Port of Gladstone East Banks Sea Disposal Site Benthic Habitat Monitoring 2021

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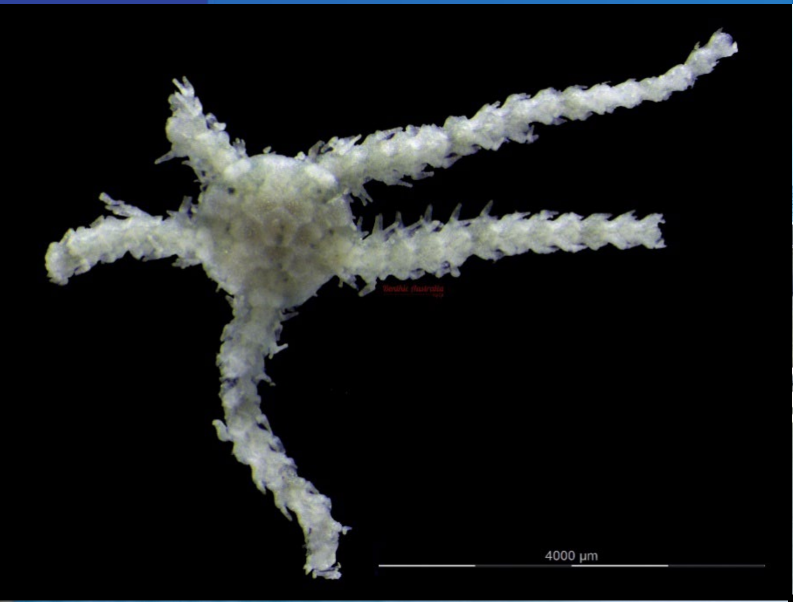

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KEY FINDINGS

1. Seagrasses and benthic infauna at and adjacent to the dredge material placement area (the East Bank Spoil Disposal Site (EBSDS)) in the PoG were surveyed between the 8th – 10th of November 2021.

2. There was no evidence that sediment deposition in the EBSDS was having any measurable effect on benthic habitats surrounding the EBSDS.

3. Extensive deep-water seagrass meadows occurred immediately to the east and north of the EBSDS consisting of the species *Halophila decipiens* and *Halophila ovalis*.

4. Seagrass cover was sparse throughout the survey meadows and mean biomass was low (0.20 ± 0.20 g DW m^2) typical of deep-water seagrass species found throughout Queensland.

5. Small areas of seagrass extended into the EBSDS which is consistent with previous surveys.

6. A total of 670 benthic invertebrates were collected belonging to 98 taxa including 9 phyla and 85 families.

7. Polychaetes were the most common taxa followed by crustaceans. These two groups represented 78% of the invertebrates collected.

8. Infauna communities were more diverse and abundant in the EBSDS and to the east of the EBSDS than to the west and in control locations.

9. There were small declines in species richness and annelid abundance at increasing distance to the EBSDS but there was no relationship between other infauna variables measured.

10. Infauna assemblages could not be directly statistically compared to previous surveys because of changes in sampling designs and techniques that have occurred during the program, however overall composition and distribution were similar.

11. Sediment was predominantly sand (7 5µm – 2 mm) across the survey area. In the EBSDS fine sediment composition (< 75 µm) was higher and sand sediment lower than in the other locations. These results contrast previous surveys in 2005, 2010/11 and 2016/17 when fine sediment was lower in the EBSDS.

12. Due to the highly variable nature of deep-water seagrass communities, we suggest that future EBSDS assessments continue to incorporate a broader port limits survey area for seagrass assessment to ensure a true picture of seagrass presence between years.

Contents

ACRONYMS AND ABBREVIATIONS

ALS	Australian Laboratory Services
dbMSL	Depth below Mean Sea Level
DW	Dry Weight
EBSDS	East Bank Spoil Disposal Site
GIS	Geographic Information System
GLM	General Linear Model
GPC	Gladstone Ports Corporation
GPS	Global Positioning System
JCU	James Cook University
LMDMP	Long - Term Maintenance Dredging Management Plan
MSQ	Maritime Safety Queensland
NATA	National Association of Testing Authorities
NFIE	Near Field Impact East
NFIW	Near Field Impact West
nMDS	non-metric Multi-Dimensional Scaling
PoG	Port of Gladstone
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research

1 INTRODUCTION

The Port of Gladstone (PoG) is a major shipping hub located in Central Queensland comprising of over 20 wharves and loading 122 million tonnes of cargo to 1800 ships in 2021. The PoG is managed by the Gladstone Ports Corporation (GPC) who undertake maintenance dredging annually or as required to maintain navigational depths. Dredge material from the PoG is disposed of at the dredge material placement area known as the East Bank Sea Disposal Site (EBSDS), a designated dredge material area approximately 10 km offshore within the port limits (Figure 1). The sediments are tested as part of a sediment analysis plan (SAP) every five years to ascertain that they are suitable for sea placement in line with the national assessment guidelines for dredging. The last sediment sampling and analysis plan confirmed previous results showing that sediment removed from PoG channels are suitable for sea placement. As part of the Long-term Maintenance Dredging Management Plan (LMDMP) for maintenance of dredging at PoG, GPC is required to undertake an assessment of the benthic habitat and sediment inside and outside the EBSDS every five years. These assessments investigate the potential impacts of sea placement activities on benthic habitats inside and outside the EBSDS with a specific focus on benthic flora and fauna.

Deep-water areas such as those in the PoG can provide important habitats for flora and fauna. Deep-water seagrasses found within the PoG limits may harbour diverse fish and benthic infauna assemblages (Hayes et al. 2020). Seagrasses provide a range of critically important and economically valuable ecosystem services including coastal protection, support of fisheries production, nutrient cycling, and particle trapping (Costanza et al. 2014; Hemminga and Duarte 2000). Seagrass meadows show measurable responses to changes in water quality, making them ideal indicators to monitor the health of marine environments (Orth et al. 2006; Abal and Dennison 1996; Dennison et al. 1993). The distribution of deep-water *Halophila* seagrass species like those found in deep-water habitats in Gladstone Harbour fluctuate rapidly in response to variations in light conditions and water quality (York et al. 2015). *Halophila* species are highly susceptible to low light conditions, even over short time periods, but can colonise habitats quickly, and are often annual recruiting from seed for only part of the year making monitoring difficult (Chartrand et al. 2018, York et al., 2015). JCU conducts annual seagrass monitoring in Port Curtis and Rodds Bay for GPC including deep-water seagrass surveys in 2009, 2013, 2014 and 2019 (Smith et al. 2020). Deep-water seagrass meadows in these surveys have been recorded adjacent to the EBSDS and in 2019 and 2014 were found in small areas within the EBSDS but were highly variable in their spatial distribution between surveys (Smith et al. 2020).

Coastal infauna communities can also provide an indication of ecosystem health and anthropogenic impacts, and play an important role in nutrient cycling and the coastal food web (Dauvin et al. 2012, Culhane et al. 2018). The deposition of dredge material can have a range of impacts on benthic habitats from no detectable effect, to shifts in species compositions and assemblages (Jones 1986, Harvey et al. 1998, Smith and Rule 2001).

Monitoring of the EBSDS has previously been conducted in 2005, 2010/11 and 2016/17 (BMT 2006, 2012, Vision Environment 2017). The focus of previous surveys has varied making long term comparisons difficult. The 2016/17 survey included sediment particle size, nutrient and metal concentrations and benthic macroinvertebrates assemblages along transects extending from the EBSDS (Vision Environment), whereas in 2005 and 2010/11 sediment and benthic invertebrate assemblages were surveyed within control, impact and near impact locations before and after dredging activities (BMT 2006, 2012). In order to improve capabilities for detecting changes in benthic habitat relative to the EBSDS, and also allow comparisons to previous surveys, sampling in this survey combined methods outlined in the PoG EBSDS LMDMP, previous EBSDS surveys and those used in previous PoG deep-water seagrass surveys. Sediment grain size and macroinvertebrate sampling followed previous EBSDS sampling and seagrass monitoring used the same methods as previous PoG deep-water seagrass monitoring surveys applied in 2009, 2013, 2014 and 2019, but with an increased sampling intensity around the EBSDS. By utilising a consistent monitoring method for seagrass and benthic habitats, that are applied by the TropWATER team throughout Queensland and within the EBSDS, we can put results into a broader regional context. This is especially valuable given the highly variable nature of subtidal seagrass meadows and other benthic habitats that occur in the deeper-water of PoG.

1.1 Objectives and scope of the environmental assessment

This monitoring survey was developed for the PoG to investigate the potential impacts of sea placement activities on benthic habitats; specifically, benthic infauna and seagrass. The survey was designed in accordance with the PoG LMDMP. The last EBSDS assessment was undertaken in 2016 and this report fulfils the five yearly reporting requirement in the LMDMP for 2021.

Our primary objectives was to:

- Assess if deposited dredge material results in long term changes to benthic communities outside the EBSDS;

In order to achieve this we:

- Compare the EBSDS with nearby benthic habitats to assess any impacts of dredge material placement;
- Compare temporal and spatial variations in benthic habitat and communities to previous surveys of the EBSDS where possible, and place in context of wider PoG and North Queensland seagrass monitoring.

2 METHODS

2.1 Field surveys

The EBSDS and broader deep-water benthic habitats in PoG were surveyed between November 8th – 10th 2021. The survey was conducted at two spatial scales: nearfield benthic sampling similar to previous EBSDS surveys (Figure 1, 2), and, an expansive port wide deep-water seagrass survey similar to the five yearly deep-water seagrass surveys (Figure 1).

Nearfield sampling was used to assess seagrass, infauna and sediment grain size and replicated sites specified in the LMDMP. These included five sites within the EBSDS (EBSDS a-e), two sites adjacent to the EBSDS (Near Field Impact West (NFIW) and East (NFIE)), two control sites (control north, control south) and five sites in two transect lines perpendicular to the EBSDS from NFIE and NFIW at 250, 500, 1000, 2000 and 5000 m distance from the EBSDS boundary (Figure 1, 2).

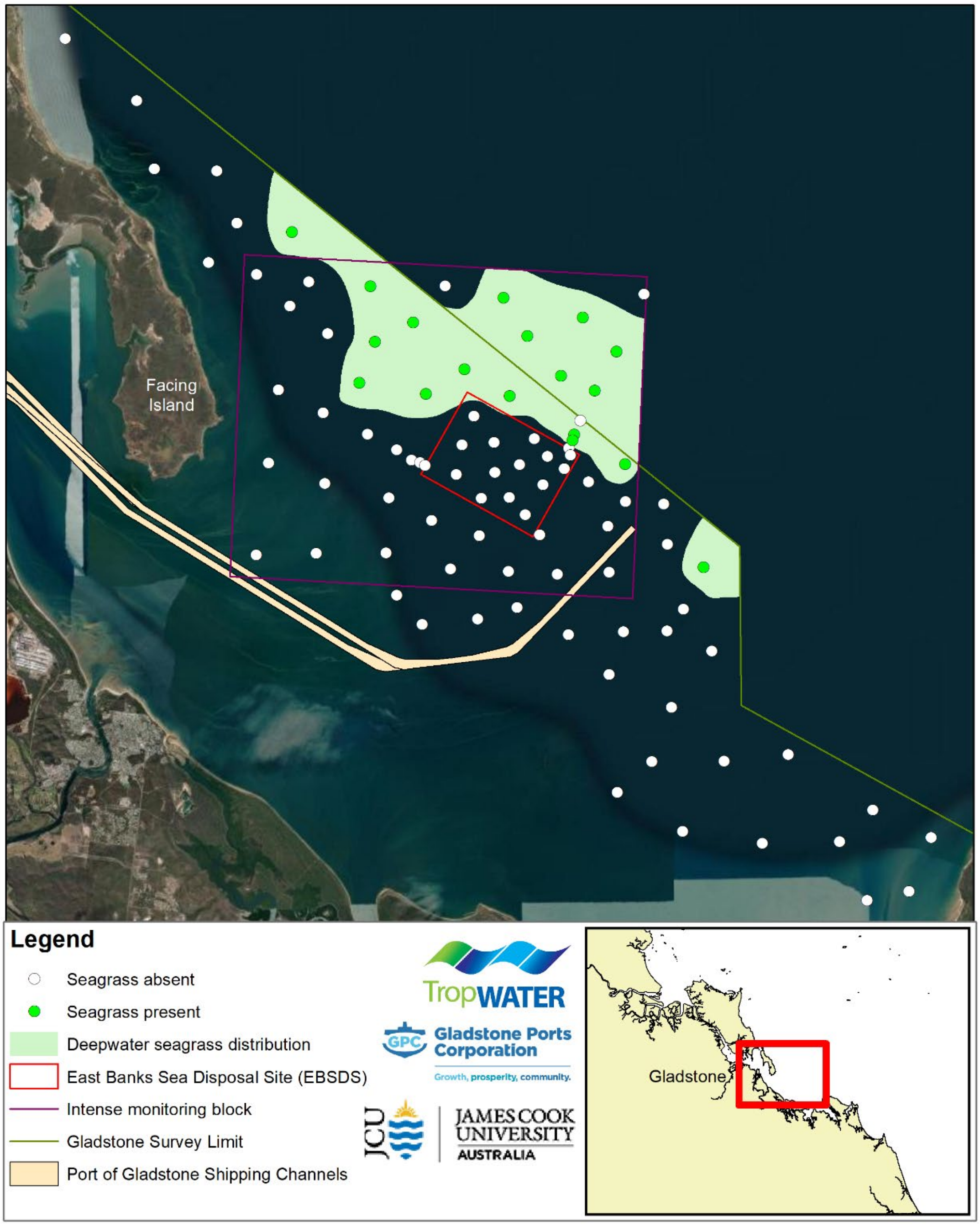

Figure 1. Seagrass survey sites and meadows across deep-water habitats in the Port of Gladstone.

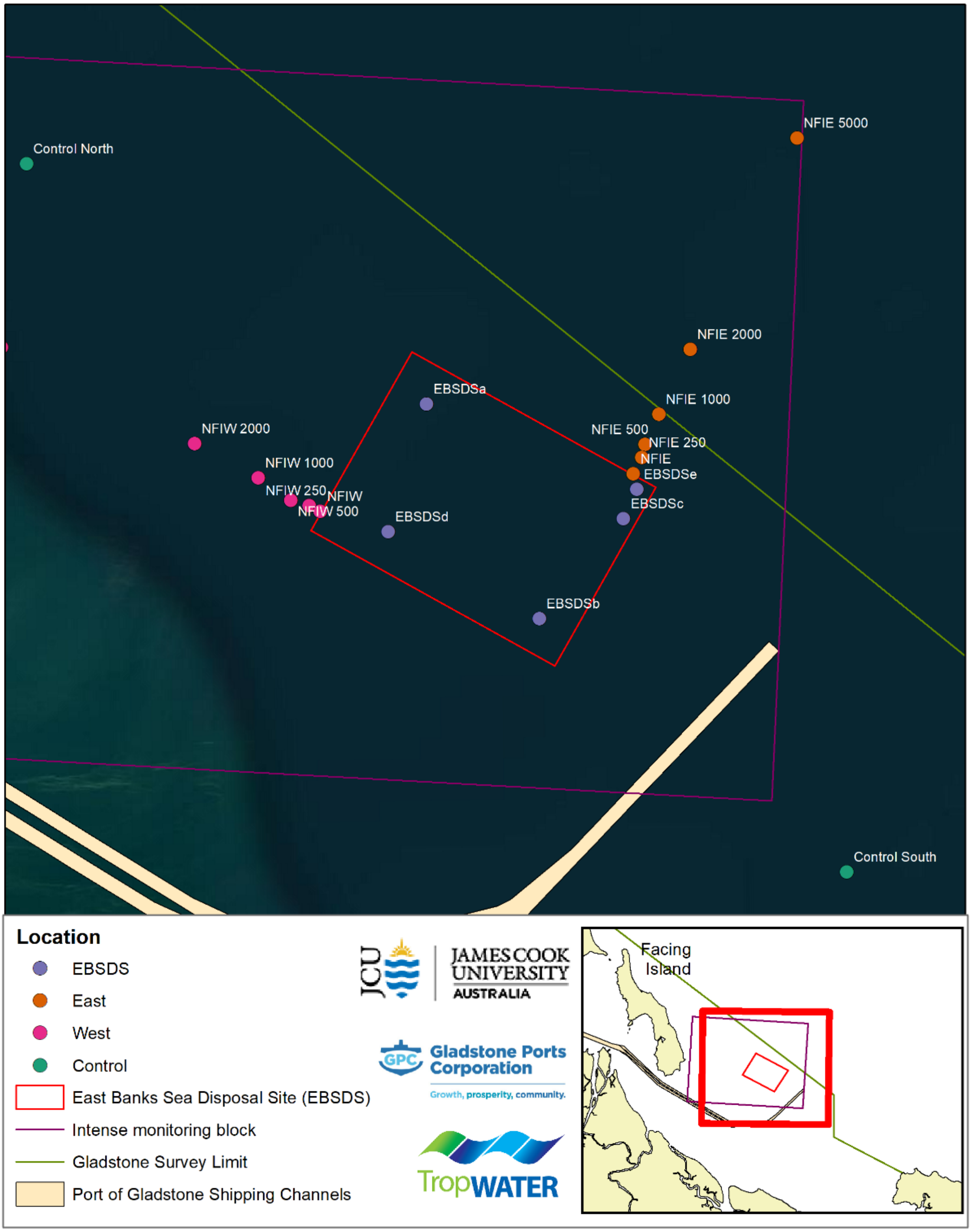

Figure 2. Benthic infauna and sediment sampling sites at each location in the EBSDS survey in the Port of Gladstone.

2.2 Benthic infauna sampling

Benthic infauna and sediment grain size were sampled using a Van Veen grab (16.5 cm x 17.5 cm, depth 8 cm; Figure 2a). At each site, four replicate infauna grabs and one sediment grain size grab were collected. Sediment infauna samples were sieved to 1 mm and preserved in 95% ethanol. In the laboratory all macroinvertebrates were picked from the sediment, identified to the lowest taxonomic level possible and counted at Benthic Australia. Benthic Australia are experts in marine macroinvertebrate taxonomy including rigorous QA/QC protocols. Sediment grain size samples were processed at the National Association of Testing Authorities (NATA) accredited Australian Laboratory Services (ALS) laboratories. Samples were wet sieved to 75 µm and the proportion of fine (< 75 µm), sand (75 µm – 2mm) and gravel (> 2 mm) within each sediment sample was calculated.

2.3 Seagrass sampling

At each survey site, seagrass was sampled using an underwater CCTV camera system, with real-time monitor, towed from a research vessel. At each site the underwater camera system was lowered to the sea floor and towed for 50 m at drift speed (<1 knot). Footage was observed on a TV monitor and recorded. The camera was mounted on a sled that incorporates a 600 mm width and 250 mm deep net with a 10 mm-mesh aperture (Figure 3). Surface benthos was captured in the net (semi-quantitative bottom sample) and used to confirm seagrass species observed on the monitor. Transect footage was recorded and used to determine seagrass meadow characteristics, including percent seagrass cover and percent cover category (absent; sparse: <10% cover; moderate: 10 – 50% cover, dense: >50% cover) seagrass species composition and seagrass above-ground biomass across the transect. Depth below mean sea level, and time and location (latitude/longitude using Global Positioning System) were also recorded.

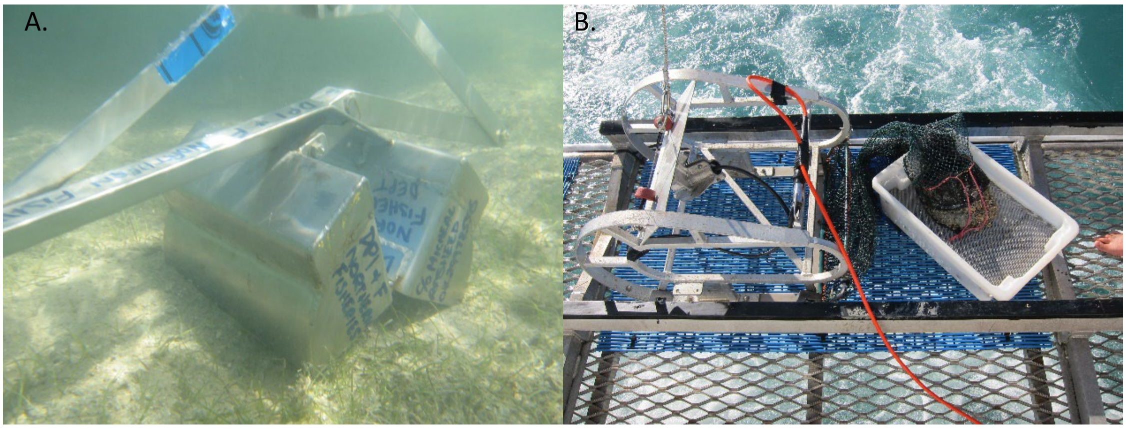

Figure 3. (A) Van Veen grab used for sampling benthic infauna and sediment, and (B) video sled and net used to sample seagrass.

Seagrass above-ground biomass was determined using a modified “visual estimates of biomass” technique described by Mellors (1991). This technique involves an observer ranking seagrass biomass from video footage at each deep-water sled tow site. In each video the footage was paused at 10 randomly allocated time points and a 0.25 m^2 quadrat transposed onto the screen from which seagrass biomass was ranked. Ranks are made in reference to a series of quadrat photographs of similar seagrass habitats for which the above-ground biomass has previously been measured. The relative proportion of the above-ground biomass (percentage) of each seagrass species within each quadrat was also recorded. Biomass ranks were then converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^2). At the completion of sampling, each observer ranked a series of calibration quadrats that represented the range of seagrass biomass in the survey that had been harvested and actual above ground biomass measured in the laboratory. A separate regression of ranks and biomass from these calibration quadrats was generated for each observer and applied to the field survey data to determine above-ground biomass. Average seagrass biomass and standard error was calculated across the 10 replicate quadrats at each site.

2.5 Data Analysis

Benthic habitat and communities inside and outside the PoG EBSDS were compared using a range of univariate and multivariate analyses. The following response variables were modelled using two separate General Linear Models (GLM): percent fine sediment (beta-regression), percent sand (beta-regression), percent gravel (beta-regression) and infauna species richness (Poisson distribution), infauna diversity (Shannon's Index; Gaussian distribution), infauna evenness (Gaussian distribution), infauna total abundance (negative binomial distribution), and the abundance of the two most abundant taxa, annelids and crustaceans (negative binomial distribution). The models examined:

- Variation in the response variable among four sampling locations; within the EBSDS (EBSDS), NFIW transect (West), NFIE transect (East) and the control locations.

- Variation in the response variable with distance to the EBSDS between transects in the west and east locations.

GLMs were conducted using the *nme4* (Bates et al. 2015) and *betareg* (Cribari-Neto and Zeileis 2010) package in R (version 1.3.1, R Core Team 2020). Residuals were examined for each best-fit model to ensure model assumptions were met and residual deviance and residual degrees of freedom assessed for over dispersion. Tukeys post hoc tests were conducted where appropriate using the R package *emmeans* (Lenth 2020).

Multivariate analysis was used to assess differences in benthic infauna community assemblages across locations inside and outside the EBSDS. Assemblages across locations were compared using the manyGLM function where location was treated as a factor and replicate pooled for each site. A non-metric multidimensional scaling (nMDS) plot and a dendrogram of similarities was constructed from a Bray-Curtis dissimilarity matrix to visually assess differences in infauna assemblages across locations. All multivariate analysis were done using the *vegan* and *MVAbund* packages in R (Wang et al. 2012, Oksanen et al. 2020).

3 RESULTS

3.1 Sediment Particle Size

Sediment across survey sites consisted predominantly of sand (75 µm – 2 mm) ranging from 24 – 98% of the sediment sampled at each site (Figure 4, 5, 6). Analysis comparing locations found a significant difference across locations for fine and sand sediment (Table 1). Fine sediment (< 75 µm) composition was greater (p = 0.021), and sand composition lower (p = 0.021) in the EBSDS than the west location but there were no other significant differences. Analysis was not done on gravel sediment because of the large number of 0's (39% of samples) but gravel content was greater in the EBSDS ranging from 4 – 41% but was no greater than 11% elsewhere, and not above 1% in the west location. Overall there was a significant decrease in the percentage of fine sediment as the distance to the EBSDS increased and an increase in the percentage of sand sediment (Table 1, Figure 7). The sediment sample at site EBSDSb was not analysed because it consisted only of large rocks.

Table 1. Results from Beta regression General Linear Model comparing percent fine sediment (<75 µm), sand (75 µm – 2 mm) and gravel (> 2 mm) at each location (A) and with distance to the EBSDS in the north and east locations (B). Bold = significant (p < 0.05)

		Fine Sediment		**Sand**	
A. Location	Df	LR ChiSq	P	LR ChiSq	P
Location	3	9.650	**0.022**	12.765	**0.001**
B. Distance to EBSDS					
Distance to EBSDS	1	15.66	**<0.001**	11.94	**0.001**
Location	1	7.59	0.006	11.38	**0.001**
Distance EBSDS x Location	1	1.05	0.304	1.56	0.211

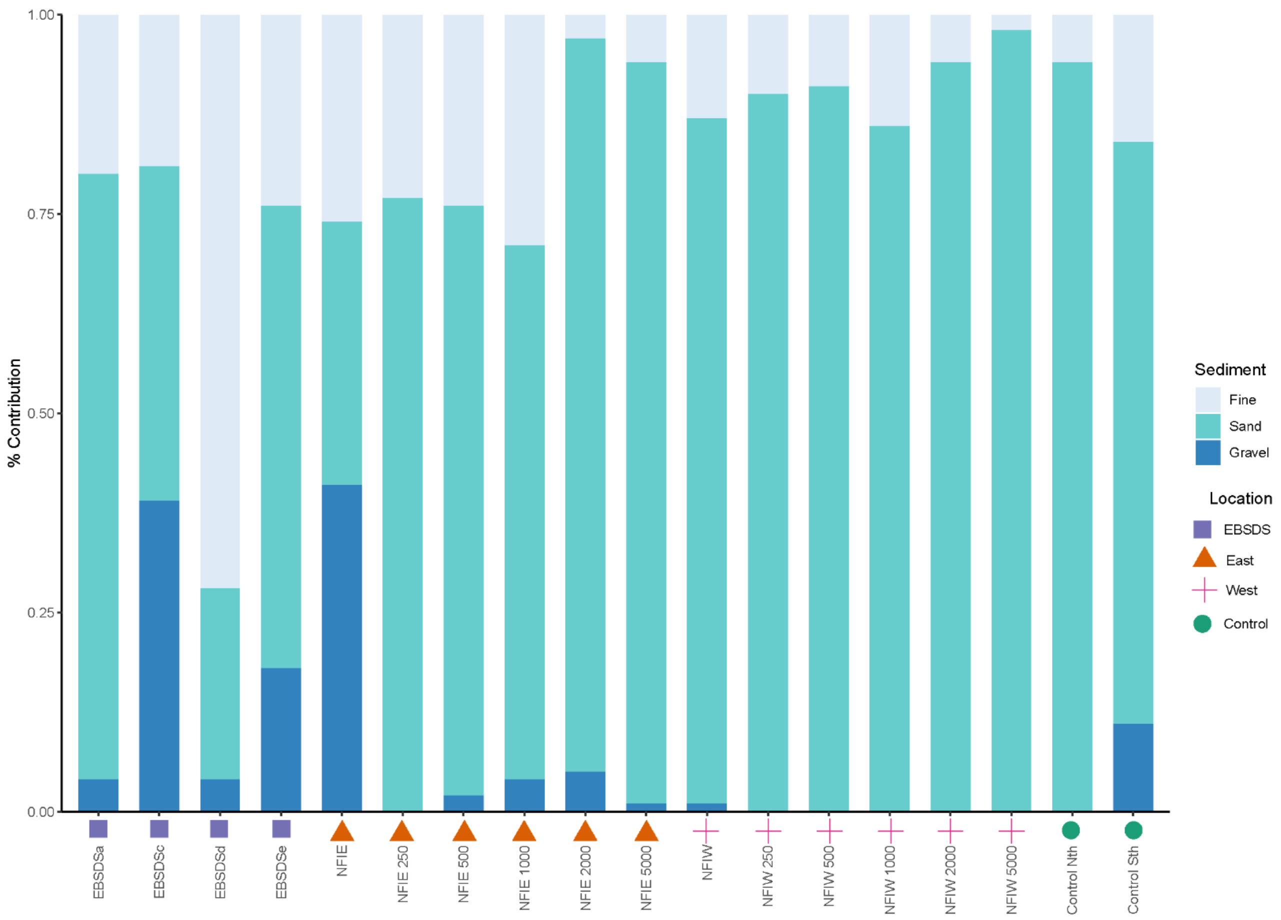

Figure 4. Proportion of fine sediment (< 75 µm), sand (75 µm – 2 mm) and gravel (> 2 mm) at sites in the Port of Gladstone EBSDS.

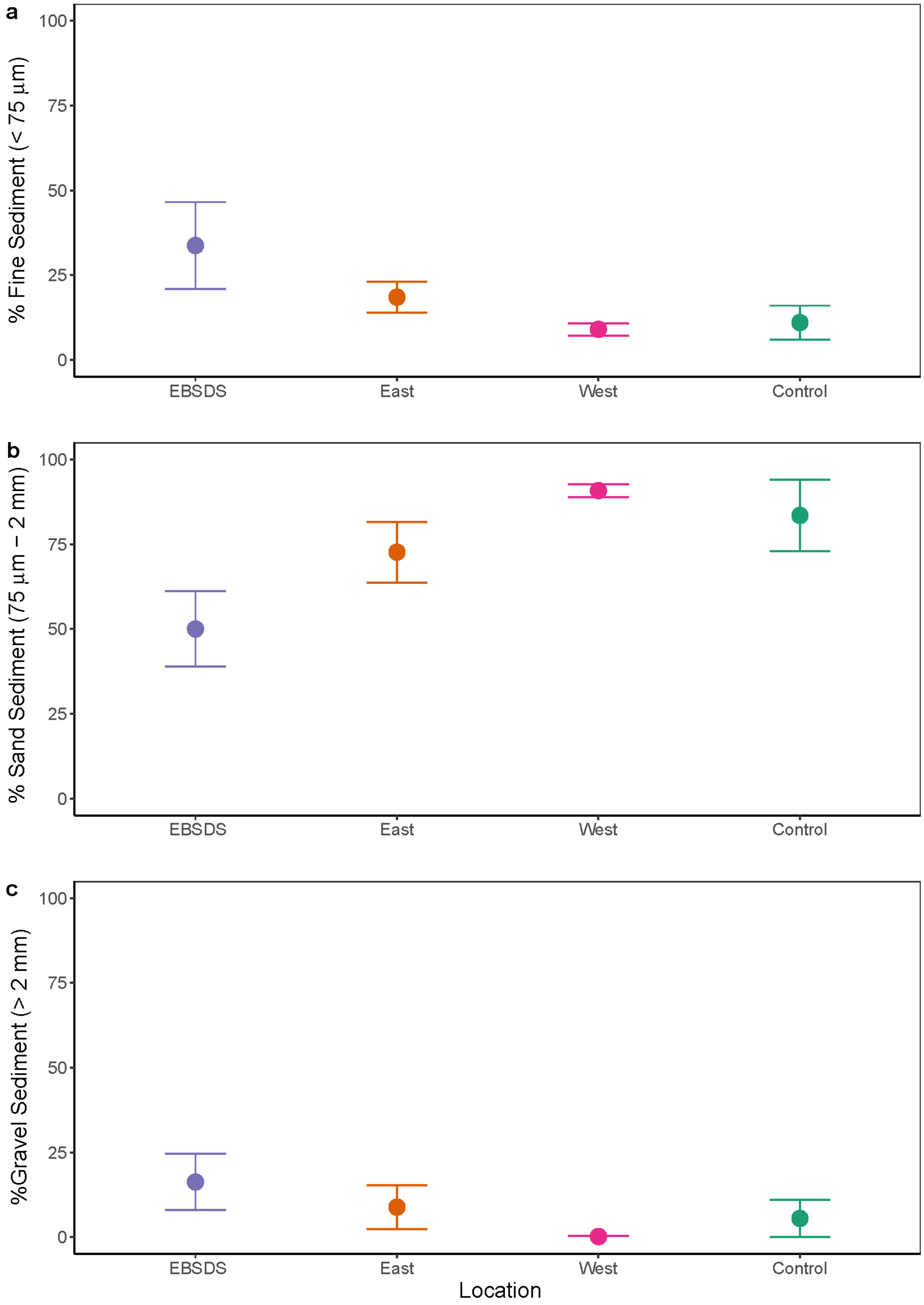

Figure 5. Mean (± SE) percentage of (a) fine (< 75 µm), (b) sand (75 µm – 2mm) and (c) gravel (> 2 mm) sediment at each location in the EBSDS survey area.

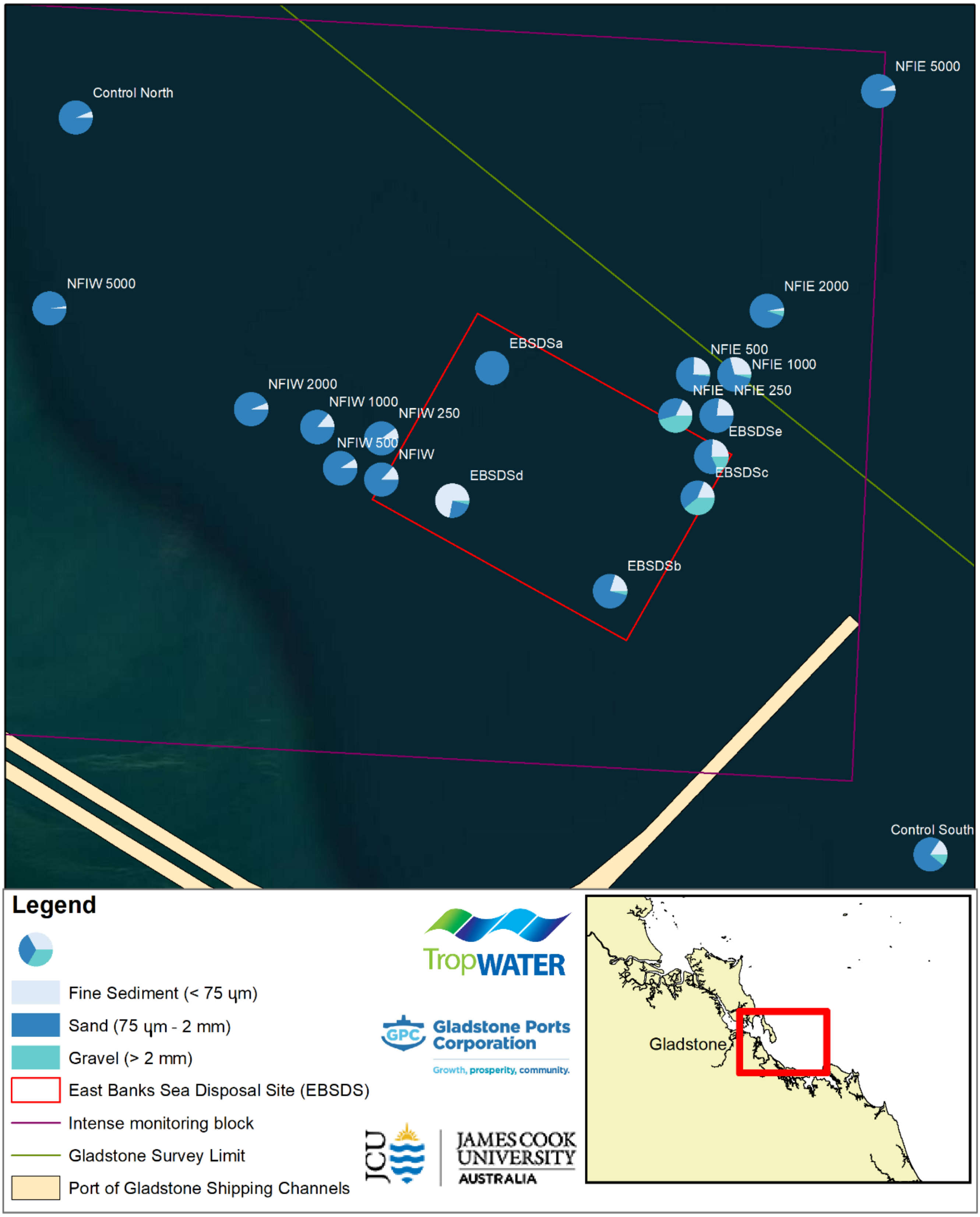

Figure 6. Sediment composition across the survey area at the Port of Gladstone EBSDS in 2021.

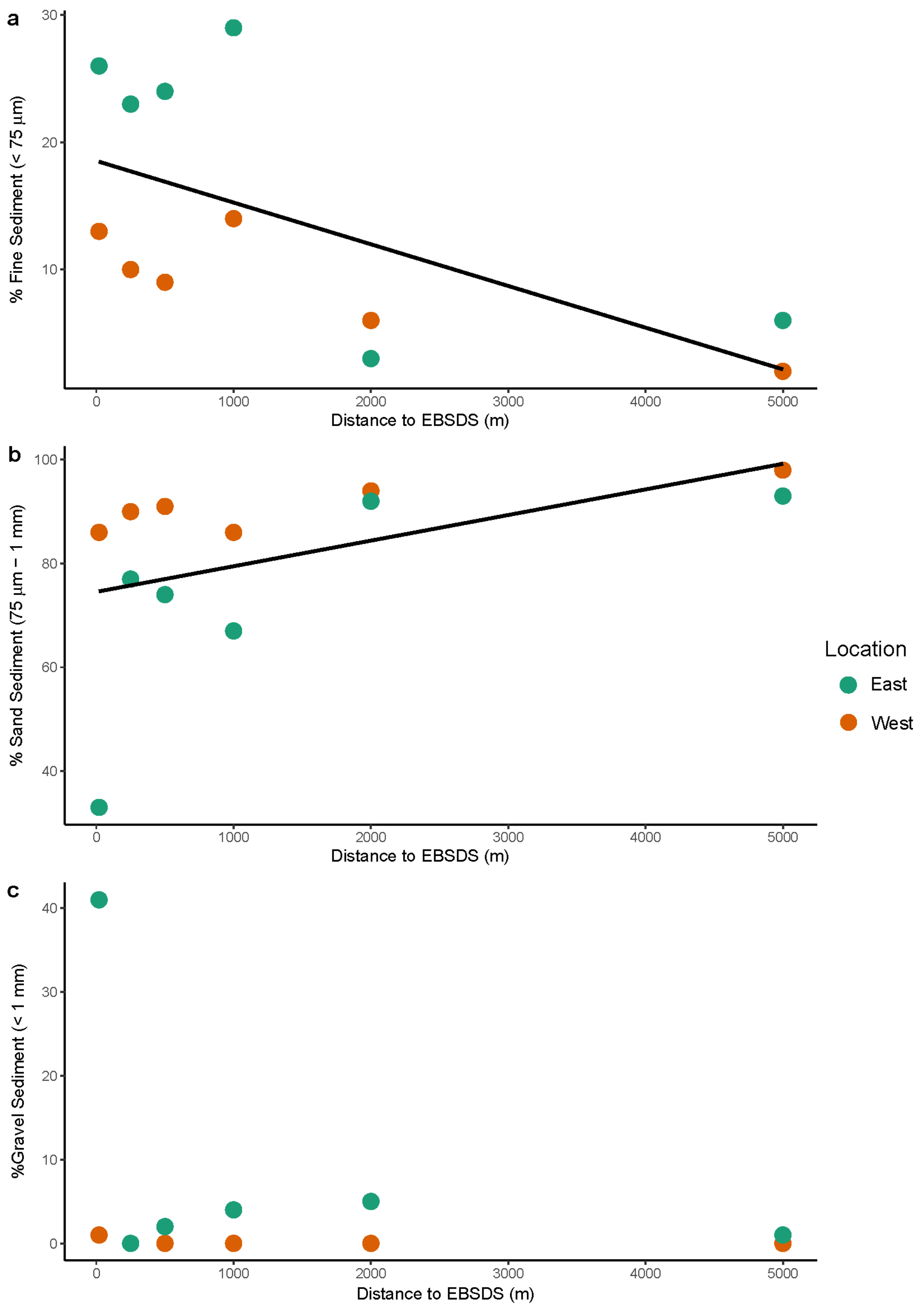

Figure 7. Change in percentage of (a) fine sediment (< 75 µm), (b) sand (75 µm – 2 mm) and (c) gravel (> 2 mm) in the east and west locations as distance to the EBSDS increases. Lines represent significant relationships.

3.2 Deep-Water Seagrasses

A total of 93 deep-water seagrass transect sites were surveyed in the EBSDS benthic survey (Figure 1). Two species of seagrass were recorded, *Halophila ovalis* and *H. decipiens* (Figure 8). A total seagrass area of 4,400 ± 508 ha was mapped across two meadows. The largest of these meadows covered 4,107.6 ± 363.7 ha to the east and north of the EBSDS crossing into small areas within the EBSDS. Both meadows extended beyond the survey limit and would therefore cover a greater total area than reported here. Seagrass biomass was low throughout both of the deep-water meadows (0.39 ± 0.22 g DW m^2 and 0.01 g DW m^2), and did not reach greater than 4 g DW m^2 within their footprint (Figure 9).

Seagrass distribution in deep-water surrounding the EBSDS was similar in 2021 to previous surveys (Figure 10). While direct comparisons to previous surveys are difficult because of different survey boundaries, surveys in 2019, 2014 and 2013 had large areas of seagrass to the north and east of the EBSDS. In this survey seagrass covered a similar area but was in closer proximity to the EBSDS than previous surveys. In 2019, seagrass was recorded directly to the south of the EBSDS for the first time but was not recorded here in this survey. Deep-water seagrass biomass was similar to deep-water meadows in 2014 (0.35 g DW m^2) and greater than in 2002 (0.01 – 0.17 g DW m^2), 2013 (0.04 – 0.22 g DW m^2) and 2019 (0.01 – 0.15 g DW m^2).

Halophila ovalis

Halophila decipiens

Figure 8. Seagrass species present in the Port of Gladstone EBSDS survey in 2021.

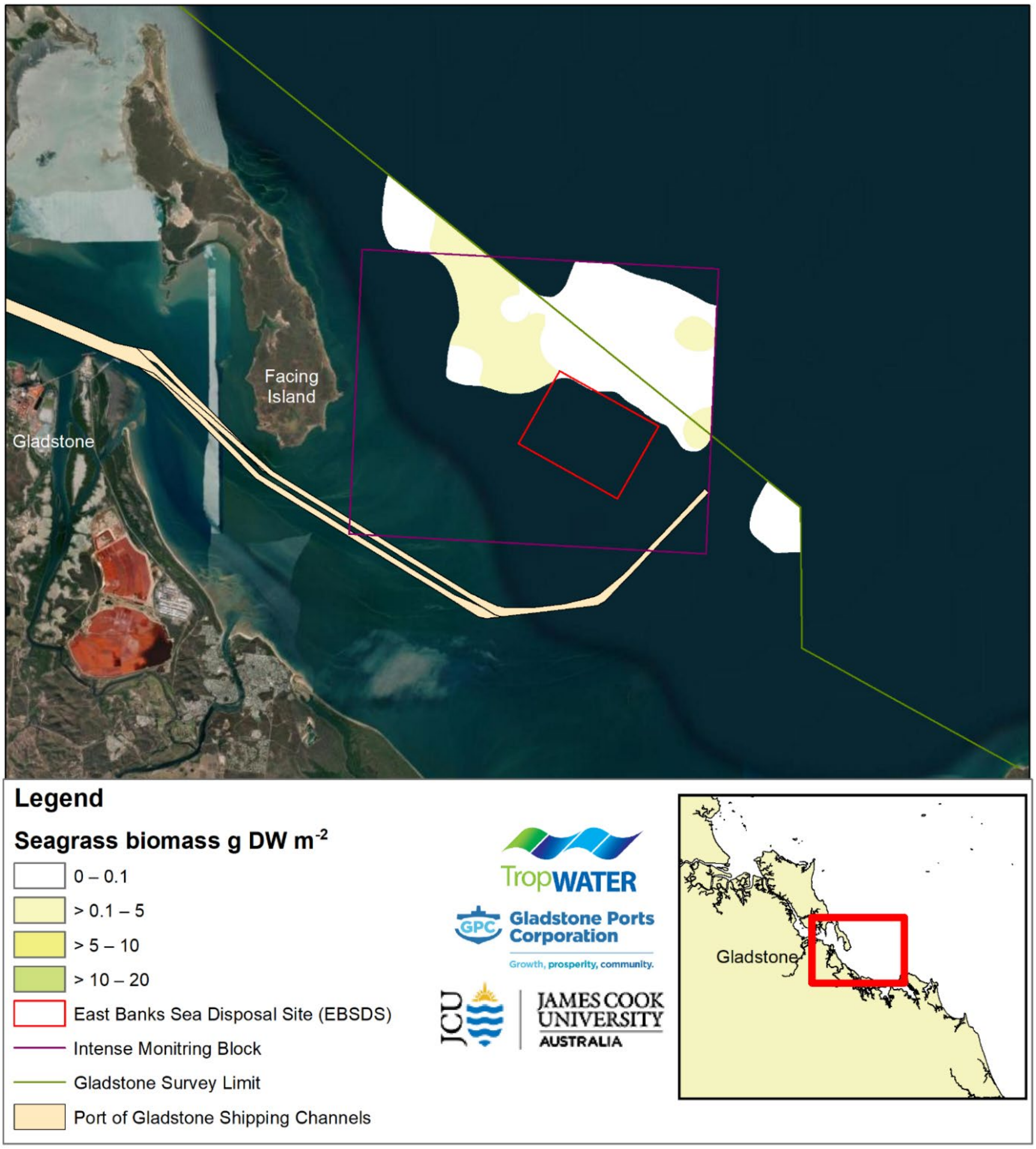

Figure 9. Seagrass biomass in deep-water meadows in the Port of Gladstone.

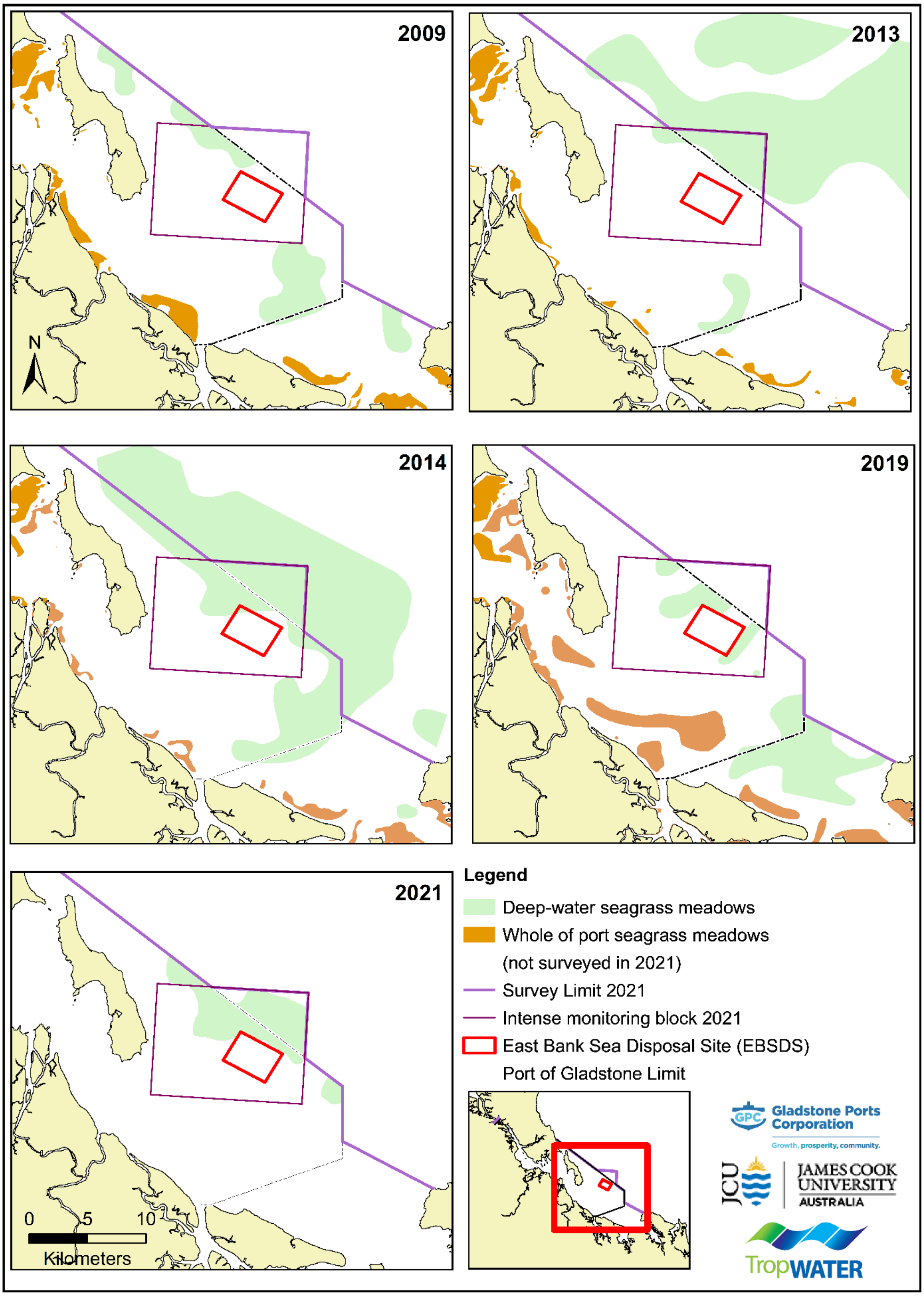

Figure 10. Comparison of deep-water seagrass distribution in the Port of Gladstone during surveys in 2009, 2013, 2014, 2019 and 2021. Surveys in 2009 and 2019 only extended as far the port boundary. Surveys in 2013 and 2014 extended past the 2021 survey boundary.

3.3 Infauna Invertebrate Communities in the EBSDS

A total of 670 invertebrates, from 98 taxa in nine phyla and 85 families were collected in samples. The most common occurring taxa were a Tanaid crustacean from the Apseudidae family (34 individuals from one species), followed by the Echinoderm *Ophiurodea* sp1. (30 individuals from one species) and Tanaid *Pseudozeuxoidae* sp1 (28 individuals from one species) (Table 4, Figure 11). The most common phyla sampled were Annelids (all polychaetes; 253 individuals) and Crustaceans (273 individuals). These two phyla accounted for more than 78% of the individuals sampled. At sites outside the EBSDS, in the east and north locations, Apseudidae, Ostracoda and Ischyroceridae were the most common taxa (Table 4). At the two control sites, the polycheate, *Lumbrineris* sp1, was the most common taxa sampled followed by *Spinonidae* sp2 and the crustacean, Platyischnopidae 1 (Table 4). Within the EBSDS the echinoderm, Ophiuroidae 1 was the most common followed by unidentified bivalves with no shells, and the crustacean Pseudozeuxoidae (Table 4).

Table 4. Count of most numerically dominant taxa at EBSDS survey area (EBSDS, east location, west location, control).

East Location		**West Location**		**EBSDS**		**Control**	
Taxa	**Count**	**Taxa**	**Count**	**Taxa**	**Count**	**Taxa**	**Count**
Apseudidae 1 (crustacea)	23	Apseudidae 1 (crustacea)	10	Ophiuroidea 1 (echinoderm)	15	*Lumbrineris* sp1 (annelid)	8
Ostracoda 1 (crustacea)	17	Ostracoda 1 (crustacea)	9	Bivalvia-no-Shell (bivalve)	12	*Spionidae* sp.2 (annelid)	4
Ischyroceridae 1 (crustacea)	15	Ischyroceridae 1 (crustacea)	8	Pseudozeuxoidae 1 (crustacea)	9	Corophiidae 1 (crustacea)	3
Lumbrineris sp.2 (annelid)	15	*Lumbrineris* sp.2 (annelid)	8	Apseudidae 1 (crustacea)	6	Platyischnopidae 1 (crustacea)	3
Ophiuroidea 1 (echinoderm)	14	Ophiuroidea 1 (echinoderm)	7	*Eunice* sp.1 (annelid)	5		

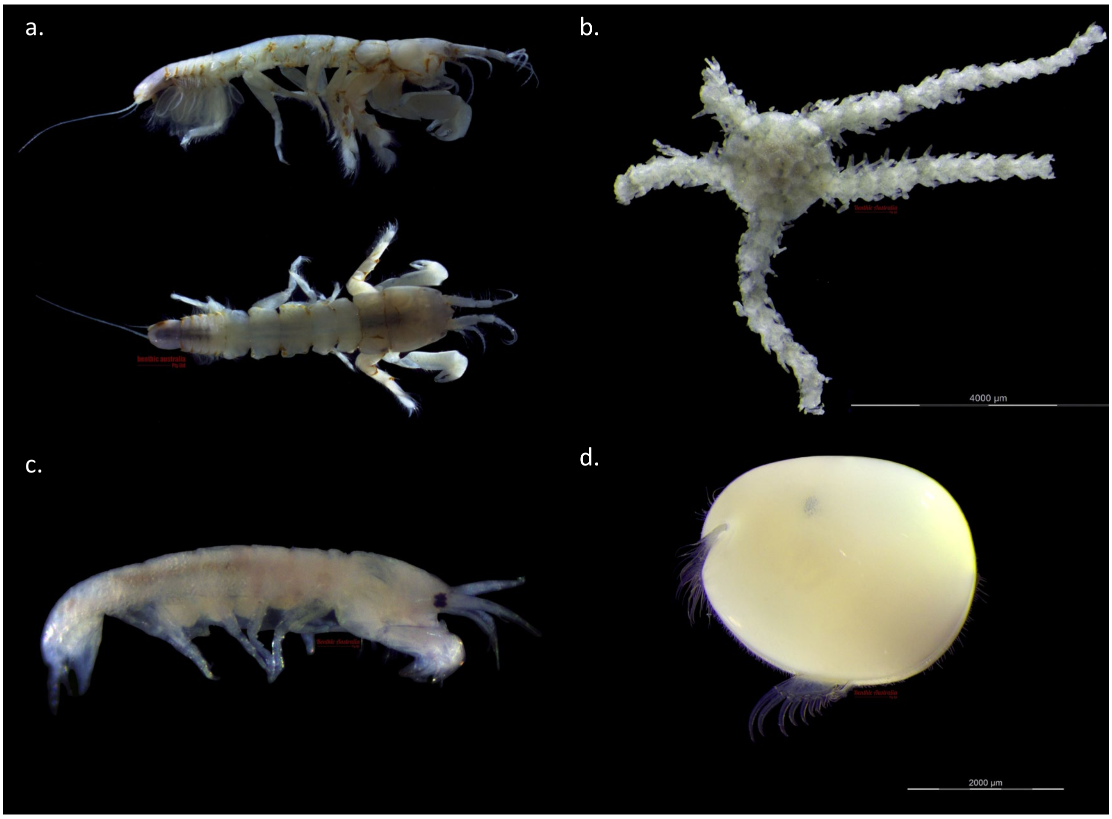

Figure 11. The four most common benthic invertebrate taxa sampled in the Port of Gladstone EBSDS, Apseudidae 1. (a), Ophiuroide 1. (b), *Pseudozeuxoidae* sp1 (c) and Ostracoda 1 (d).

Infauna communities showed few consistent patterns across locations or along transects from the EBSDS Species richness, and infauna and annelid abundance, varied across locations but there was no difference for species diversity, evenness and crustacean abundance (Table 5). Species richness was greater in the EBSDS and the east location than the control (p = 0.009 and 0.003 respectively) and west locations (p = 0.001 and 0.001 respectively) but there was no difference between the EBSDS and east location or control and west location (Figure 12, 13). There was an overall significant difference in invertebrate abundance across locations where abundances were higher in the EBSDS and east locations than the controls (p = 0.035 and 0.030 respectively) and west location (p = 0.018 and 0.013 respectively). Annelid abundance was greater in the east than the west locations (p = 0.016) but there were no other significant differences (Figure 12, 13).

Distance to the EBSDS along transects to the east and west had little effect in determining infauna communities. There was a significant interaction between location and distance to EBSDS for species richness and between annelid abundance and distance to the EBSDS but not for any other invertebrate measure (Table 5). Species richness declined as distance to the EBSDS increased in the east location (p = 0.024) but there was no difference in the west while there was an overall decrease in annelid abundance as distance to the EBSDS increased (Figure 14). However, the decline in both species richness and annelid abundance along the sampling transects was only small. Mean species richness at the Near Field Impact East site was the highest of all sites (16.25 species) but all other sites along the east transect ranged from 4.50 (NFIE 250) to 8.50 species per sample (NFIE 2000) while annelid abundance along the transects was below 5 species per sample except for NFIE where an average of 8.50 annelids where collected.

Table 5. General Linear Model results for models comparing locations across the survey area (A), the relationship with distance to the EBSDS in the east and west location (B) for each of the invertebrate variable measured (species richness, species diversity, species evenness, infauna abundance, annelid abundance, and crustacean abundance). Bold = significant (<0.05).

		Species Richness		**Species Diversity**		**Species Evenness**		**Infauna Abundance**		**Annelid Abundance**		**Crustacean Abundance**	
	df	LR ChiSq	P	LR ChiSq	P	LR ChiSq	P	LR ChiSq	P	LR ChiSq	P	LR ChiSq	P
Model Distribution		*Poisson*		*Gaussian*		*Gaussian*		*Negative Binomial*		*Negative Binomial*		*Negative Binomial*	
A. Location													
Location	3	30.88	**<0.001**	4.84	0.183	1.35	0.717	10.534	**0.015**	9.49	**0.023**	3.71	0.294
B. Distance to the EBSDS													
Location	1	19.73	**<0.001**	3.12	0.077	0.34	0.558	7.05	**0.008**	10.04	**0.005**	1.27	0.243
Distance to EBSDS	1	0.61	0.435	0.08	0.777	0.30	0.581	0.08	0.784	7.81	**0.002**	1.36	0.260
Location x Distance to EBSDS	1	6.77	**0.009**	3.80	0.051	0.83	0.362	1.32	0.251	0.01	0.927	0.23	0.630

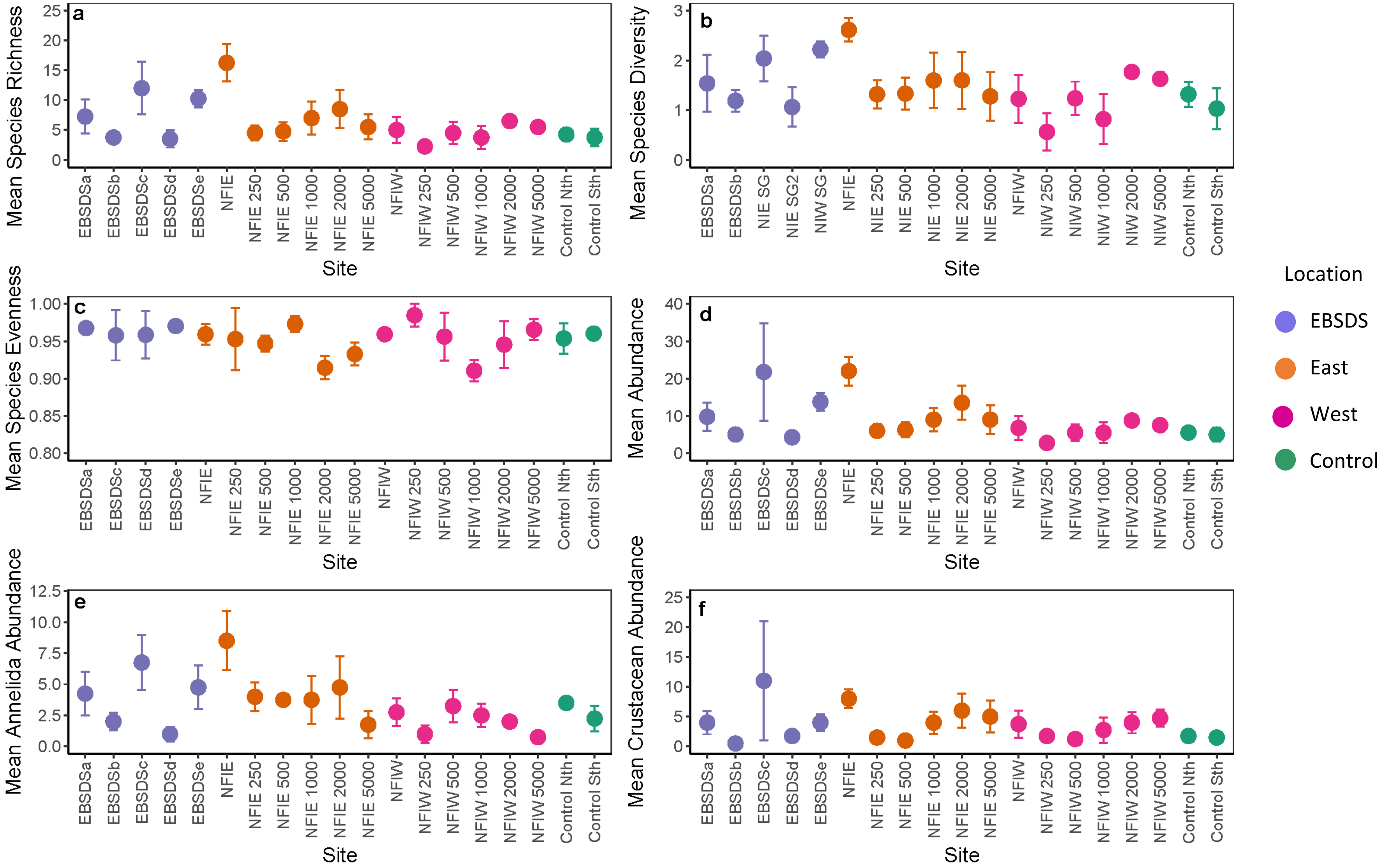

Figure 12. Mean (± SE) infauna species richness (a), species diversity (b), species evenness (c), abundance (d), annelid abundance (e) and crustacean abundance (f) at each site across the EBSDS survey area (EBSDS, east location, west location, control location).

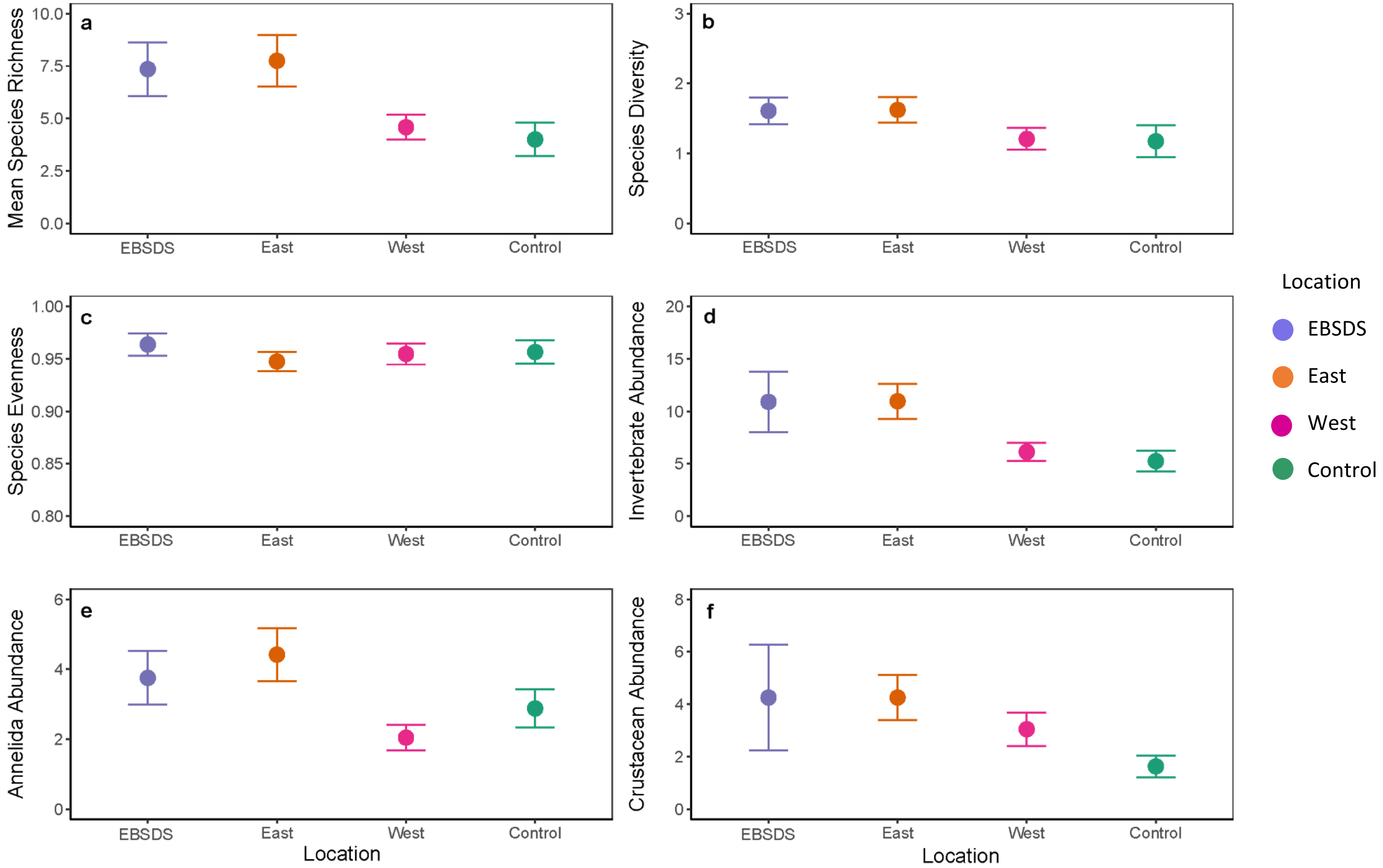

Figure 13. Mean (± SE) infauna species richness (a), species diversity (b), species evenness (c), abundance (d), annelid abundance (e) and crustacean abundance (f) within each survey location.

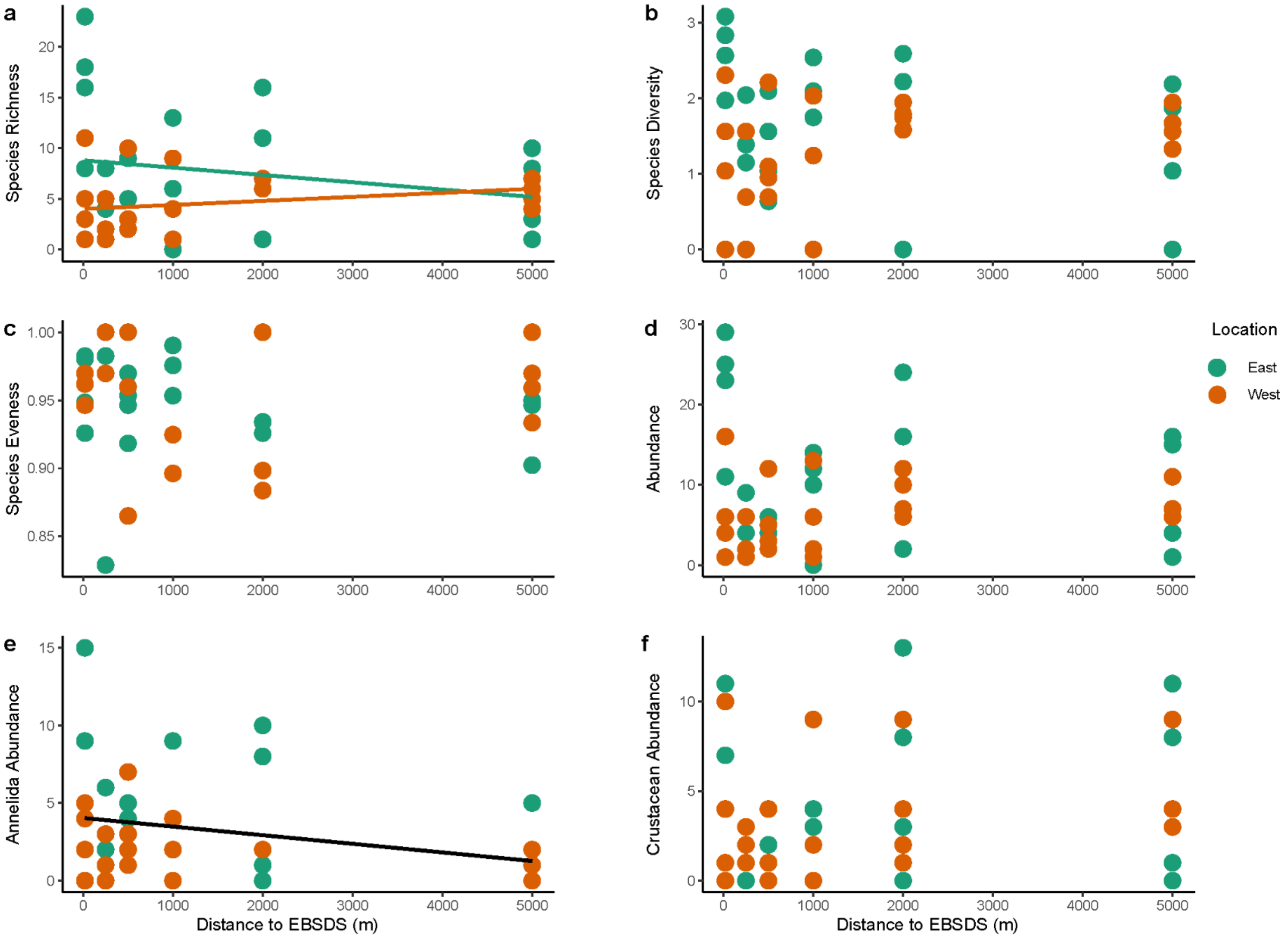

Figure 14. Relationship between infauna species richness (a), species diversity (b), species evenness (c), abundance (d), annelid abundance (e) and crustacean abundance (f) as distance to the EBSDS increases in the west and east locations.

3.4 Community Assemblages

Multivariate analysis found no difference in benthic infauna communities from locations across the EBSDS survey area ($F_{3, 15}$ = 389.5., p = 0.062, Figure 15). There was no clustering of sites from any of the locations although sites from locations in the west and controls tended to be on the left of the nMDS plot and those from the east and EBSDS on the right (Figure 15). Interestingly, the three sites where seagrass was recorded (NFIE 250, 500, 2000) are located in the bottom right of the plot. A dendrogram based on similarity across sites shows little similarity between sites within locations (Figure 16).

Figure 15. nMDS plot based on Bray Curtis dissimilarity for sites across the EBSDS survey area.

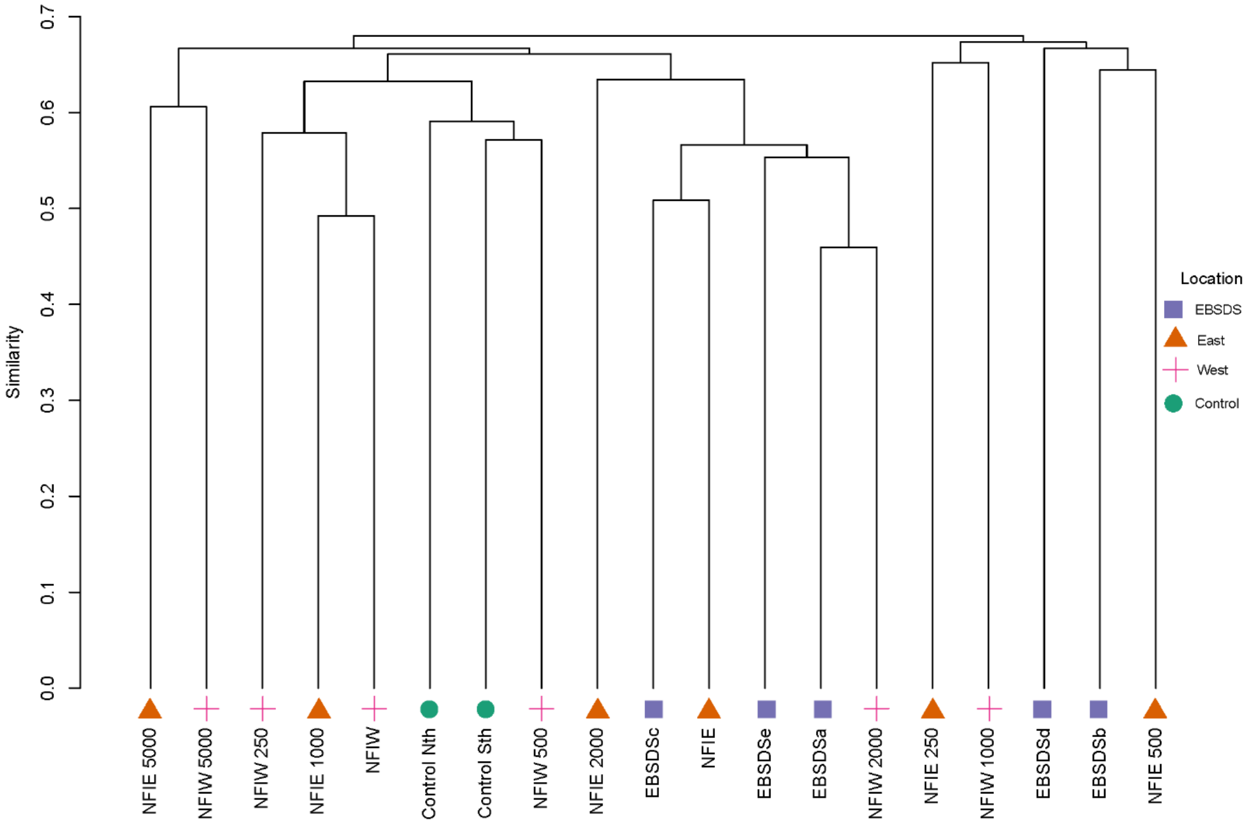

Figure 16. Similarity of sites across the EBSDS survey area based on Bray Curtis dissimilarity.

4 DISCUSSION

Seagrass was found throughout large areas of the PoG deep-water survey area including adjacent to the EBSDS. There was no pattern to indicate a gradient effect associated with proximity to the EBSDS on seagrass and little effect on infauna communities. Sediment composition changed across the survey area with a greater percentage of fine sediment in the EBSDS that declined as distance to the EBSDS increased.

4.1 Particle size analysis

Sediment particle size can be a major contributor to determining infauna composition and can impact seagrass condition (Bergen et al. 2001, Ferguson et al. 2016). Sediment consisted primarily of sand and there was higher proportion of fine and some gravel sediment in the EBSDS compared to the other locations. High gravel content in the EBSDS is consistent with previous surveys in 2012 and 2017 that found slightly higher gravel content in the EBSDS (1-20% sediment composition) and little gravel at sites outside the EBSDS (BMT 2012, Vision Environment 2017). Fine sediment content was higher in the EBSDS and near field impacts sites to the east of the EBSDS up to 1 km from the EBSDS (~25% fine sediment) relative to sites in the west and controls. Previous surveys have found no difference in fine sediment inside and outside the EBSDS but the range of fine sediment within the EBSDS was similar to this survey (4-30% fine sediment, BMT 2006, 2012, Vision Environment 2017).

Declining fine sediment composition away from the EBSDS, particularly in an easterly direction supports hydrodynamic modelling that predicts some increases in sedimentation to the east of the EBSDS but little to the west (BMT 2012). Fine sediments will move from the placement within the EBSDS to deeper water (Vision Environment 2017) and explains the higher proportion of fine sediment moving in an easterly direction away from the EBSDS.

4.2 Seagrass

Seagrass was found immediately to the east and north of the EBSDS but extended into only a very small area of the EBSDS. The meadow area mapped was over 4,000 ha and extended beyond the survey boundary. Seagrass has consistently occurred in this area in previous deep-water seagrass surveys but with spatial footprint and exact location varying between surveys. In 2013 and 2014 the survey boundary extended 10 – 18 km eastward from the PoG limits where a single large meadow covered between 20,000 (2013) and 25,000 ha (2014) east of the EBSDS (Smith et al. 2020). In 2009 and 2019 deep-water seagrass meadows have only been mapped to the port limit and may have been similar in area to this survey or those in 2013 and 2014. The presence of such large seagrass meadows in close vicinity to the EBSDS consistently over the previous 12 years suggest dredge material placement in the EBSDS is not having a measurable impact on deep-water seagrass distribution in the PoG.

Seagrass biomass in the EBSDS survey area was typical of deep-water *Halophila* species in Queensland and Gladstone, having a mean of 0.20 ± 0.20 g DW m^2 ranging from 0.01 to 3.56 g DW m^2 with only two sites greater than 1.00 g DW m^2. Biomass was similar to previous Gladstone deep-water seagrass surveys in 2014 (0.01 to 3.20 g DW m^2) and greater than in 2019 (0.01 – 0.77 g DW m^2), 2013 (0.04 – 0.54 g DW m^2), 2009 (0.00 –0.09 g DW m^2) and 2002 (0.01 – 0.17 g DW m^2) (Smith et al. 2020). Compared to other deep-water seagrass surveyed recently in Queensland the biomass was similar to deep-water meadows in Hay Point (0.96 – 1.35 g DW m^{-2}, York and Rasheed 2020), Abbot Point (0.55 – 2.64 g DW m^{-2}, Van De Wetering et al. 2020) and Bundaberg (0.06 – 3.69 g DW m^2, Smith and Rasheed 2021a). The relatively high seagrass biomass recorded within the PoG deep-water survey area suggest that seagrass there are in good condition relative to other similar seagrass in North Queensland.

Deep-water *Halophila* species are largely ephemeral colonising species that change rapidly in response to light conditions (Chartrand et al. 2018). Relatively high seagrass biomass in this survey may reflect improved conditions for seagrass establishment and growth. Greater seagrass biomass and area seen in 2021 deep-water seagrass reflects broader trends in coastal and deep-water seagrass across north Queensland over the previous five years, that have seen high biomass and meadow area in response to below average rainfall and improved water clarity (Reason et al. 2022; Smith et al. 2021, 2022).

Deep-water seagrasses like those surrounding the PoG EBSDS are ephemeral and highly variable in both space and time creating a level of difficulty for monitoring and interpreting changes (Chartrand et al. 2018; York et al. 2015). Monitoring benthic habitats within and surrounding the EBSDS are designed to determine any impacts of dredge material placement on seagrass and benthic infauna. Effects of dredge material placement will be difficult to detect given the ephemeral nature of deep-water seagrass and benthic communities and changes need to be interpreted with caution. Undertaking EBSDS benthic monitoring in conjunction with the broader port wide seagrass monitoring survey every five years allows benthic habitats to be compared over a broader area and provide a greater ability to detect potential change in seagrasses associated with the EBSDS. We recommend that future PoG EBSDS surveys be coupled with the broader port wide seagrass survey to improve ability to interpret seagrass condition and detect any changes associated with the EBSDS.

4.3 Infauna Composition

Benthic infauna communities are regarded as indicators of ecosystem health and provide a number of important functions such as nutrient cycling and forming the basis of marine food webs (Ieno et al. 2006). Dredge material placement can affect benthic infauna composition through smothering, contamination and changes to sediment condition resulting in reduced diversity, abundance and altered species composition (Bolam et al 2016, Do et al. 2012). Infauna species composition and abundance in and surrounding the PoG EBSDS were highly variable and there were few significant differences between sampling locations and no clear pattern to indicate an influence of the EBSDS outside of the designated EBSDS boundary. Infauna in the EBSDS and to the east of the EBSDS showed similar patterns generally having higher richness and abundance than in the west or control locations. Species richness and annelid abundance were lower further from the EBSDS but the difference were only very small. The lack of spatial differences inside and outside the EBSDS suggest dredge material placement is not having any detectable impact on infauna communities.

Previous surveys have used a variety of survey designs and methods making direct comparisons of infauna between surveys difficult. Infauna have been sampled at pre and post wet season (2016/2017 survey), pre and post dredge (2005 survey) and multiple sampling pre and post dredging (2011 survey), and, at different spatial scales to include impacted locations in the EBSDS and controls (2005 survey), impacted EBSDS, near impact and control locations (2010/20111 survey) and locations in the EBSDS, controls and transect sites to the east and west of the EBSDS (2016/2017 survey). Sediment grabs were used to sample invertebrates in each survey however the volume of the grab varied from 0.008 m^3 (2016/2017) to 0.10 m^2 (2005) but was unspecified in 2012. Our survey followed a similar survey design to 2017 and included sites in the EBSDS, controls, and near field impact sites to assess any direct impacts of dredge material placement, and, transects to the east and west of the EBSDS to assess the spatial extent of dredge material placement outside the EBSDS. Infauna assemblages in previous surveys were highly variable across sampling times and there were no patterns before or after dredging or between seasons. Therefore, sampling was only undertaken at one time point in this survey. Fewer species, families and individuals were collected in this survey than previous surveys which can be explained by lower sampling timepoints and replicates.

Patterns of infauna community distribution across the EBSDS survey area from previous surveys are generally highly variable and shown little difference between sites within the EBSDS and control or near field impact sites (BMT 2007, 2012, Vision Environment 2017). The previous surveys in 2016/2017 found species richness and abundance was generally lower in the EBSDS than sites to the east and west but were not different to control north and south sites (Vision Environment 2017). Similarly, in the 2005 and 2010/2011 surveys there was no differences in species richness and abundance between the infauna from sites in the EBSDS and control or near field impact sites (BMT 2007, 2012). Broadly similar patterns in species richness, diversity and abundance across this survey and previous surveys suggest dredge material placement in the EBSDS is having little detectable effect on the infauna communities.

Seagrass presence can alter infauna community assemblages and generally have greater infauna diversity and abundance than bare habitats (Webster et al. 1998, Casares and Creed 2008, Barnes 2020). These patterns are commonly observed in large growing seagrass species but are also true for small seagrass genera such as *Halophila,* although there has been little research in deep-water *Halophila* meadows (Smith et al. 2021, Barnes 2020, Casares and Creed 2008). At the Port of Bundaberg dredge material placement area the presence of seagrass contributed to more diverse and abundant infauna communities (Smith and Rasheed 2021b). Seagrass was recorded in only three infauna sampling sites in the EBSDS survey and there was no difference in species richness, diversity and abundance relative to the other sites. Seagrass biomass at sites surrounding the EBSDS was low and therefore may not have been able to sustain higher infauna diversity and abundance compared to the Bundaberg dredge material placement area. These sites were however located close together in the MDS plot suggesting that they had similar communities relative to the other sites in the survey without having higher diversity.

There was no evidence that sediment deposition in the EBSDS was having a measurable effect on benthic habitats surrounding the EBSDS. Fine sediment was higher in the EBSDS than outside the EBSDS but it was only significantly higher than sites sampled to the west of the EBSDS ad while there was no seagrass within the EBDS there was a large meadow directly to the east of the EBSDS boundary. Infauna diversity and abundance was high inside the EBSDS but comparable to sites east of the EBSDS and there was no evidence of impacts of dredge material on sediment infauna or seagrass occurring outside the EBSDS regardless of the proximity to the EBSDS. Given the high level of seasonal and inter-annual spatial variability in deep-water seagrasses, we suggest that future EBSDS assessments continue incorporate the broader deep-water habitat of the PoG to ensure a clearer picture of seagrass change and comparability to historical seagrass surveys.

5 REFERENCES

Abal, E. G., and Dennison, W. C. (1996). Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia. Marine and Freshwater Research, **47**(6), 763–771.

Barnes, R. S. K. (2020). Do different sympatric seagrasses support macrobenthic faunas of differing composition, abundance, biodiversity or patchiness? Marine Environmental Research, **160**, 104983.

Barton, K. (2020). MuMIn: Multi-Model Inference. R package version 1.43.17. https://CRAN.R-project.org/package=MuMIn

Bates, D., Mächler, M., Bolker, B. and Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, **67**(1), 1-48.

Bergen, M., Weisberg, S., Smith, R., Cadien, D. B., Dalkey, A., Montange, D. E., Strull, J. K., Velarde, R. G. and Ranasinghe, J. A. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology **138,** 637--647.

BMT WBM (2006). Benthic macroinvertebrate monitoring – Port of Gladstone dredged material ocean disposal site. Brisbane, QLD, Australia 53 pp.

BMT WBM (2012). Port of Gladstone offshore disposal monitoring program. Brisbane, QLD, Australia, 132 pp.

Bolam, S. G., McIlwaine, P. S. O., and Garcia, C. (2016). Application of biological traits to further our understanding of the impacts of dredged material disposal on benthic assemblages. Marine Pollution Bulletin, **105**(1), 180-192.

Casares, F. A. and Creed, J. C. (2008). Do small seagrasses enhance density, richness and diversity of macrofauna? Journal of Coastal Research **24**(3), 790--797.

Chartrand, K. M., Szabó, M., Sinutok, S., Rasheed, M. A. and Ralph, P. J. (2018). Living at the margins – The response of deep-water seagrasses to light and temperature renders them susceptible to acute impacts. Marine Environmental Research, **136**, 126-138.

Chartrand, K., Bryant, C., Carter, A., Ralph, P.,and Rasheed, M. (2016). Light thresholds to prevent dredging impacts on the Great Barrier Reef seagrass, *Zostera muelleri* spp. *capricorni*. Frontiers in Marine Science, **3**(17).

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., and Turner, R. K. (2014). Changes in the global value of ecosystem services. Global Environmental Change, **26,** 152-158.

Cribari-Neto, F. and Zeileis, A. (2010). Beta regression in R. Journal of Statistical sSoftware, **34**(2), 1-24.

Culhane, F. E., C. L. J. Frid, E. Royo Gelabert, L. White, and L. A. Robinson (2018). Linking marine ecosystems with the services they supply: what are the relevant service providing units? Ecological Applications, **28**(7), 1740 – 1751.

Dauvin, J. C., Alizier, S., Rolet, C., Bakalem, A., Bellan, G., Gesteira, J. G., Grimes, S., de-la-Ossa-Carretero, J. A. and Del-Pilar-Ruso, Y. (2012). Response of different benthic indices to diverse human pressures. Ecological Indicators, **12**(1), 143-153.

Dennison, W., Orth, R., Moore, K., Stevenson, J., Carter, V., Kollar, S., Bergstrom, P. and Batiuk, R. (1993). Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health. BioScience, **43,** 86-94.

Do, V. T., de Montaudouin, X., Blanchet, H. and Lavesque, N. (2012). Seagrass burial by dredged sediments: Benthic community alteration, secondary production loss, biotic index reaction and recovery possibility. Marine Pollution Bulletin, **64**(11), 2340-2350.

Ferguson, A. J., R. K. Gruber, M. Orr and P. Scanes (2016). Morphological plasticity in *Zostera muelleri* across light, sediment, and nutrient gradients in Australian temperate coastal lakes. Marine Ecology Progress Series **556,** 91-104.

Hayes, M. A., McClure, E.C., York, P.H., Jinks, K.I., Rasheed, M.A., Sheaves, M. and Connolly, R.M. (2020). The Differential Importance of Deep and Shallow Seagrass to Nekton Assemblages of the Great Barrier Reef. Diversity, **12**(8), 292.

Harvey, M., Gauthier, D. and Munro, J. (1998). Temporal changes in the composition and abundance of the macro-benthic invertebrate communities at dredged material disposal sites in the Anse-a-Beaufils, Baie des Chaleurs, eastern Canada. Marine Pollution Bulletin **36**, 41-55.

Hemminga, M. A. and Duarte, C. M. (2000). *Seagrass Ecology*. Cambridge, Cambridge University Press.

Ieno, E. N., Solan, M., Batty, P., and Pierce, G. J. (2006). How biodiversity affects ecosystem functioning: roles of infaunal species richness, identity and density in the marine benthos. Marine Ecology Progress Series, **311**, 263-271.

Jones, A. R. (1986) The effects of dredging and spoil disposal on macrobenthos, Hawkesbury Estuary, NSW. Marine Pollution Bulletin **17**, 17-20.

Lenth R. (2020). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.5.2-0010002.

Mellors, J. E. (1991). An evaluation of a rapid visual technique for estimating seagrass biomass. Aquatic Botany, **42,** 67-73.

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. M., Szoecs E. and Wagner H. (2020). vegan: Community Ecology Package. R package version 2.5-7.

Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J., Olyarnik, S., Short, F. T., Waycott, M. and Williams, S. L. (2006). A global crisis for seagrass ecosystems. BioScience, **56**, 987-996.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reason C. L., York P. H. and Rasheed M.A. (2022). Seagrass habitat of Cairns Harbour and Trinity Inlet: Cairns Shipping Development Program and Annual Monitoring Report 2021. JCU Publication, Centre for Tropical Water & Aquatic Ecosystem Research Publication 22/03, Cairns.

Smith, S. D., and Rule, M. J. (2001). The effects of dredge-spoil dumping on a shallow water soft-sediment community in the Solitary Islands Marine Park, NSW, Australia. Marine Pollution Bulletin, **42**(11), 1040-1048.

Smith T. M., Chartrand K. M., Wells J. N. Carter A. B., and Rasheed M. A. (2020). Seagrasses in Port Curtis and Rodds Bay 2019 Annual long-term monitoring and whole of port survey. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 20/02, James Cook University, Cairns, 71 pp.

Smith T. M., Reason C., McKenna S., and Rasheed M. A. (2021). Seagrasses in Port Curtis and Rodds Bay 2019: Annual long-term monitoring and whole of port survey. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 20/02, James Cook University, Cairns, 54 pp.

Smith T. M. and Rasheed M. A. (2021a). Port of Bundaberg seagrass baseline survey 2020. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 21/07, James Cook University, Cairns, 21 pp.

Smith T. M. and Rasheed M. A. (2021b) Port of Bundaberg spoil ground seagrass and benthic fauna survey 2020. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 21/08, James Cook University, Cairns, 40 pp.

Smith T. M., Reason C., McKenna S. and Rasheed M. A. (2022). Seagrasses in Port Curtis and Rodds Bay 2021 annual long-term monitoring. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 21/14, James Cook University, Cairns, 54 pp.

Van De Wetering C., York P.H., Reason C.L., Wilkinson J. and Rasheed M.A (2020). Port of Abbot Point long-term seagrass monitoring program - 2019', JCU Publication 20/12, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns. 46 pp.

Vision Environment (2017). Port of Gladstone East Banks Sea Disposal Site macroinvertebrate monitoring program 2016/2017. Vision Environment, Gladstone, QLD, Australia. 41 pp.

Webster, P. J., Rowden, A. A. and Attrill M. J. (1998) Effect of shoot density on the infaunal macro-invertebrate community within a *Zostera marina* seagrass bed. Estuarine, Coastal and Shelf Science **47**, 351-357.

Wang, Y, Naumann, U, Wright, S. T and Warton, D. I. (2012). mvabund– an R package for model-based analysis of multivariate abundance data. Methods in Ecology and Evolution, **3**(3), 471-474.

York, P.H., Carter, A.B., Chartrand, K., Sankey, T., Wells, L., Rasheed, M.A. (2015). Dynamics of a deep-water seagrass population on the Great Barrier Reef: annual occurrence and response to a major dredging program. Scientific Reports, **5**(1), 1-9.

York, P. H., Reason, C., Scott, E. L., Sankey, T. and Rasheed, M. A. (2016). Seagrass habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring Report 2015. Cairns, Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) Publication 16/13, James Cook University, 58 pp.

York P. H and Rasheed M. A (2020). Annual seagrass monitoring in the Mackay-Hay Point Region – 2019, JCU Centre for Tropical Water & Aquatic Ecosystem Research Publication 40 pp.

Appendix 1. Queensland ports seagrass monitoring program

A long-term seagrass monitoring and assessment program is established in the majority of Queensland's commercial ports. The program was developed by the Seagrass Ecology Group at James Cook University's (JCU) Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) in partnership with the various Queensland port authorities. A common method and rationale provides a network of seagrass monitoring locations comparable across the State (Figure A1).

A strategic long-term assessment and monitoring program for seagrass provides port managers and regulators with key information for effective management of seagrass habitat. This information is central to planning and implementing port development and maintenance programs to ensure minimal impact on seagrass.

The program provides an ongoing assessment of many of the most vulnerable seagrass communities in Queensland, and feeds into regional assessments of the status of seagrass. The program provides significant advances in the science and knowledge of tropical seagrass ecology. This includes the development of tools, indicators, and thresholds for the protection and management of seagrass, and an understanding of the reasons for seagrass change.

Figure A1. Location of Queensland ports where seagrass monitoring occurs. Red dots: long-term monitoring; blue dots: baseline mapping only.

For more information on the program and reports from other monitoring locations see www.tropwater.com/project/management-of-ports-and-coastal-facilities/