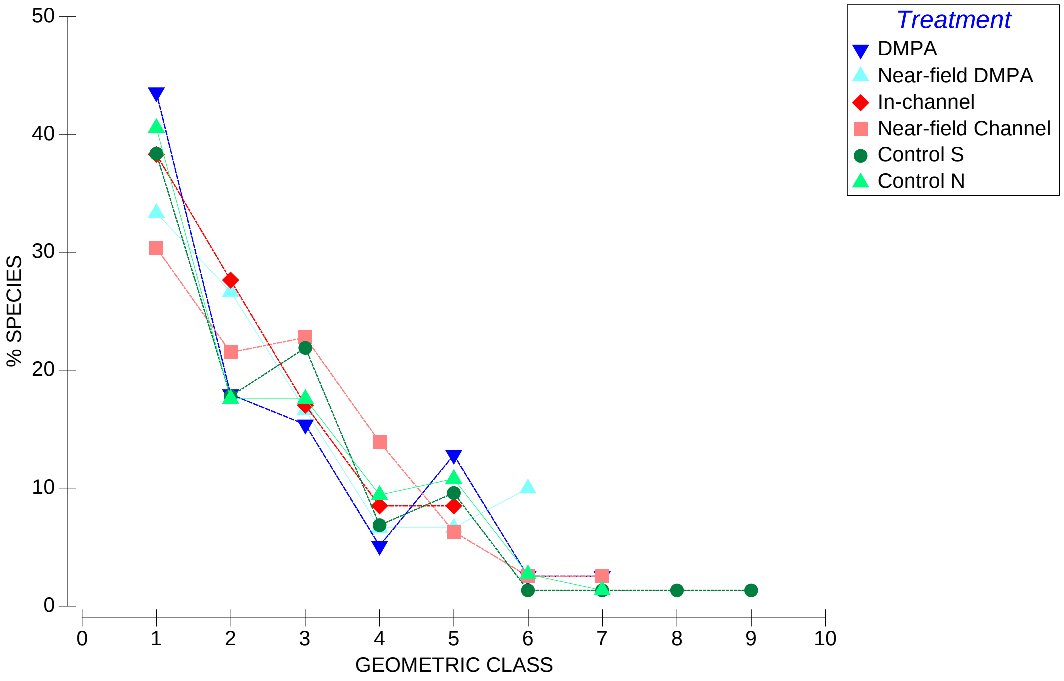

Figure 3-4 Geometric abundance curves for each location

Figure 3-5 presents ‘k-dominance’ curves for the seven sampling locations, which are based on cumulative ranked abundances against logged species ranks. The shape of the curves provides an indication of ‘stress’ levels in assemblages: a curve with a shallow gradient and a higher proportion of rare species indicates low levels of pollution/stress (Lambshead *et al.* 1983). The curves for test locations were generally within the range of the two control locations. The curve for location Control South was slightly shallower than curves for the other locations (typically indicative of more stressed conditions), although differences overall were not large. The k-dominance curves do not suggest that the test locations had assemblages that were markedly different to control locations, nor were they indicative of having higher levels of stress.

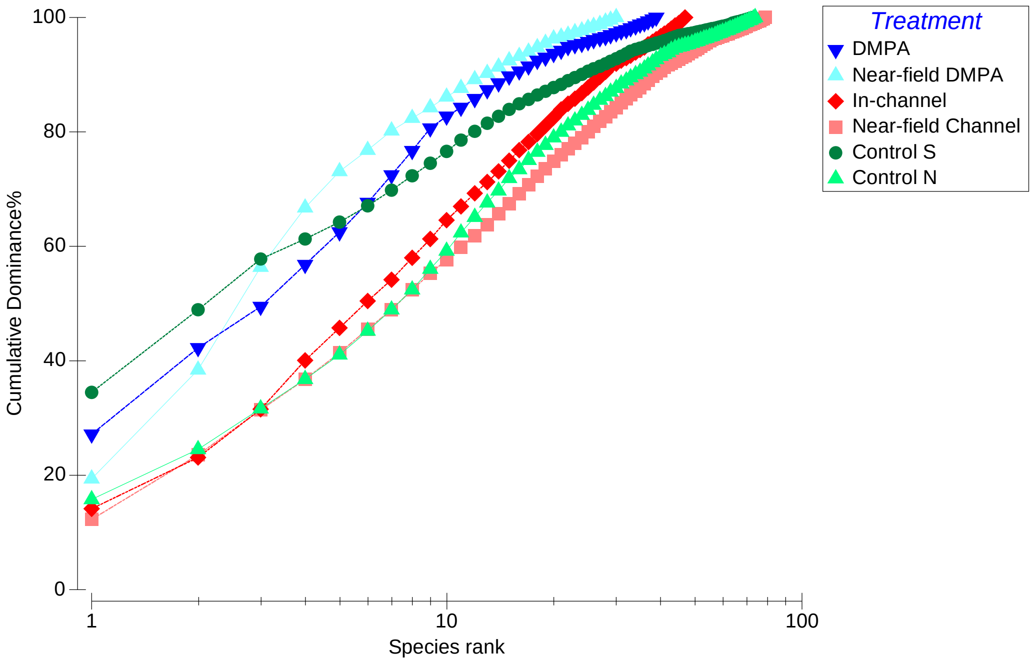

Figure 3-5 k-dominance curves for each location

A bi-plot of site averaged taxonomic distinctness (Delta +) and taxonomic richness (*S*) scores for each site (samples pooled) is provided in Figure 3-6. Superimposed on the bi-plot are the simulated ‘expected’ Delta+ and species richness scores (average and upper/lower 95% confidence limits), which were generated using the taxonomic master list compiled in the present study. All but two sites had average taxonomic distinctness scores that were not significantly different from the simulated ‘expected’ average taxonomic distinctness score. The exceptions to this were two of the Control North sites, which had lower than predicted average taxonomic distinctness. It is notable that one of these sites had the second highest taxonomic richness recorded in the study area, indicating that many of the species captured at this site were taxonomically closely related. The other Control North site had an average taxonomic distinctness score that was similar to the simulated mean ‘expected’ taxonomic distinctness score.

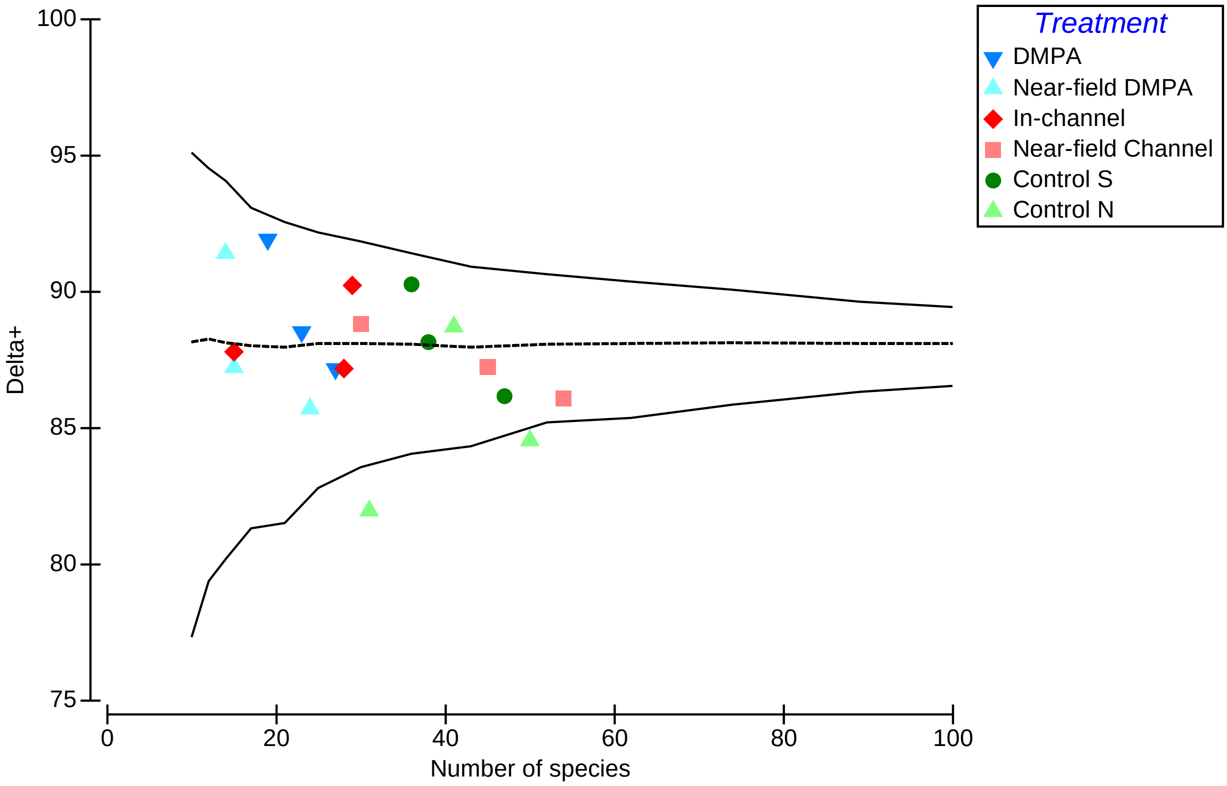

Figure 3-6 Funnel plot showing predicted (expected) and actual (observed) average taxonomic distinctness (Delta+) and species richness scores for site averaged benthic fauna data. Dotted line is the simulated (predicted) average predicted Delta+ and funnel lines represent upper and lower 95% confidence limits

Overall, these results do not suggest that the putatively impacted locations had taxonomically impoverished benthic fauna assemblages, as would occur if under stress (e.g. from historical dredging or material placement).

3.3.2 Average Diversity, Richness, Abundance

For most diversity metrics, there were significant differences among locations (i.e. scales measured in kilometres), and among sites nested within locations (i.e. scales measured in 100s of metres) (Table 3-2, Figure 3-7, Figure 3-8).

There were significant differences in all metrics among locations Control South, Control North and the near-field channel location had similarly high abundance, richness (*S*) and Margalef's diversity index (*D*) of benthic fauna, whereas the other locations had similarly low benthic fauna abundance and richness. Pielou's evenness measure (*J'*) was similar among most locations, except Control South which had low evenness (i.e. high abundances of a few taxa).

Table 3-2 ANOVA results for diversity measures across all locations

Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (α=0.05)
Log *S*						
Location	5	2.12	0.42	9.64	**<0.001**	0.99
Site (location)	12	0.53	0.04	2.33	**0.01**	
Residual	72	1.36	0.02			
Total (Adjusted)	89	4.00				
Total	90					
Log *N*						
Location	5	4.44	0.89	19.87	**<0.001**	0.99
Site (location)	12	0.54	0.04	1.52	0.14	
Residual	72	2.11	0.03			
Total (Adjusted)	89	7.09				
Total	90					
Log *D*						
Location	5	0.98	0.20	4.99	**0.01**	0.89
Site (location)	12	0.47	0.04	2.84	**0.003**	
Residual	72	0.99	0.01			
Total (Adjusted)	89	2.44				
Total	90					
Log *J′*						
Location	5	0.083	0.02	4.17	**0.02**	0.82
Site (location)	12	0.048	0.00	3.21	**<0.001**	
Residual	72	0.089	0.00			
Total (Adjusted)	89	0.22				
Total	90					

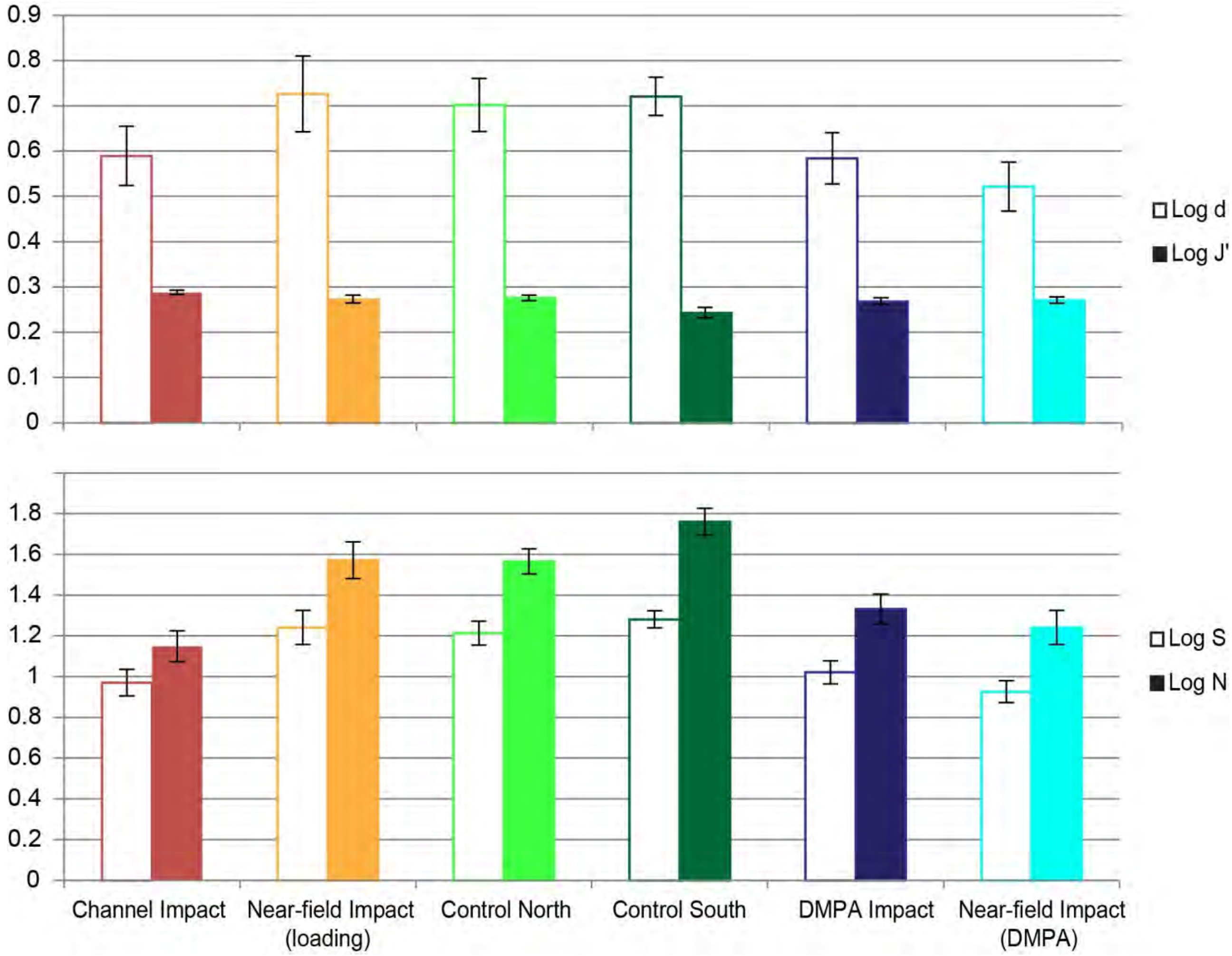

Figure 3-7 Differences in mean (±SE) log (x+1) transformed Margalef's richness (*D*), evenness (*J'*), abundance (*N*) and richness (*S*) among locations per sample (0.13 m^2)

Site variability within locations is shown in Figure 3-8. Abundance (*N*) was the only parameter where there were no significant differences among sites, which as shown in Figure 3-8, was remarkably consistent within locations (except at nearfield channel, where site NC-C had high abundance). Species richness (*S*) and Margalef's diversity (*D*) was similar among sites within locations, except the near-field channel where one site (site NC-C) had higher mean richness and diversity. Mean evenness (*J'*) was similar among sites within locations, except at Control South where one site had lower evenness compared to other sites.

These results show that for abundance and richness, differences among locations (i.e. scales measured in kilometres) were larger than differences at smaller spatial scales (i.e. among sites within locations). Notwithstanding this, as there were significant differences observed among sites within locations, it would not be appropriate to pool sites and test at the location level only. For Margalef's species richness (*D*) and evenness (*J'*), differences among sites was greater than differences among locations (i.e. assemblages were patchy within locations). As a consequence of these higher levels of 'within location' variability, it may be more difficult to detect dredging effects for these parameters than for abundance (*N*) and richness (*S*) metrics.

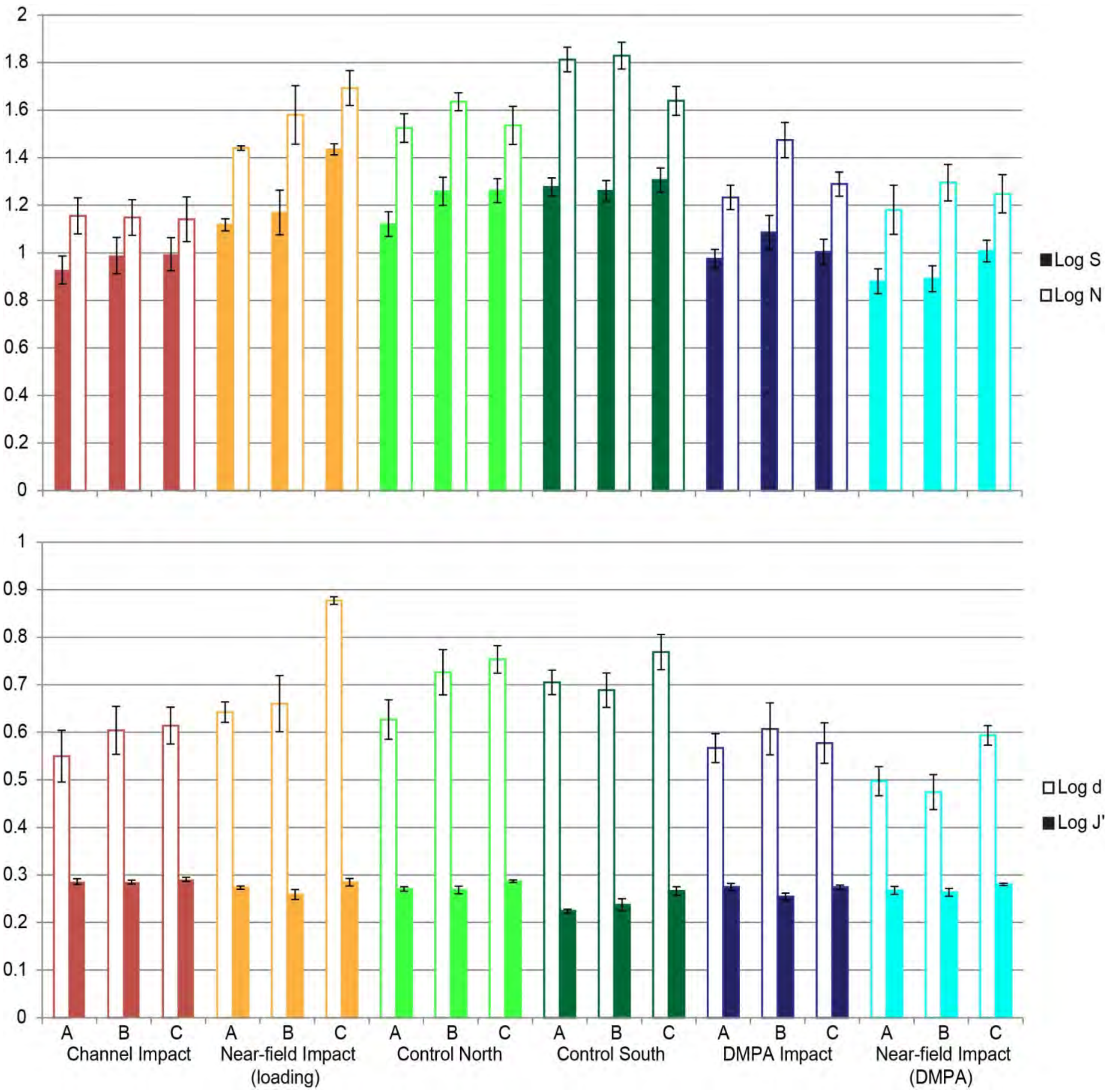

Figure 3-8 Differences in mean (±SE) log (x+1) transformed Margalef's richness (*D*), evenness (*J'*), abundance (*N*) and richness (*S*) among sites per sample (0.13 m^2)

The relationship between replication effort and minimum detectable change for all of the diversity metrics are shown in Figure 3-9. This relationship uses the residual variance measure from the ANOVA to compare how large a difference could be detected between two means, using proportional reduction. For example, with the present design, where 15 replicates were used to test for differences among locations, we could expect to resolve a 34% proportional reduction in mean Log transformed abundance. For the log transformed species richness, the power to detect change was slightly lower, with 15 replicates capable of detecting a change of approximately 40%. The power curves for *D* and *J’* were identical, and had the least capability to detect change. Fifteen replicates could detect a relative change of 46%.

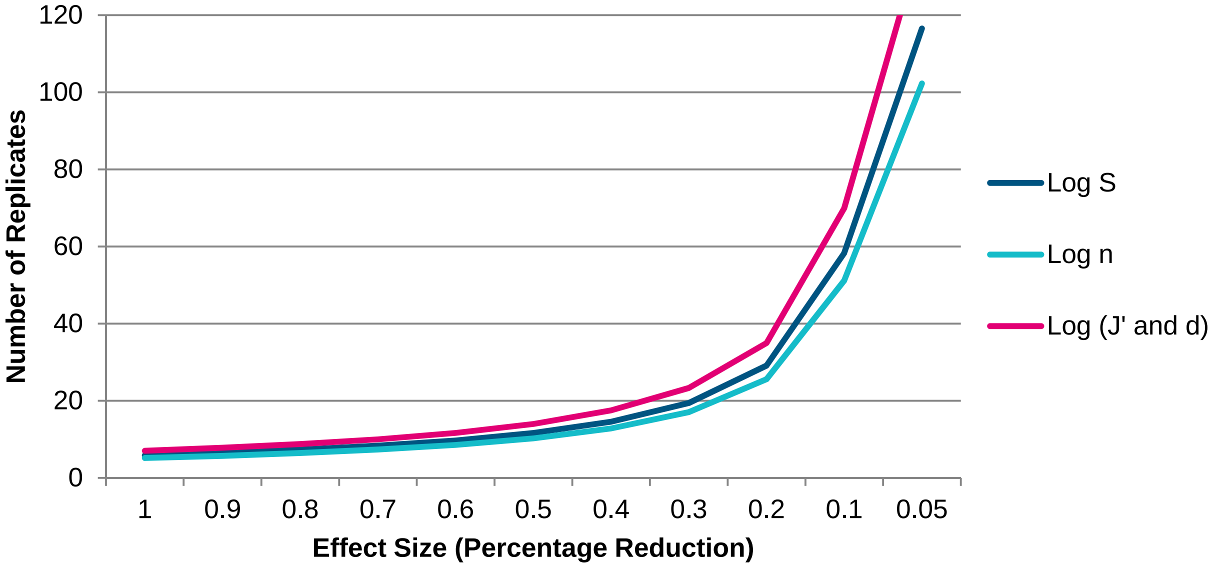

Figure 3-9 Relationship between replication level and effect size for diversity metrics (α=0.05, β=0.1)

To detect small changes in relative abundance, as little as 10%, almost 60 replicates would be required. However, it should be noted that sampling designs with fewer replicates could still detect small changes because the above power calculations are based around simple two-sample means testing, rather than using tests that examine interactions, such as Before/ After, Control/ Impact (BACI) designs. Because BACI designs use the interaction between control and impact with before and after, rather than changes in main effects to examine impacts, smaller changes could be detected.

Power calculations for complicated BACI designs involving interactions are not practical to determine. Nevertheless, the above power analysis serve as a guide for determining the level of replication required to distinguish changes in main effects, and if this can be achieved, then much smaller changes will be observable through the use of BACI interactions.

The asymmetrical analyses between the DMPA putative impact location and the two control locations show that differences in species richness (*S* and *D*) were different between the DMPA and controls, and that the variation between controls was negligible (Table 3-3).

Table 3-3 ANOVA results for asymmetrical analysis comparing the DMPA and Controls

Source Term		DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	df	F crit
Log *S*								
Location		2	0.641	0.321	16.137	**	2, 6	5.14
	DMPA vs Controls	1	0.602	0.602	38.241	**	1, 36	4.08
	Among Controls	1	0.039	0.039	2.479	ns	1, 36	4.08
Site(location)		6	0.119	0.020	1.262	ns	6, 36	2.33
	DMPA vs Controls	2	0.039	0.019	1.232	ns	2, 36	3.23
	Among Controls	4	0.080	0.020	1.276	ns	4, 36	2.60
S		36	0.567	0.016				
Total (Adjusted)		44	1.327					
Total		45						
Log *N*								
Location		2	1.472	0.736	13.431	**	2, 6	5.14
	DMPA vs Controls	1	1.173	1.173	62.289	**	1, 36	4.08
	Among Controls	1	0.300	0.300	15.910	**	1, 36	4.08
Site(location)		6	0.329	0.055	2.911	*	6, 36	2.33
	DMPA vs Controls	2	0.174	0.087	4.628	ns	2, 36	3.23
	Among Controls	4	0.154	0.039	2.053	ns	4, 36	2.60
S		36	0.678	0.019				
Total (Adjusted)		44	2.479					
Total		45						
Log *D*								
Location		2	0.283	0.141	8.017	**	2, 6	5.14
	DMPA vs Controls	1	0.278	0.278	21.167	**	1, 36	4.08
	Among Controls	1	0.005	0.005	0.353	ns	1, 36	4.08
Site(location)		6	0.106	0.018	1.342	ns	6, 36	2.33
	DMPA vs Controls	2	0.007	0.003	0.253	ns	2, 36	3.23
	Among Controls	4	0.009	0.025	1.887	ns	4, 36	2.60
S		36	0.473	0.013				
Total (Adjusted)		44	0.862					
Total		45						
Log *J*								
Location		2	0.046	0.023	3.867	ns	2, 6	5.14
	DMPA vs Controls	1	0.005	0.005	3.175	ns	1, 36	4.08
	Among Controls	1	0.042	0.042	29.083	**	1, 36	4.08
Site(location)		6	0.036	0.006	4.170	*	6, 36	2.33
	DMPA vs Controls	2	0.006	0.003	2.231	ns	2, 36	3.23
	Among Controls	4	0.029	0.007	5.140	ns	4, 36	2.60
S		36	0.052	0.001				
Total (Adjusted)		44	0.133					
Total		45						

For abundance, differences were significant between the DMPA and controls, but also between controls, and sites nested within locations. For evenness the only significant differences were among controls, and for sites nested within locations.

In order to investigate the relationships between abundance and richness with respect to site-based environmental variation, lines were regressed between diversity metrics (mean transformed abundance and richness) and:

- Site depth
- Maximum modelled tidal velocity
- The percentage fine material at each site.

3.3.3 Relationships between Physical Attributes and Diversity Measures

Figure 3-10 shows the relationships between the major physical attributes of each site (peak tidal velocity [modelled], depth, and percentage fines), and log-transformed abundance and richness. Sites are colour coded according to their treatment group. Formulae for each relationship and Pearson's r values are shown on each graph.

Generally speaking, the r values are relatively weak (< 0.6) for all comparisons drawn. The highest absolute r value was for the relationship between abundance and maximum tidal velocity (-0.49), while the lowest r value was for the relationship between depth and abundance (0.001). Weak negative relationships for maximum tidal velocity vs abundance and richness and also percentage fines vs abundance and richness suggest that sites with higher proportions of coarser material and/or sites in less hydrodynamically intense environments may have richer and more abundant communities. These trends may be the result of coarser substrates providing a greater variety of habitats, supporting a greater range of taxa. Lower current velocities may also lead to reduced sediment mobility, and more stability of the benthic habitat.

In terms of commonality of physical features among sites, the treatments generally had reasonable overlap between sites with respect to depth and the percentage of fines. However, the channel sites tended to have consistently higher maximum modelled tidal velocities compared with other sites. This was largely unavoidable given the physical nature of the channel. Otherwise the sites were relatively similar with respect to depth, maximum tidal velocity, and proportions of fine material.

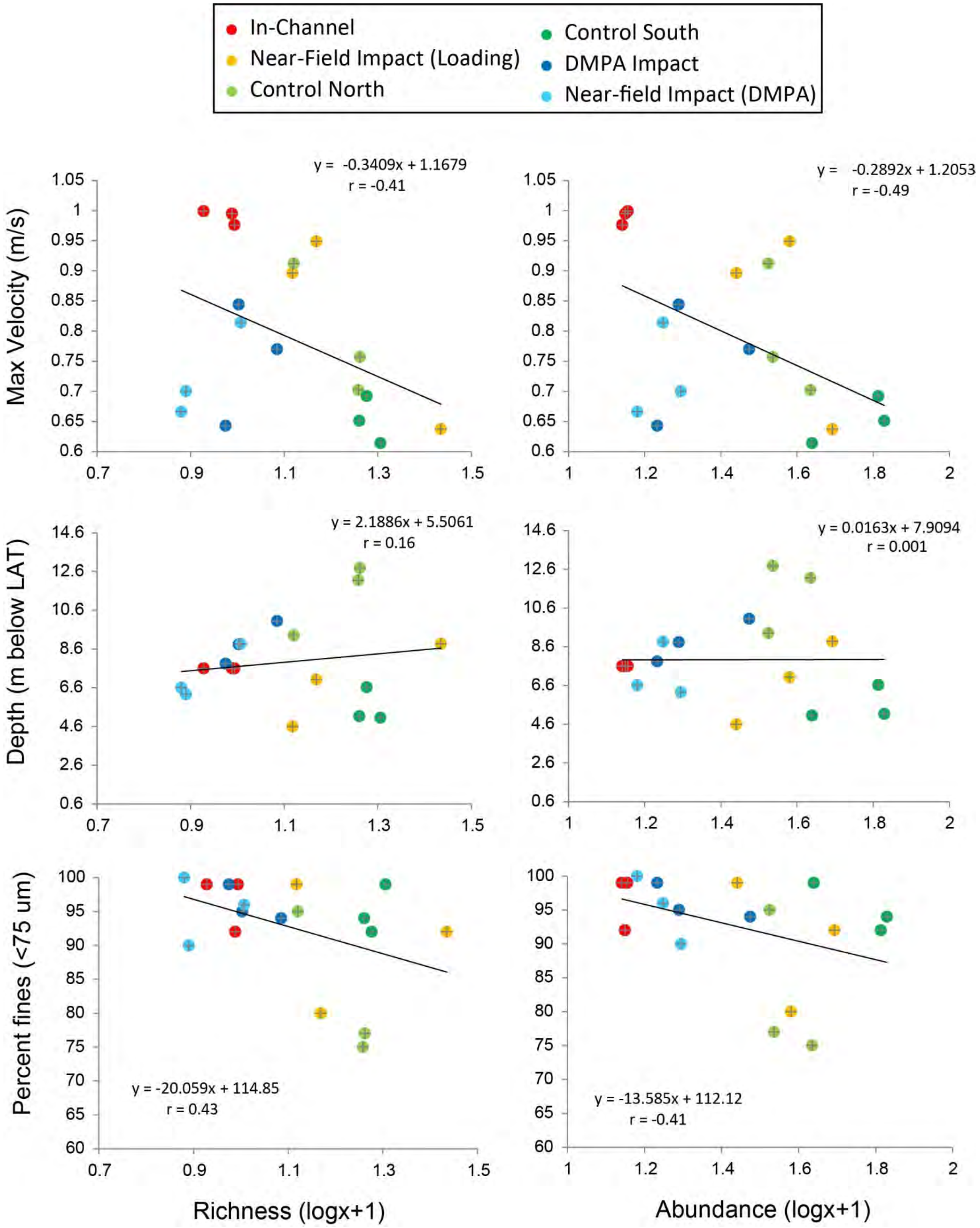

Figure 3-10 Relationships between peak tidal flow (top row), depth (middle row), and percent fines (bottom row) versus richness (left column) and abundance (right column).

3.3.4 Multivariate Analysis

Figure 3-11 are two non-metric multidimensional scaling ordinations (n-MDS) showing similarities among sites (samples pooled), and sites groupings generated by cluster analysis[1]. The upper ordination is based on all species, the lower ordination only includes taxa contributing >2% of total abundance. Sites that have similar assemblages are positioned close together, while those that are dissimilar are positioned wide apart.

The ordination based on all data shows:

- Control North sites grouped together at the 35% similarity level, but assemblages at one of the sites (site CNC) were dissimilar to other sites. As shown in Table 3-4, the relative dispersion value at this location was moderately high compared to other locations, reflecting this ‘within-location’ variability.
- Control South sites were similar to each other, and one of these sites had assemblages that were similar to sites in the near-field channel location. As shown in Table 3-4, the relative dispersion value at Control South was in the lower range compared to other locations, reflecting a lower degree of ‘within-location’ variability.
- The near-field channel location had a high degree of ‘among site’ variability in assemblages that was similar to that observed within the channel (Table 3-4).
- Assemblages within the channel showed great ‘within-location’ variation, as evidenced by the wide scatter of sites in the n-MDS (Figure 3-11) and the high relative dispersion value (Table 3-4). In this regard, two sites (A and C) formed separate groupings at the 45% similarity level, whereas the third channel site (RC) had assemblages that were similar to those found at the DMPA and surrounding areas.
- Assemblages at the DMPA and surrounding ‘near-field’ areas were very similar among sites, as evidenced by the tight grouping and the low relative dispersion values.

The ordination based on only abundant taxa contributing >2% total abundance shows broadly the same similarity patterns as described above.

Table 3-4 Multivariate relative dispersion values comparing the degree of ‘within location’ variation in assemblages among the nested sites

Factor	Relative Dispersion
DMPA	0.49
DMPA Nearfield	0.60
Control South	0.88
Control North	1.19
Nearfield channel	1.30
Within channel	1.54

---

[1] Stress level was 0.13, which indicates an excellent representation of data in higher dimensional space

Figure 3-12 is the same ordination presented in Figure 3-11 but presented as ‘bubble plots’, illustrating the number of species and individuals recorded at each site. Figure 3-12 shows that patterns in site similarity broadly conformed to patterns in taxa richness and total abundance. In this regard, sites with lower species richness and abundance tended to group together towards to the upper right quadrant of the ordination (i.e. DMPA, nearfield DMPA and inside channel sites). Control sites and sites adjacent to the channel had higher taxa richness and abundance, but were scattered widely through the ordination space outside the upper right quadrant. Figure 3-13 also shows that there was a linear relationship between n-MDS vector 1 and various biotic metrics. These results suggest that the lower taxa richness and abundance at the DMPA, nearfield DMPA and inside channel sites were also broadly represented in patterns in assemblage dissimilarity.

Nested analysis of similarity (ANOSIM) was undertaken to test the following hypotheses:

H1: There are no differences among sites within each location

H2: There are no differences between locations

There were significant differences among locations and among sites within locations (Table 3-5 and Table 3-6). Pair-wise comparisons between sites were all not significant due to the low degrees of freedom of tests, but nonetheless, the $\check{R}$ values were generally high (>0.8) indicating a high degree of dissimilarity among locations. The exception to this were the DMPA and DMPA near-field location ($\check{R}$ = 0.07), which as shown in n-MDS, had similar assemblages. Assemblages also differed between the near-field channel location and those in the channel ($\check{R}$ = 0.22) and Control South ($\check{R}$ = 0.26), as shown also in the n-MDS.

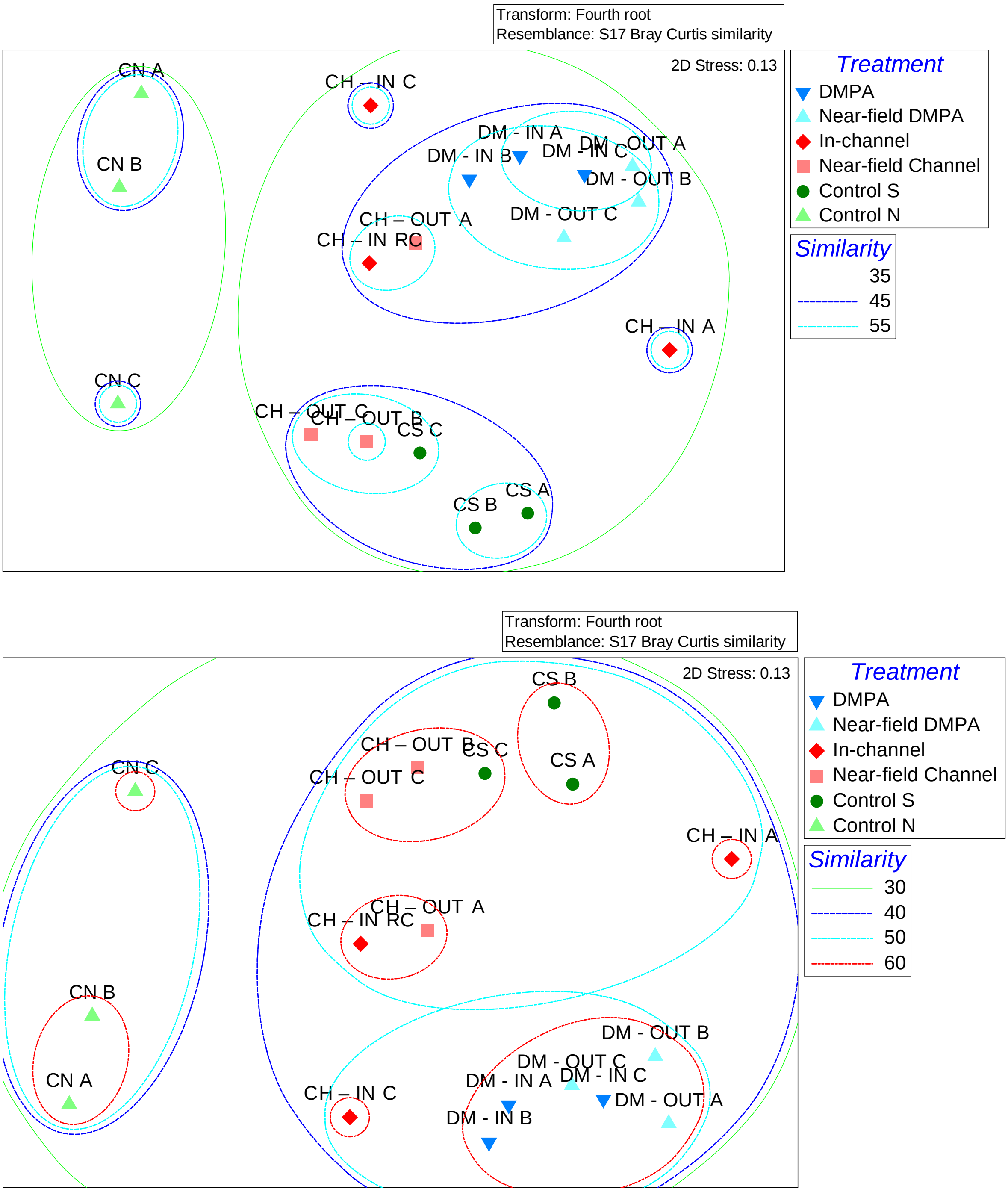

Figure 3-11 n-MDS ordination of fourth-root transformed site averaged benthic fauna data: upper plot all species, lower plot >2% total abundance. Groupings from cluster analysis at the 35, 45 and 55% Bray Curtis similarity level are superimposed

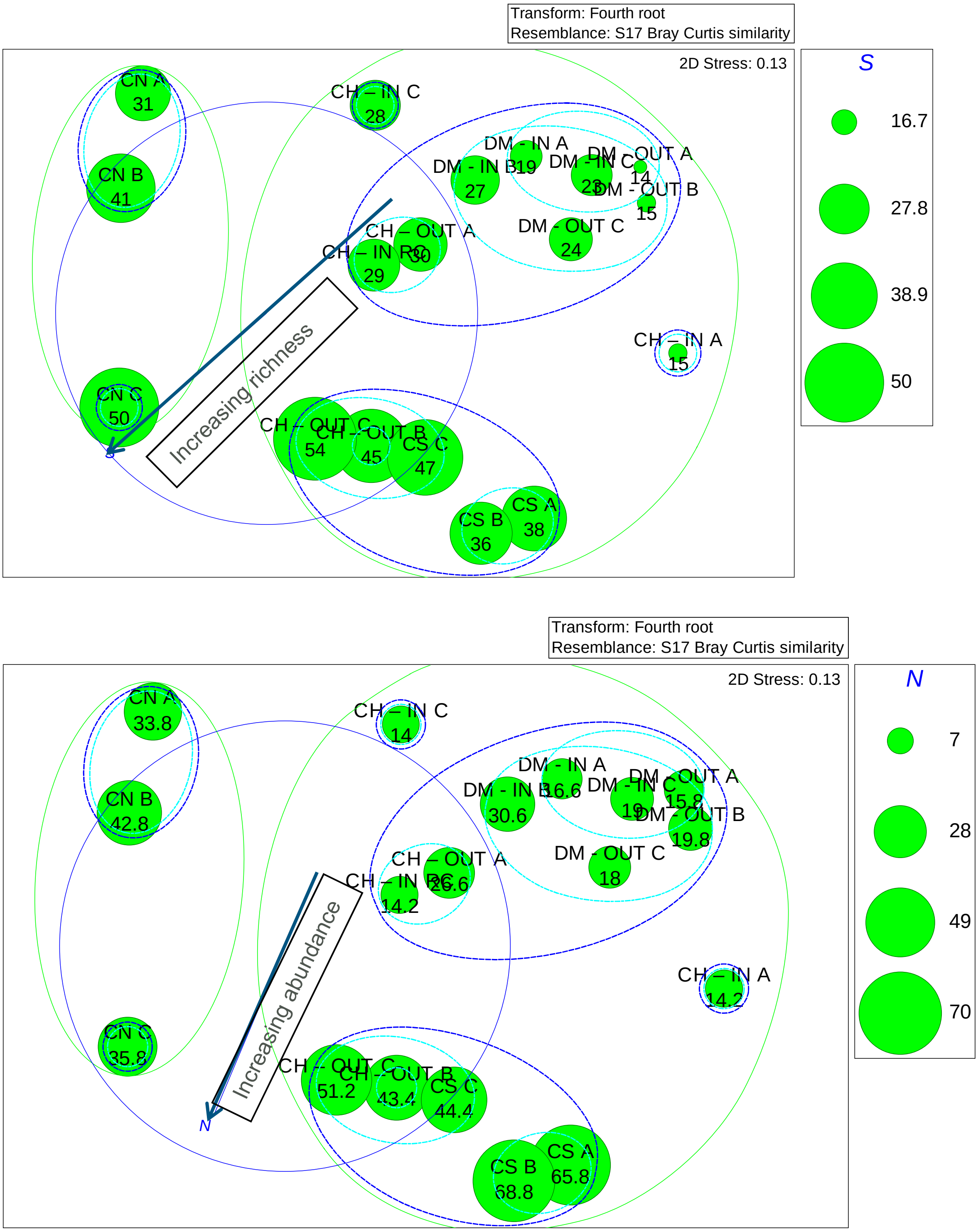

Figure 3-12 n-MDS ordination of fourth-root transformed site averaged benthic fauna data (all species). Groupings from cluster analysis at the 35, 45 and 55% Bray Curtis similarity level are superimposed. Symbol size scaled to denote the number of taxa (upper plot) and total abundance (lower plot) recorded at the site

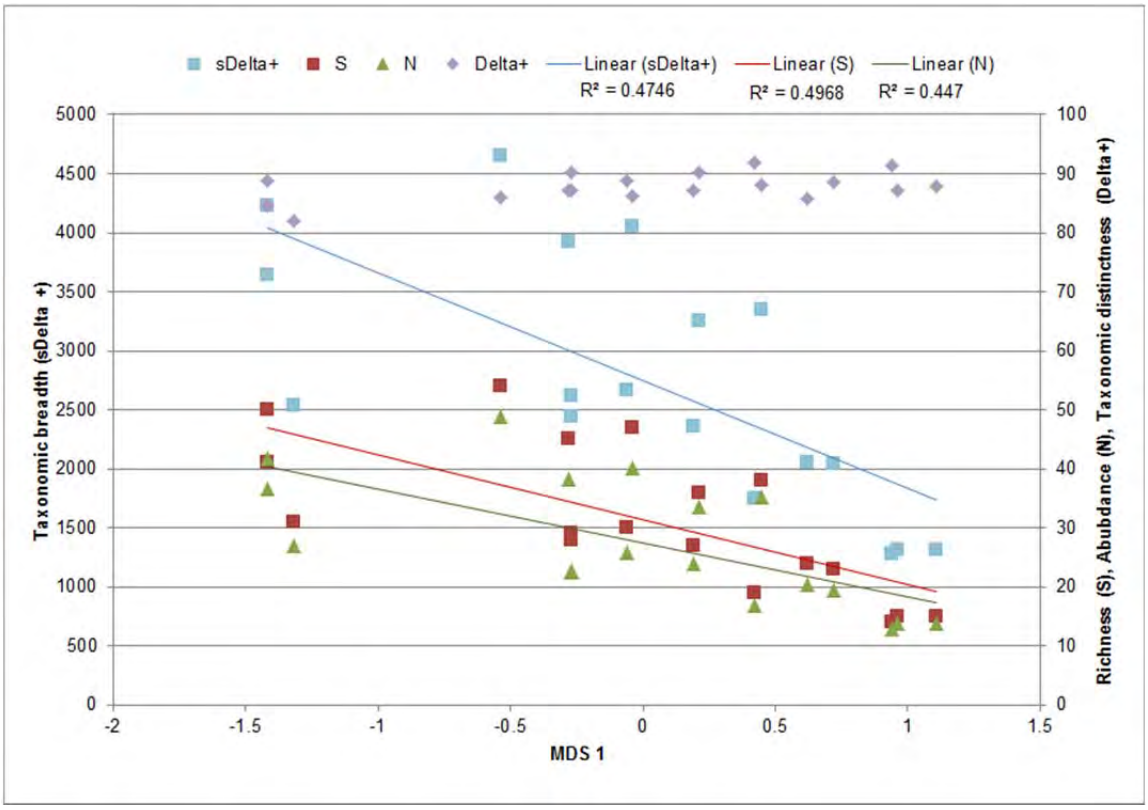

Figure 3-13 Bi-plots showing relationships between nMDS vector 1 and various biotic metrics

Table 3-5 Nested ANOSIM comparing assemblages among locations (DMPA, near-field DMPA, controls) and sites nested within locations

Factor level	Ř Statistic	*P*
Locations	0.75	0.001 (0/999)
DMPA nearfield vs DMPA	0.07	0.4 (4/10)
DMPA nearfield vs Control S	1.00	0.1 (1/10)
DMPA nearfield vs Control N	0.93	0.1 (1/10)
DMPA vs Control S	1.00	0.1 (1/10)
DMPA vs Control N	0.89	0.1 (1/10)
Control S vs Control N	0.93	0.1 (1/10)
Sites (within Locations)	0.45	0.001 (0/999)

Table 3-6 Nested ANOSIM comparing assemblages among locations (channel, near-field channel, controls) and sites nested within locations

Factor level	*R* Statistic	*P*
Locations	0.62	0.001 (0/999)
Channel nearfield vs Channel	0.22	0.3 (3/10)
Channel nearfield vs Control S	0.26	0.3 (3/10)
Channel nearfield vs Control N	0.74	0.1 (1/10)
Channel vs Control S	0.81	0.1 (1/10)
Channel vs Control N	0.93	0.1 (1/10)
Control S vs Control N	0.93	0.1 (1/10)
Sites (within Locations)	0.56	0.001 (0/999)

4 Discussion and Recommendations

4.1 Patterns in Community Structure

Benthic communities within the study area were characterised by having the following attributes:

- Comprised exclusively of marine/estuarine species, with no freshwater species recorded;
- A few taxa were numerically abundant;
- A large proportion of uncommon taxa; and
- A suite of numerically dominant taxa that was typically common across the study area.

Of the 144 infauna taxa recorded in grab samples in the present study, only a few of these can be considered to be abundant. Six taxa together accounted for 44% of the total number of benthic infauna captured in the present study. High overall taxonomic richness but dominance of a few taxa is a common feature recorded by others in other sub-tropical and tropical systems (Alongi 1989; Skilleter 1998; Currie and Small 2005).

The other notable characteristic of the composition of benthic infauna communities in the study area was the large proportion of uncommon taxa. Of the 144 morpho-species captured, 28% were singletons, and a further 12% morpho-species were represented by two individuals. The high proportion of uncommon taxa is also a typical feature of benthic communities in other tropical and sub-tropical soft sediment habitats (Alongi 1989), including Port Curtis (BMT WBM 2012; Currie and Small 2005; see Table 4-1).

There were, however, several distinct differences in community structure between Port Alma and those sampled in Port Curtis by Currie and Small (2005) and offshore of Port Curtis sampled BMT WBM (2012). Currie and Small (2005) surveyed the soft sediment benthic fauna at 30 locations in Port Curtis, using a similar grab sampler (0.10 m^2 van Veen grab compared to 0.14 m^2) and taxonomic resolution (morpho-species) as adopted in the present study, but a coarser sieve mesh size (1 mm compared with 0.5 mm). BMT WBM (2012) used the same 0.14 m^2 van veen grab as used in the present study, but adopted a 1 mm mesh size. As shown in Table 4-1, the mean abundance of all benthic fauna, polychaetes and crustaceans measured in the study area was higher than that recorded by Currie and Small (2005), but the mean abundance of molluscs was generally lower in the present study than that recorded by Currie and Small (2005). The minimum mean abundance per site of polychaetes, crustaceans and molluscs was lower in the present study than recorded by BMT WBM (2012), but mean maximum values for polychaetes and crustaceans were comparable.

The most notable differences between the three studies were the types of dominant taxa. Currie and Small (2005) found that the bivalve *Carditella torresi* and to a lesser extent the sea-squirt *Ascidia sydneiensis* were the most abundant taxa, particularly in subtidal waters. Neither ascidians nor bivalves were abundant in the present study or by BMT WBM (2012); instead the most abundant taxa recorded were crustaceans (Amphipod 1, Decapod shrimp 1) and the polychaetes *Paraprionospio* sp, *Terebellides* sp and *Onuphis* sp, and the acorn worm *Glossobalanus* sp. None of these species were recorded in high numbers by Currie and Small (2005). BMT WBM (2012) recorded high numbers of the gastropod snail *Turritella* sp. 1 and the amphipod *Cerapus* sp, whereas neither of these species was abundant at Port Alma.

Table 4-1 Abundance and richness measures measured in the present study Currie and Small (2005) and BMT WBM (2012)

Parameter	Currie and Small (2005)	BMT WBM (2012)	Present study
Dominant taxa	*Carditella torresi* (14% of individuals) *Ascidia sydneiensis* (4% of individuals)	*Turritella* sp. 1 (15% of individuals) *Cerapus* sp. 2 (7.5% of individuals)	*Paraprionospio* sp (13% of individuals) *Glossobalanus* sp (11% of individuals)
Proportion of uncommon taxa (accounting for <2% of individuals)	98% of species	98% of species	93% of species
Mean (± s.e.) no. individuals	5.9 ± 0.40 to 24.4 ± 1.25 per 0.1 m^2	25.9 ± 2.09 to 95.0 ± 13.5 per 0.14 m^2	14.0 ± 2.81 to 51.2 ± 8.97 per 0.14 m^2
Mean (± s.e.) no. taxa	3.6 ± 0.20 to 11.6 ± 0.48 per 0.1 m^2	9.9 ± 0.68 to 20.2 ± 0.94 per 0.14 m^2	6.8 ± 8.94 to 26.4 ± 1.50 per 0.14 m^2
Mean (± s.e.) no. polychaetes	1.0 ± 0.09 to 8.0 ± 0.59 per 0.1 m^2	9.5 ± 1.0 to 31.0 ± 2.03 per 0.14 m^2	3.2 ± 1.24 to 31.2 ± 11.24 per 0.14 m^2
Mean (± s.e.) no. molluscs	4.0 ± 0.32 to 10.3 ± 0.71 per 0.1 m^2	2.3 ± 0.37 to 59.4 ± 12.38 per 0.14 m^2	0.2 ± 0.20 to 5.8 ± 1.62 per 0.14 m^2
Mean (± s.e.) no. crustaceans	0.6 ± 0.09 to 2.7 ± 0.28 per 0.1 m^2	9.8 ± 1.1 to 31.7 ± 4.94 per 0.14 m^2	3.8 ± 1.85 to 21.6 ± 7.32 per 0.14 m^2

It is not known to what extent the differences in studies reflected changes in structure over time, or spatial differences in assemblage structure due to different positioning of stations. Nearshore tropical and sub-tropical benthic fauna communities are dynamic, varying across multiple temporal scales (Stephenson 1980; Alongi 1989; Currie and Small 2005; BMT WBM 2012). Currie and Small (2005) and BMT WBM (2012) found that benthic communities in Port Curtis did not show predictable seasonal trends, unlike in higher latitudes where seasonal changes in water temperature and other processes can lead to changes in community structure. Instead, Currie and Small (2005) found that temporal changes in communities were more closely aligned with the Southern Oscillation Index (SOI), with the most significant El Ninõ (drought) episode during the measurement period coincident with a halving of taxonomic richness and abundance. Correlation analysis found significant positive correlations between benthos abundance/richness and turbidity, on which Currie and Small (2005) concluded that high turbidity provided favourable conditions for benthic communities.

Spatial differences in benthic communities and differences in the range of habitat types sampled may also partly account for differences between studies. Currie and Small (2005) found that species richness and abundance were lowest on fine muddy sediments located in the intertidal zone, and greatest in coarse sandy sediment occurring in deeper channel areas. Unlike Currie and Small (2005) which sampled a broad range of habitats, the present study design considered a single habitat in order to improve detection of potential differences between communities at the dredging-affected areas and other areas.

Disturbance is expected to be an important driver of benthic fauna communities at Port Alma. The study area is affected by flood plumes from the Fitzroy River and adjacent coastal streams, waves during storm events, and strong tidal currents. Case-studies elsewhere suggest that areas that are frequently disturbed have low abundance and species richness, and are dominated by opportunistic species that are able to quickly colonise an area (e.g. small spionid polychaetes, capitellid polychaetes and amphipods) or deep burrowing taxa that can tolerate sediment movement (Posey et al. 1996; Smith and Rule (2001). Small opportunistic and/or mobile taxa were also the numerically dominant taxa found in the study area.

Hydrodynamic conditions may also control other physical and biological processes that drive benthic community structure. For example, high rates bed mobility would result in limited accumulation of fine organic material (food) in sediments. Settlement patterns and recruitment processes could also be affected by wave and current patterns. It is not possible to associate changes in benthic communities to any one of these single attributes as the complexities of soft bottom communities defy any simple paradigm relating macrobenthic patterns to any single factor or attribute (Mancinelli et al. 1998).

4.2 Benthic Communities as Indicators of Dredging Impacts

Table 4-2 is a summary of trends in indicators examined in present study as potential lines of evidence of long term changes in benthic communities associated with dredging and dredged material placement. The metrics are based on Table 2-1, which also describes the expected direction of change of indicators resulting from stress/disturbance. The pilot study found that:

- Fewer benthic macroinvertebrate taxa and individuals were recorded in the DMPA (39 taxa), channel (47 taxa) and areas immediately adjacent to the DMPA (30 taxa) compared to control locations (73 and 74 taxa). Benthic assemblages in the immediate environs of the channel (79 taxa) were not, however, different from those recorded at control locations.
- Benthic macroinvertebrate assemblages at most test locations had numbers of rare taxa that were similar to the control locations, which does not suggest dredging or dredged material placement resulted in the simplification of communities. An exception was at the near channel test treatment, which had slightly fewer rare species.
- Benthic macroinvertebrate assemblages in the dredged channel were more heterogeneous than those in the controls, whereas the other test treatments had similar (or lower) levels of heterogeneity as controls.
- Benthic macroinvertebrate assemblages in the dredged channel, DMPA and near DMPA, which all had low taxonomic richness and abundance, were more similar to each other than to control sites.

Table 4-2 Lines of evidence indicating potential differences in environmental stress to benthic fauna assemblages between control and test locations

Metric/test	Response to environmental stress	Channel	Near channel	DMPA	Near DMPA
Number of taxa (taxonomic richness *S*)	↓relative to controls at high stress levels ↑ in abundance of some taxa in areas indirectly affected by plumes	Lower than controls	No difference to controls	Lower than controls	Lower than controls
Abundance of individuals (*N*)		Lower than controls	No difference to controls	Lower than controls	Lower than controls
Margalef's Richness (*D*)		Lower than controls	No difference to controls	Lower than controls	Lower than controls
Peilou's evenness (*J'*)		No difference to controls	No difference to controls	No difference to controls	No difference to controls
Average phylogenetic distinctness (Delta+) vs S	Significant departure from simulated 'expected' average Delta+ scores based on permutations	Obs: Exp similar to controls	Obs: Exp similar to controls	Obs: Exp similar to controls	Obs: Exp similar to controls
Number of rare and common species	Small number of rare taxa Assemblage comprised of a small number of common taxa	Similar to controls	Fewer rare species than controls	Similar to controls	Similar to controls
Heterogeneity in assemblages within locations	↑ variation between sites relative to variation within control locations	High relative to controls	Similar to controls	Low relative to controls	Low relative to controls
Similarity in assemblages	Assemblages at test locations highly dissimilar to control	Distance between controls and channel similar to dissimilarity (distance) between controls	Dissimilarity between controls and near-channel less than dissimilarity between controls	Distance between controls and DMPA similar to dissimilarity (distance) between controls	Distance between controls and near-field DMPA similar to dissimilarity (distance) between controls
	Significant difference between control and test location	Channel grouped with other sites with low richness and abundance	No differences to controls	DMPA grouped with other sites with low richness and abundance	Near-DMPA grouped with other sites with low richness and abundance

Pink shading – potential evidence of stress/disturbance

These lines of evidence suggest that the DMPA and adjacent environs, as well as the dredged channel, have depauperate assemblages compared to those at control sites. This could reflect either of the following (Table 4-3):

- Impacts from past dredging and dredged material placement activities
- Other anthropogenic effects at and adjacent to the channel and DMPA
- Experimental design artefacts.

Table 4-3 Potential processes influencing benthic assemblages among locations

Potential cause of differences	Potential processes	Lines of evidence
Impacts from past dredging and dredged material placement activities	Altered habitat conditions e.g. sediment types and hydrodynamic conditions	🟥 • Channel and DMPA had similar current velocities and sediment types as controls
	Slow recovery rates from previous dredging campaigns	🟥 • Assemblages comprised of small-bodied opportunistic species that would be able rapid recolonise following disturbance • Elsewhere, recolonisation of these species typically occurs in months to less than 2 years. Dredging has not been carried out since 2011 (>3 years)
Other anthropogenic effects at and adjacent to the channel and DMPA	Physical disturbance of habitats by vessel wake and propeller wash	🟦 • DMPA, near-field DMPA and channel sites are within or close proximity to channel (<50 m) and would likely be subject to disturbance • Two of the three nearfield channel sites (NFA, NFB) were located >50 m from channel, and were similar to controls
		🟥 • The third near-field site (NFC) located within 50 m of channel had high richness and abundance
	Physical disturbance due to fishing activities	🟦 • Trawling prohibited in berthing area, but allowed in other areas, and practiced in shipping channels
	Sediment contamination	🟥 • Placement of contaminated dredged material not permitted in accordance with the National Assessment Guidelines for Dredging (NAGD 2009)
Experimental design artefacts	Differences in environmental conditions between control and test locations	🟥 • Sites selected to minimise confounding environmental influences • Remarkable similarity in benthic assemblages between control locations do not suggest a high degree of natural heterogeneity at the location scale
	High levels of natural variability at various spatial scales (among locations, and among sites within locations) confounding comparisons	🟥 • As above for environmental conditions

Pink = do not support. Blue = supporting line of evidence

The depauperate benthic fauna assemblages observed at the Port Alma DMPA and adjacent areas are not consistent with observations at other Queensland ports. Case studies undertaken in other east Australian subtropical ports suggest that benthic fauna communities rapidly recover from dredged material placement, typically measured within months to years. For example, monitoring of benthic communities within and adjacent to the Townsville DMPA (Cruz-Motta 2000) indicated that benthic macroinvertebrate communities are resilient to changes in morpho-dynamics, and that despite a long history of dredged material placement activities, long-term changes in community structure within or adjacent to the DMPA were not observed. Similarly, case studies at the Port of Cairns (BMT WBM in Arup 2014) and Port of Mackay (WBM 2004) recorded slight changes in benthic communities between the DMPA and adjacent reference sites. This reflects the ability of fauna to rapidly recover following disturbance, a necessary adaptation to living in such dynamic environments.

An exception to this is where dredged material placement results in changes to substrate conditions. For example, BMT WBM (2012) found that dredged material placement appears to have increased the availability of hard substrate (cobble) at the Port Curtis DMPA, which resulted in more abundant hard substrate associated species. This is not the case at Port Alma, as sediment types found at the DMPA (silts) were similar to those in adjacent areas. Very little gravel, and no cobble, was observed across all sites.

Few studies in Queensland ports have examined in any detail, the effects of dredging on benthic fauna communities. Recent exceptions are port dredging EISs for the Port of Townsville Port Expansion Project (BMT WBM in Aecom 2013) and Port of Cairns Shipping Development Project (BMT WBM in Arup 2014), which compared benthic macroinvertebrate communities between maintained channels and adjacent undredged areas. Both studies found that benthic macroinvertebrate assemblages in maintained channels typically had lower abundance and richness than adjacent habitats, but supported a similar range of different types of taxa. However, in both studies maintenance dredging was undertaken annually, which is far more regularly than undertaken at Port Alma. It would be expected that in the several years since maintenance dredging was last undertaken at Port Alma that there would be an opportunity for benthic communities to recover.

Another key process that could affect benthic fauna communities is disturbance associated with channel operation. This could include for example physical disturbance to sediments by vessels (i.e. vessel wake, propeller wash, trawler scars etc.). It is notable that all sites where depauperate communities were recorded were within or directly adjacent to the navigation channel (including the DMPA), and could therefore experience ongoing disturbance by vessels traffic or trawling. Of the potential processes that could lead to the observed patterns in community structure, this appears to have the most lines of supporting evidence (Table 4-3).

Other ecosystem processes (particularly disturbance by waves, currents and floods) unrelated to dredging would influence these spatial patterns in community structure, as described earlier. For example, the Control South location may be more sheltered from wave action and Fitzroy River flood flows than other locations, whereas Control North may be more exposed to these disturbances. Notwithstanding this, the two control locations, despite being separated by distances measured in kilometres (similar to distances between control and test locations) had relatively consistent numbers of taxa and individuals to each other, and to the test location adjacent to the channel. This does not suggest that these differences were an artefact of high levels of natural heterogeneity in communities at broad (among location) and fine (sites within locations) spatial scales.

4.3 Recommendations

It is important to note that the present pilot study represents a snap-shot in time, and that impact detection needs to consider not only spatial differences in indicators (i.e. among and within treatments), but also the direction and magnitude of temporal changes observed at different spatial scales. On this basis, it is not possible to conclude with a high degree of certainty that observed differences in benthic fauna communities were a response to legacy impacts of past dredging and dredged material placement activities in 2009 and earlier.

Based on BACI experimental design principles (Underwood 1991; 1992; 1993; 1994), it is important to consider interaction terms (treatment by time) in order to detect impacts. It is, therefore, recommended that future monitoring should involve sampling before and after dredging and dredged material placement to quantify impacts. Additional future sampling events to assess recovery trajectories of assemblages should be considered if there are any initial impacts detected. This should be undertaken at multiple treatments, locations and sites within and adjacent to the primary test site, as adopted in the present study.

It is likely that dredging impacts are minimal given the relatively small scale of the dredging disturbance relative to regular flood disturbances. Monitoring should therefore test the impact of dredging and material placement on benthic communities, but focus more on sediment and water quality monitoring. Sediment testing as per the NAGD (2009) guidelines, and water quality monitoring using grab-based and plume monitoring should be used to test the modelled predictions about plume behaviour and concentration. If dredging and material placement activities of a given volume are demonstrated to be benign to macroinvertebrate communities, we would suggest that campaigns of lesser or equal volume (where the material is demonstrably clean) should not only be infrequently monitored (every five years) to validate previous study findings.

5 Conclusions

The key findings of the present were:

- Benthic communities within the study area were comprised exclusively of marine/estuarine species, with no freshwater species recorded.
- All treatments had similar physical attributes, such as particle size distributions, maximum tidal velocities, and depths. Percentage of fines and maximum tidal velocity were slightly negatively correlated with abundance and richness.
- A suite of a few numerically dominant taxa were typically common across the study area, however most (93%) of taxa were uncommon. This indicated that most animals collected consisted of a select few species, present at most sites, with occasional rare specimens from a large number of species.
- Benthic communities were comprised exclusively of small opportunistic and/or mobile taxa.
- The above benthic fauna community features are consistent with trends in other similar sub-tropical and tropical coastal environments. Disturbance (e.g. by flood plumes from the Fitzroy River and adjacent coastal streams, waves during storm events, and strong tidal currents) is expected to be an important driver of these patterns.
- Fewer benthic macroinvertebrate taxa and individuals were recorded in the DMPA (39 taxa), channel (47 taxa) and areas immediately adjacent to the DMPA (30 taxa) compared to control locations (73 and 74 taxa). Benthic assemblages in the immediate environs of the channel (79 taxa) were not however different from those recorded at control locations.
- The more depauperate communities observed in the test locations could reflect either: impacts from past dredging and dredged material placement activities, experimental design artefacts, including differences in environmental conditions between control and test locations, and high levels of natural variability at various spatial scales (among locations, and among sites within locations).
- The simplification of communities in shipping channels has been observed in other Queensland ports. Where impacts are dredge-related, material placement does not typically cause long term declines in benthic communities (particularly outside the DMPA).
- It is not possible to conclude with a high degree of certainty that observed differences in benthic fauna communities were a response to legacy impacts of past dredging and dredged material placement activities. The present pilot study represents a snap-shot in time, and impact detection needs to consider not only consider spatial differences in indicators (i.e. among and within treatments), but also the direction and magnitude of temporal changes observed at different spatial scales.
- It is recommended that future macroinvertebrate monitoring should involve sampling before and after dredging and material placement to quantify impacts. Further assessment of recovery trajectories should take place if impacts occur. This should be undertakes at multiple treatments, locations and sites within and adjacent to the primary test site, as adopted in the present study.

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Appendix A PSD Data

CERTIFICATE OF ANALYSIS

Work Order : **EB1514061**
Client : **BMT WBM GROUP LTD**
Contact : MR CONOR JONES
Address : PO BOX 203 SPRING HILL
BRISBANE QLD 4004
E-mail : conor.jones@bmtwbm.com.au
Telephone : +61 07 3831 6744
Facsimile : +61 07 3832 3627
Project : B20769-2
Order number : ----
C-O-C number : ----
Sampler : CONOR JONES
Site : ----

Quote number : ----

Page : 1 of 6
Laboratory : Environmental Division Brisbane
Contact : Customer Services EB
Address : 2 Byth Street Stafford QLD Australia 4053

E-mail : ALSEnviro.Brisbane@alsglobal.com
Telephone : +61-7-3243 7222
Facsimile : +61-7-3243 7218
QC Level : NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Date Samples Received : 04-Mar-2015 13:10
Date Analysis Commenced : 19-Mar-2015
Issue Date : 31-Mar-2015 17:50

No. of samples received : 18
No. of samples analysed : 18

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

NATA Accredited Laboratory 825

Accredited for compliance with
ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Dianne Blane	Assistant Laboratory Manager	Newcastle - Inorganics
Dianne Blane	Laboratory Coordinator (2IC)	Newcastle - Inorganics

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)			*Client sample ID*	**DM IN A**	**DM IN B**	**DM IN C**	**CN A**	**CN B**
			Client sampling date / time	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]
Compound	*CAS Number*	*LOR*	*Unit*	**EB1514061-001**	**EB1514061-002**	**EB1514061-003**	**EB1514061-004**	**EB1514061-005**
				Result	Result	Result	Result	Result
EA150: Particle Sizing								
+75µm	----	1	%	<1	**6**	**5**	**5**	**25**
+150µm	----	1	%	<1	<1	**2**	**1**	**2**
+300µm	----	1	%	<1	<1	**1**	<1	<1
+425µm	----	1	%	<1	<1	<1	<1	<1
+600µm	----	1	%	<1	<1	<1	<1	<1
+1180µm	----	1	%	<1	<1	<1	<1	<1
+2.36mm	----	1	%	<1	<1	<1	<1	<1
+4.75mm	----	1	%	<1	<1	<1	<1	<1
+9.5mm	----	1	%	<1	<1	<1	<1	<1
+19.0mm	----	1	%	<1	<1	<1	<1	<1
+37.5mm	----	1	%	<1	<1	<1	<1	<1
+75.0mm	----	1	%	<1	<1	<1	<1	<1
EA150: Soil Classification based on Particle Size								
Fines (<75 µm)	----	1	%	**99**	**94**	**95**	**95**	**75**
Sand (>75 µm)	----	1	%	**1**	**6**	**5**	**5**	**25**
Gravel (>2mm)	----	1	%	<1	<1	<1	<1	<1
Cobbles (>6cm)	----	1	%	<1	<1	<1	<1	<1

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)			*Client sample ID*	**CN C**	**CH OUT A**	**CH OUT B**	**CH OUT C**	**CH IN A**
			Client sampling date / time	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]
Compound	*CAS Number*	*LOR*	*Unit*	**EB1514061-006**	**EB1514061-007**	**EB1514061-008**	**EB1514061-009**	**EB1514061-010**
				Result	Result	Result	Result	Result
EA150: Particle Sizing								
+75µm	----	1	%	**23**	<1	**20**	**8**	<1
+150µm	----	1	%	**10**	<1	**2**	<1	<1
+300µm	----	1	%	<1	<1	<1	<1	<1
+425µm	----	1	%	<1	<1	<1	<1	<1
+600µm	----	1	%	<1	<1	<1	<1	<1
+1180µm	----	1	%	<1	<1	<1	<1	<1
+2.36mm	----	1	%	<1	<1	<1	<1	<1
+4.75mm	----	1	%	<1	<1	<1	<1	<1
+9.5mm	----	1	%	<1	<1	<1	<1	<1
+19.0mm	----	1	%	<1	<1	<1	<1	<1
+37.5mm	----	1	%	<1	<1	<1	<1	<1
+75.0mm	----	1	%	<1	<1	<1	<1	<1
EA150: Soil Classification based on Particle Size								
Fines (<75 µm)	----	1	%	**77**	**99**	**80**	**92**	**99**
Sand (>75 µm)	----	1	%	**23**	**1**	**20**	**8**	**1**
Gravel (>2mm)	----	1	%	<1	<1	<1	<1	<1
Cobbles (>6cm)	----	1	%	<1	<1	<1	<1	<1

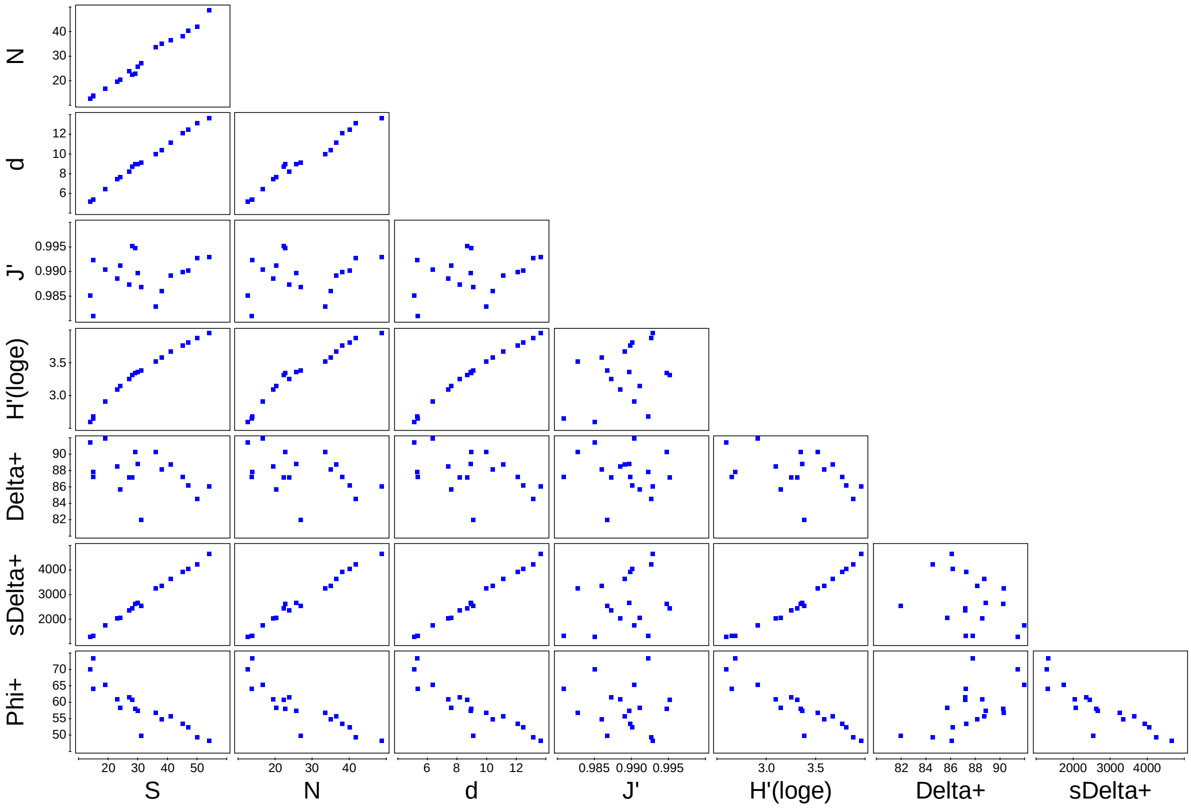
Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)			*Client sample ID*	**CH IN RC**	**CH IN C**	**DM OUT A**	**DM OUT B**	**DM OUT C**
			Client sampling date / time	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]
Compound	*CAS Number*	*LOR*	*Unit*	**EB1514061-011**	**EB1514061-012**	**EB1514061-013**	**EB1514061-014**	**EB1514061-015**
				Result	Result	Result	Result	Result
EA150: Particle Sizing								
+75µm	----	1	%	**1**	**8**	<1	**10**	**4**
+150µm	----	1	%	**1**	**6**	<1	**1**	<1
+300µm	----	1	%	**1**	**5**	<1	<1	<1
+425µm	----	1	%	<1	**5**	<1	<1	<1
+600µm	----	1	%	<1	**5**	<1	<1	<1
+1180µm	----	1	%	<1	**4**	<1	<1	<1
+2.36mm	----	1	%	<1	**3**	<1	<1	<1
+4.75mm	----	1	%	<1	**2**	<1	<1	<1
+9.5mm	----	1	%	<1	<1	<1	<1	<1
+19.0mm	----	1	%	<1	<1	<1	<1	<1
+37.5mm	----	1	%	<1	<1	<1	<1	<1
+75.0mm	----	1	%	<1	<1	<1	<1	<1
EA150: Soil Classification based on Particle Size								
Fines (<75 µm)	----	1	%	**99**	**92**	**100**	**90**	**96**
Sand (>75 µm)	----	1	%	**1**	**5**	<1	**10**	**5**
Gravel (>2mm)	----	1	%	<1	**3**	<1	<1	<1
Cobbles (>6cm)	----	1	%	<1	<1	<1	<1	<1

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)			*Client sample ID*	**CS A**	**CS B**	**CS C**	**----**	**----**
			Client sampling date / time	[18-Dec-2014]	[18-Dec-2014]	[18-Dec-2014]	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EB1514061-016**	**EB1514061-017**	**EB1514061-018**	**--------**	**--------**
				Result	Result	Result	Result	Result
EA150: Particle Sizing								
+75µm	----	1	%	**8**	**6**	<1	----	----
+150µm	----	1	%	<1	<1	<1	----	----
+300µm	----	1	%	<1	<1	<1	----	----
+425µm	----	1	%	<1	<1	<1	----	----
+600µm	----	1	%	<1	<1	<1	----	----
+1180µm	----	1	%	<1	<1	<1	----	----
+2.36mm	----	1	%	<1	<1	<1	----	----
+4.75mm	----	1	%	<1	<1	<1	----	----
+9.5mm	----	1	%	<1	<1	<1	----	----
+19.0mm	----	1	%	<1	<1	<1	----	----
+37.5mm	----	1	%	<1	<1	<1	----	----
+75.0mm	----	1	%	<1	<1	<1	----	----
EA150: Soil Classification based on Particle Size								
Fines (<75 µm)	----	1	%	**92**	**94**	**99**	----	----
Sand (>75 µm)	----	1	%	**8**	**6**	**1**	----	----
Gravel (>2mm)	----	1	%	<1	<1	<1	----	----
Cobbles (>6cm)	----	1	%	<1	<1	<1	----	----

Appendix B Bi-plots of Various Diversity Metrics



BMT WBM Bangalow
6/20 Byron Street, Bangalow 2479
Tel +61 2 6687 0466 Fax +61 2 66870422
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Brisbane
Level 8, 200 Creek Street, Brisbane 4000
PO Box 203, Spring Hill QLD 4004
Tel +61 7 3831 6744 Fax +61 7 3832 3627
Email bmtwbm@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Denver
8200 S. Akron Street, #B120
Centennial, Denver Colorado 80112 USA
Tel +1 303 792 9814 Fax +1 303 792 9742
Email denver@bmtwbm.com
Web www.bmtwbm.com

BMT WBM London
International House, 1st Floor
St Katharine's Way, London E1W 1AY
Email london@bmtwbm.co.uk
Web www.bmtwbm.com

BMT WBM Mackay
PO Box 4447, Mackay QLD 4740
Tel +61 7 4953 5144 Fax +61 7 4953 5132
Email mackay@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Melbourne
Level 5, 99 King Street, Melbourne 3000
PO Box 604, Collins Street West VIC 8007
Tel +61 3 8620 6100 Fax +61 3 8620 6105
Email melbourne@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Newcastle
126 Belford Street, Broadmeadow 2292
PO Box 266, Broadmeadow NSW 2292
Tel +61 2 4940 8882 Fax +61 2 4940 8887
Email newcastle@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Perth
Level 3, 20 Parkland Road, Osborne, WA 6017
PO Box 1027, Innaloo WA 6918
Tel +61 8 9328 2029 Fax +61 8 9486 7588
Email perth@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Sydney
Level 1, 256-258 Norton Street, Leichhardt 2040
PO Box 194, Leichhardt NSW 2040
Tel +61 2 8987 2900 Fax +61 2 8987 2999
Email sydney@bmtwbm.com.au
Web www.bmtwbm.com.au

BMT WBM Vancouver
Suite 401, 611 Alexander Street
Vancouver British Columbia V6A 1E1 Canada
Tel +1 604 683 5777 Fax +1 604 608 3232
Email vancouver@bmtwbm.com
Web www.bmtwbm.com