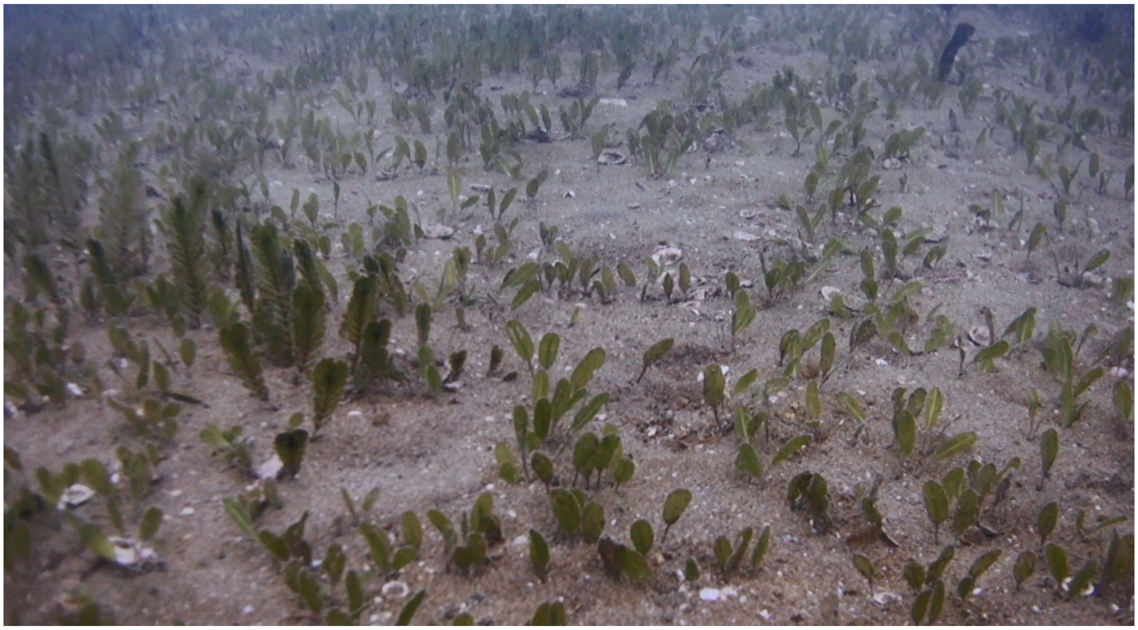

# Port of Bundaberg Spoil Ground Seagrass and Benthic Fauna Survey 2020

Smith TM & Rasheed MA
Report No. 21/08
May 2021

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## A Report for Gladstone Ports Corporation

### Report No. 21/08

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# KEY FINDINGS

1. Seagrasses and benthic infauna at the Port of Bundaberg spoil ground were surveyed between the 27th –30th of October 2020 in conjunction with a whole port survey.

2. There was no evidence that sediment deposition in the Port of Bundaberg spoil ground was having any measurable effect on benthic habitats surrounding the spoil ground.

3. Seagrass was found at all sites sampled both inside and outside the spoil ground and was part of a large deep-water meadow consisting of the species *Halophila decipiens*, *H. ovalis* and *H. spinulosa*.

4. Seagrass cover was sparse to moderate and mean biomass was low (0.83 ± 0.15 g DW $m^{-2}$) typical of deep-water seagrass species found throughout North Queensland. Seagrass biomass was not significantly different inside the spoil ground compared to outside the spoil ground or as distance to the spoil ground increased.

5. More sites had seagrass in 2020 than the previous survey in 2015 but seagrass cover was lower than in 2015.

6. A total of 924 benthic invertebrates were collected belonging to 103 taxa including 10 phyla and 88 families.

7. Polychaetes were the most common taxa followed by crustaceans. These two groups represented 85% of the invertebrates sampled.

8. Infauna communities were more diverse and abundant outside the spoil ground but there was no relationship as distance to the spoil ground increased.

9. There was a positive relationship between seagrass biomass and infauna diversity and abundance throughout the survey area.

10. Infauna assemblages were more diverse than previous surveys in 2015 and 2011 but may be related to different sampling techniques across surveys. Overall abundance and distribution was similar.

11. Sediment was dominantly sand across the survey area. Fine sediment contributed below 5% to the sediment composition. There was no difference in sediment condition inside and outside the spoil ground. These patterns are similar to surveys in 2011 and 2015.

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

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AIC | Akaike Information Criteria |
| dbMSL | Depth below Mean Sea Level |
| DW | Dry Weight |
| GIS | Geographic Information System |
| GLM | General Linear Model |
| GPC | Gladstone Ports Corporation |
| GPS | Global Positioning System |
| JCU | James Cook University |
| LTMMP | Long Term Monitoring and Management Plan |
| MSQ | Maritime Safety Queensland |
| nMDS | nonmetric Multi-Dimensional Scaling |
| PoB | Port of Bundaberg |
| SIMPER | Similarity Percentage |
| TropWATER | Centre for Tropical Water & Aquatic Ecosystem Research |

# 1 INTRODUCTION

The Port of Bundaberg (PoB) is located at the mouth of the Burnett River approximately 14 km from the City of Bundaberg and is managed by Gladstone Ports Corporation (GPC). Sediment loads from the Burnett River in the channels, swing basin and defined operational footprint need to be dredged as required to permit shipping access. Dredge spoil from the PoB swing basin and channel is disposed of in a designated spoil ground approximately 8 km offshore from the port entrance within the port limits, and has been in operation since 1994. The sediments are tested as part of a sediment analysis plan (SAP) every five years to ascertain that they are suitable for sea disposal in line with the national assessment guidelines for dredging (NAGD). The last SAP confirmed previous results showing that sediment removed from PoB channels are suitable for sea disposal. As part of the Long Term Monitoring and Management Plan (LTMMP) for maintenance of dredging at PoB, GPC commenced spoil ground monitoring in 1995 and is required to undertake an assessment of the benthic habitat inside the spoil ground and to the north and east of the spoil ground within the port limits every five years.

Deep-water areas such as those in the PoB can provide important habitats for flora and fauna. Deep-water seagrasses found within the PoB limits may harbour diverse fish and benthic infauna assemblages (AMA 2015, 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). 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 spoil 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). Previous assessments of the PoB spoil ground in 2011 and 2015 found absent or sparse seagrass (*Halophila spinulosa*) within the spoil ground, and moderate to dense *H. spinulosa* and *H. ovalis* in the area surrounding the spoil ground. Infauna assemblages showed similar patterns, being less diverse and abundant within the spoil ground compared with the surrounding area.

## 1.1 Objectives and scope of the environmental assessment

This monitoring survey was developed for the PoB to investigate the potential impacts of sea dumping activities on benthic habitats; specifically, benthic infauna and seagrass. The survey was designed in accordance with Section 11 of the PoB LTMMP. Additional habitat mapping and analysis was also conducted as part of a separate study to allow comparisons to other ports and place the PoB spoil ground in a broader regional context (Smith & Rasheed 2021). The last spoil ground assessment was undertaken in 2015 and this report fulfils the 5-yearly report requirement in the LTMMP for 2020.

Our primary objectives were to:

- Compare the spoil ground with nearby benthic habitats to assess any impacts of spoil disposal;
- Determine if impacts in the spoil ground diminish with distance from the spoil grounds

Additionally, we:

- Compare temporal variation in benthic habitat and infauna to previous surveys of the PoB spoil ground, and
- Discuss the PoB spoil grounds in the context of the wider PoB and northern Queensland seagrass.

# 2 METHODS

## 2.1 Field surveys

Survey and monitoring methods across the PoB spoil ground survey area combine methods outlined in the PoB LTMMP (WorleyParsons 2012) and those used in the established long-term seagrass monitoring and assessments for other Queensland ports conducted by TropWATER JCU, including Cairns, Mourilyan Harbour, Townsville, Abbot Point, Gladstone, Mackay, Weipa, Karumba and Thursday Island.

The area was surveyed October 27th - 30th 2020. Sampling was done at three locations within the PoB port limits, the spoil ground and locations to the north and east. At each location five sites were sampled. Sites in the north and east location were sampled in transects perpendicular to the spoil ground in a northerly and easterly direction aligned with the prevailing coastal transport flow, as specified in the LTMMP (Figure 1). All sites are sampled at the same GPS coordinates as previous surveys.

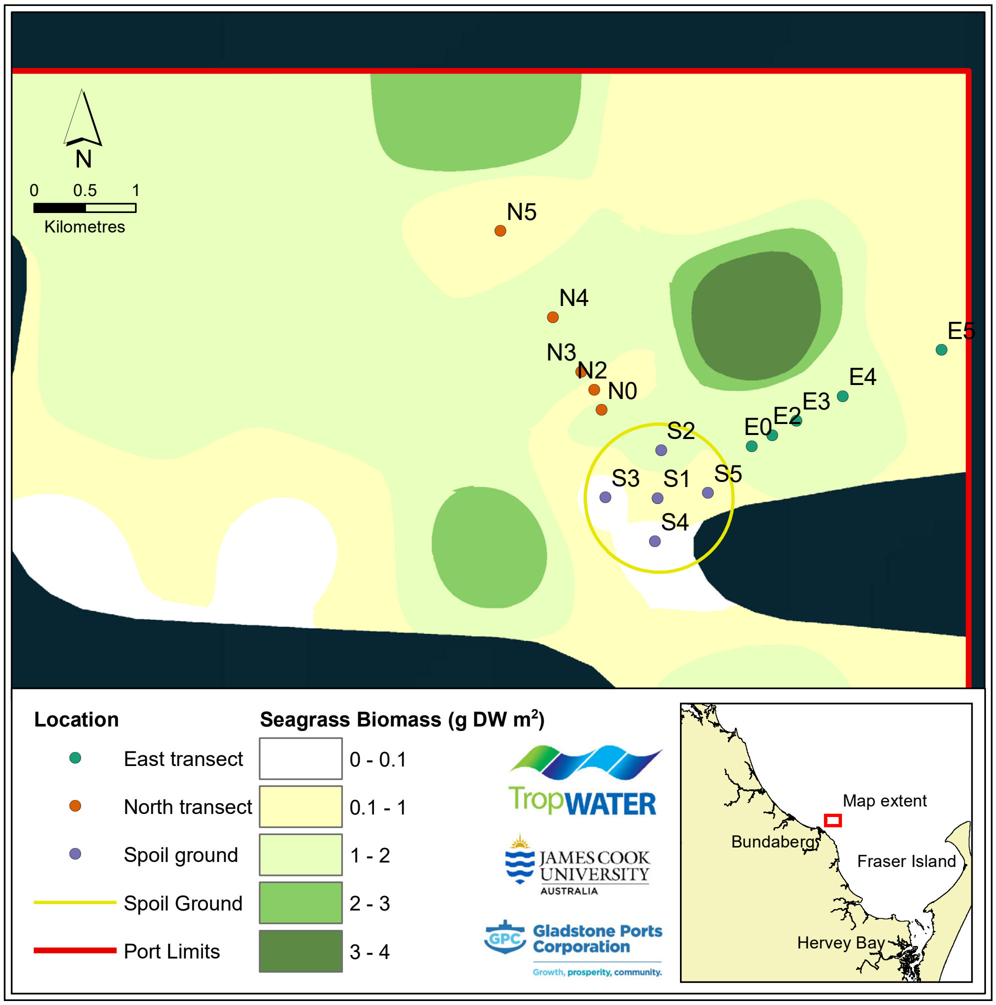

**Figure 1.** Port of Bundaberg port limits, spoil ground, seagrass and benthic infauna survey sites (S = spoil ground; N = north location, E = east location), and seagrass meadow biomass (from Smith and Rasheed 2021).

## 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 conducted. Previous monitoring used 9.5 cm diameter, 15 cm deep sediment cores for benthic sampling. Grabs are a more efficient benthic sampling method that sample a greater volume of sediment but smaller depth than sediment cores. To make the area of sediment sampled more comparable between grabs in this survey and cores in previous surveys each infauna sediment grab was divided horizontally (8.25 cm x 17.5 cm) and one section kept for processing.

Sediment infauna samples were sieved to 1 mm and preserved in 95% ethanol. In the laboratory all macroinvertebrates were identified to the lowest taxonomic level possible and counted at Benthic Australia. Sediment grain size samples were processed at the NATA accredited 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 2). 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 (MSL), and time and location (latitude/longitude using Global Positioning System) were also recorded.

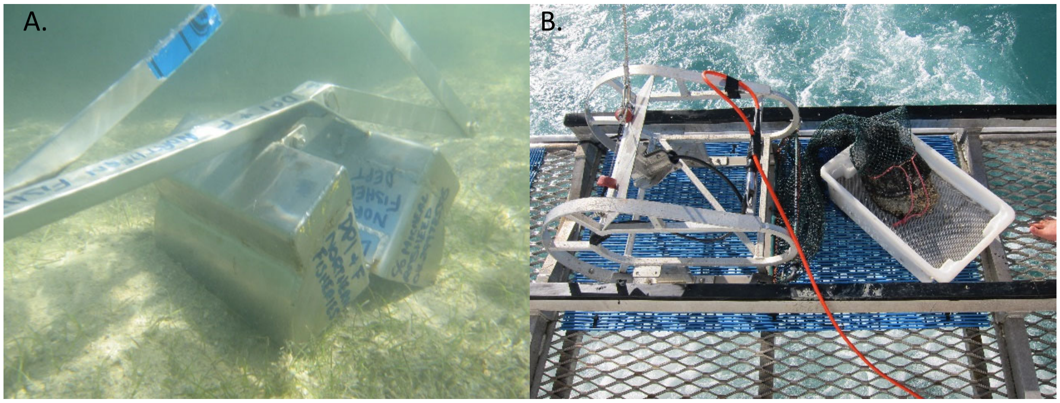

**Figure 2**. (A) Van Veen grab used for sampling benthic infauna and sediment, and (B) video sled and net used to sample seagrass.

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 an approximate 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. Field 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. 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 PoB spoil ground were compared using a range of univariate and multivariate analysis. The following response variables were modelled using two separate General Linear Models (GLM): Seagrass biomass (Gaussian distribution), 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 three sampling locations (spoil ground, north location, east location).
- Variation in the response variable with distance to the spoil ground between transects in the north and east locations.

A third GLM was conducted to compare benthic infauna variables (species richness, diversity, evenness and infauna abundances) and seagrass biomass across all sites to assess the role of seagrass in determining infauna distribution. Previous surveys have not measured seagrass biomass directly preventing direct comparisons between infauna and seagrass but we have included it in this survey as benthic infauna diversity and abundance in the PoB may have a relationship with seagrass biomass.

GLMs was 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). Model selection process was conducted to determine the best-fit model for each analysis. Akaike Information Criteria (AIC) was used to compare all possible subsets of the global (full) model using the R package *MuMin* (Barton 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 spoil ground. A non-metric multidimensional scaling (nMDS) plot was constructed from a Bray-Curtis dissimilarity matrix using location as a factor to visual differences in infauna assemblages. Assemblages across locations were compared using PERMANOVA analysis and a dendrogram of similarities was constructed from the dissimilarity matrix to visualise the similarity between sites in each location. All multivariate analysis was done using the *vegan* package in R (Oksanen et al. 2020).

Benthic infauna were compared between sampling year, locations inside and outside the spoil ground and distance to the spoil ground using GLM model selection. In order to standardise the data across surveys families were compared to allow for inconsistencies in identification of species and abundance scaled to metres squared ($m^2$) to account for the different sampling methods used in each survey. Family richness and abundance were compared across years and locations and a second analysis done comparing year, location and distance to the spoil ground for the north and east transect.

# 3 RESULTS

## 3.1 Sediment Particle Size

Sediment across survey sites consisted predominantly of sand regardless of location or distance to the spoil ground (Figure 3). Analysis comparing locations found there was no significant difference across any of the locations for any of the sediment grain sizes (Table 1A). Fine sediment (<75 µm) including clay and silt was low at all sites and contributed between 2% and 9% of the sediment composition. The highest contribution of fine sediment was found in the spoil ground (9% at site S2), but all other sites within the spoil ground were below 5% fine sediment, similar to sites outside the spoil ground. The contribution of gravel (>2 mm) to the sediment composition was more variable ranging from 1% to 21% but there were no consistent patterns across locations. The best model to describe fine sediment as distance to the spoil ground increased included only the intercept signifying no significant relationship (Table 1, Figure 4). The best model to describe the percentage of sand increased with distance from the spoil ground. Accordingly, the best model for the percentage of gravel decreased with distance to the spoil ground (Table 1B, Figure 4).

The composition of sediment at and surrounding the spoil grounds showed contrasting patterns over time (Figure 5). Gravel contributed greater percentage to the sediment in the spoil ground in 2011 and 2015 than in 2020 when sand had greater contribution. The percentage of fine sediment in the sediment was low in all years.

**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 spoil ground in the north and east locations (B). Bold = significant ($p < 0.05$)

| | | Fine Sediment | | Sand | | Gravel | |
|---|---|---|---|---|---|---|---|
| **A. Location** | Df | LR ChiSq | P | LR ChiSq | P | LR ChiSq | P |
| Location | 2 | 1.521 | 0.468 | 3.01 | 0.222 | 2.804 | 0.246 |
| **B. Distance to Spoil Ground** | | | | | | | |
| Distance to SG | 1 | | | 8.85 | **0.003** | 10.258 | **0.001** |

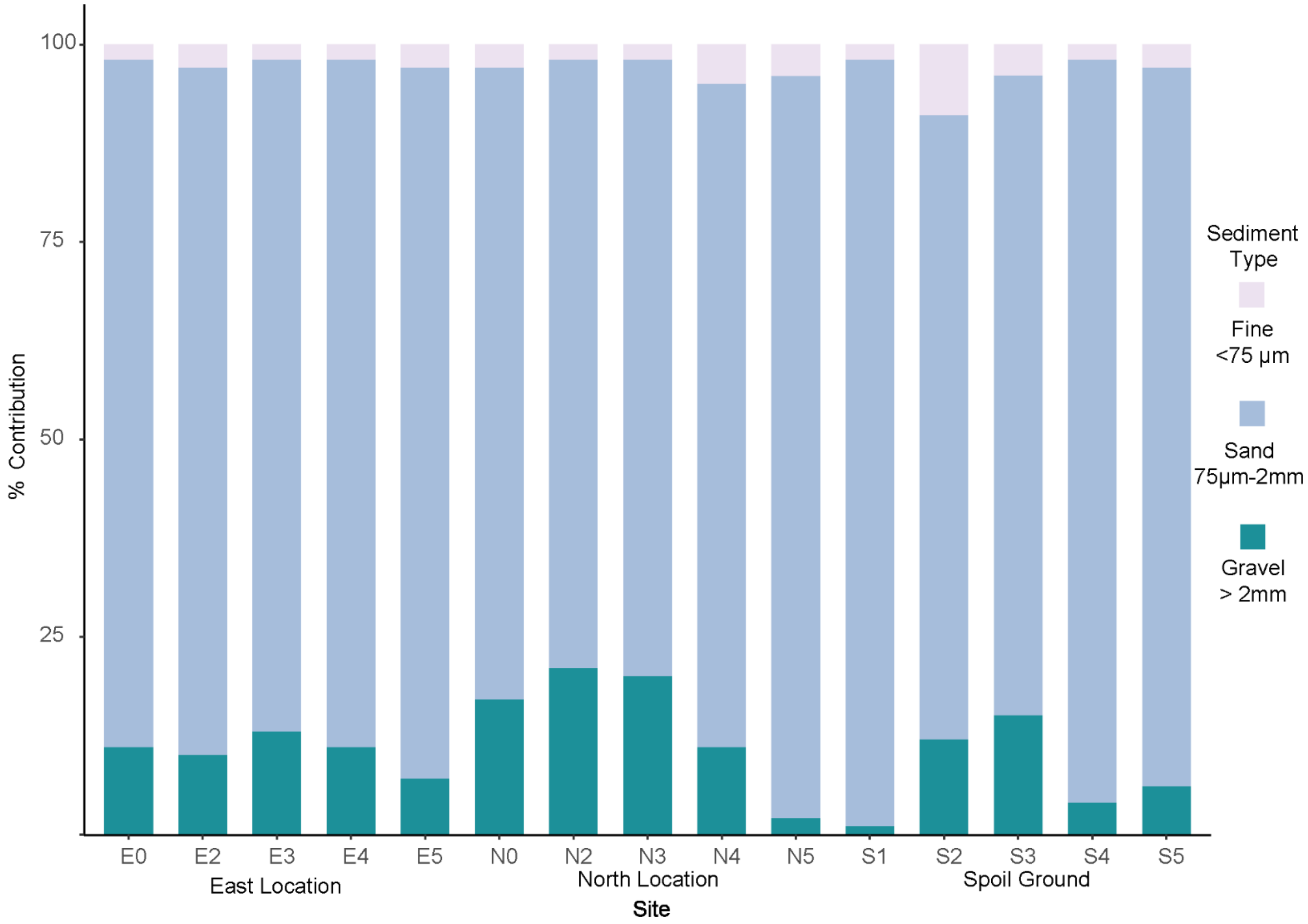

**Figure 3**. Proportion of fine sediment (<75 µm), sand (75 µm – 2 mm) and gravel (>2 mm) at sites in the Port of Bundaberg.

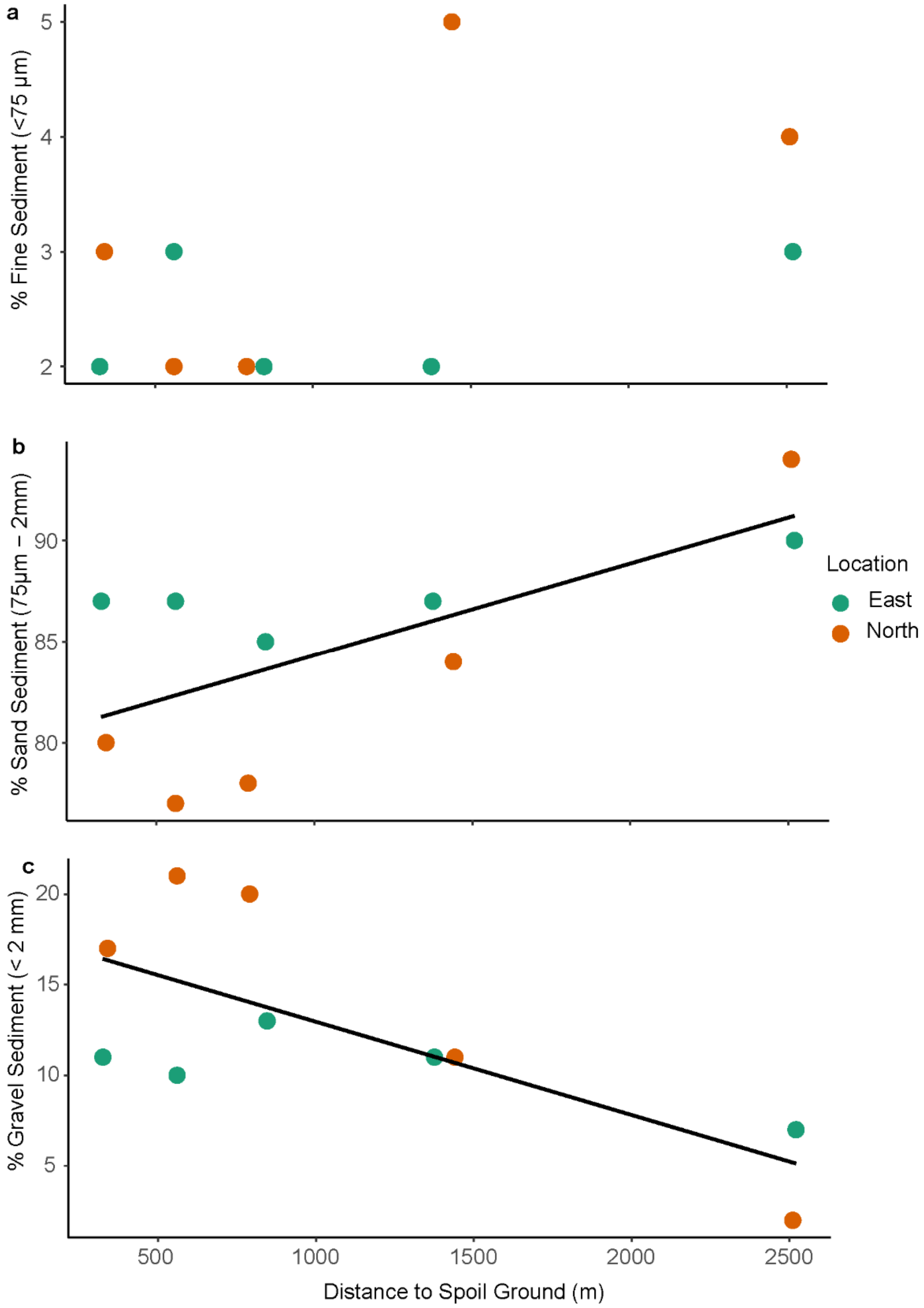

**Figure 4**. Change in percentage of (a) fine sediment (<75 µm), (b) sand (75 µm – 2 mm) and (c) gravel (> 2 mm) in the north and east locations as distance to the spoil ground increases. Lines represent significant relationships.

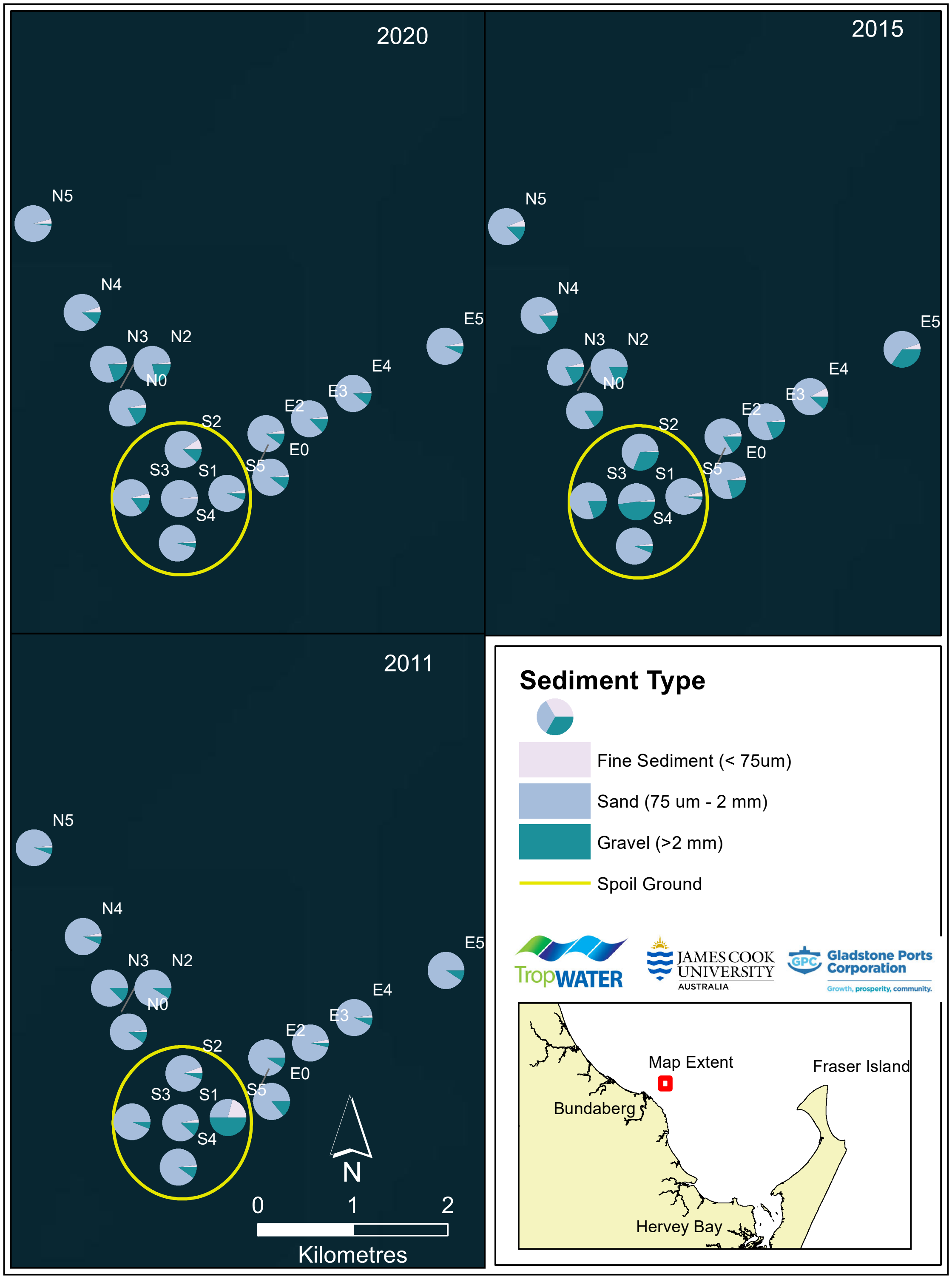

**Figure 5**. Sediment composition across the survey area at the Port of Bundaberg spoil ground in 2020, 2015 and 2011 (S = spoil ground, N = north location, E = east location)

## 3.2 Seagrasses in the Port of Bundaberg spoil ground

Seagrasses in the PoB spoil ground survey area form part of a large meadow covering 5564 ha across the entire PoB limits (Figure 1, Smith and Rasheed 2021). Seagrass was found at all 15 sites sampled as part of the spoil ground survey both within and outside the spoil ground. *Halophila decipiens* was recorded at every site, while *H. ovalis* was recorded at 13 sites and *Halophila spinulosa* at 9 sites (Figures 6, 7). Seagrass in the spoil ground and to the north had sparse to moderate cover while to the east of the spoil ground cover was moderate at all sites except the furthest from the spoil ground which was sparse (Table 2). In comparison, only one sparse site was found in the spoil ground in 2015, no sites in 2011, three sparse sites in 2008 and two sparse sites in 2006 (Table 3). Cover in the north was similar to 2015 but greater than 2011 when no seagrass was found. Seagrass density in the eastern transect was however lower than past years when it was moderate to dense (Table 3).

Seagrass biomass was low ranging from 0.09 – 1.64 g DW $m^{-2}$ (Table 2. Figure 8). There was no significant difference in seagrass biomass across the three locations (spoil ground; north and east) (LR ChiSq = 2.298, df = 2, p = 0.235) however 4 of the 5 sites inside the spoil ground had below average biomass (Figure 8). Seagrass biomass did not show any relationship with distance to the spoil ground in either of the transect locations (Location; LR ChiSq = 0.001, df = 1, p = 0.922, Distance to spoil ground; LR ChiSq = 2.592, df = 1, p = 0.107, Interaction; LR ChiSq = 0.356, df = 1, p = 0.550, Figure 8, 9).

*Halophila spinulosa* *Halophila ovalis* *Halophila decipiens*

**Figure 6.** Seagrass species present in the Port of Bundaberg survey in 2020.

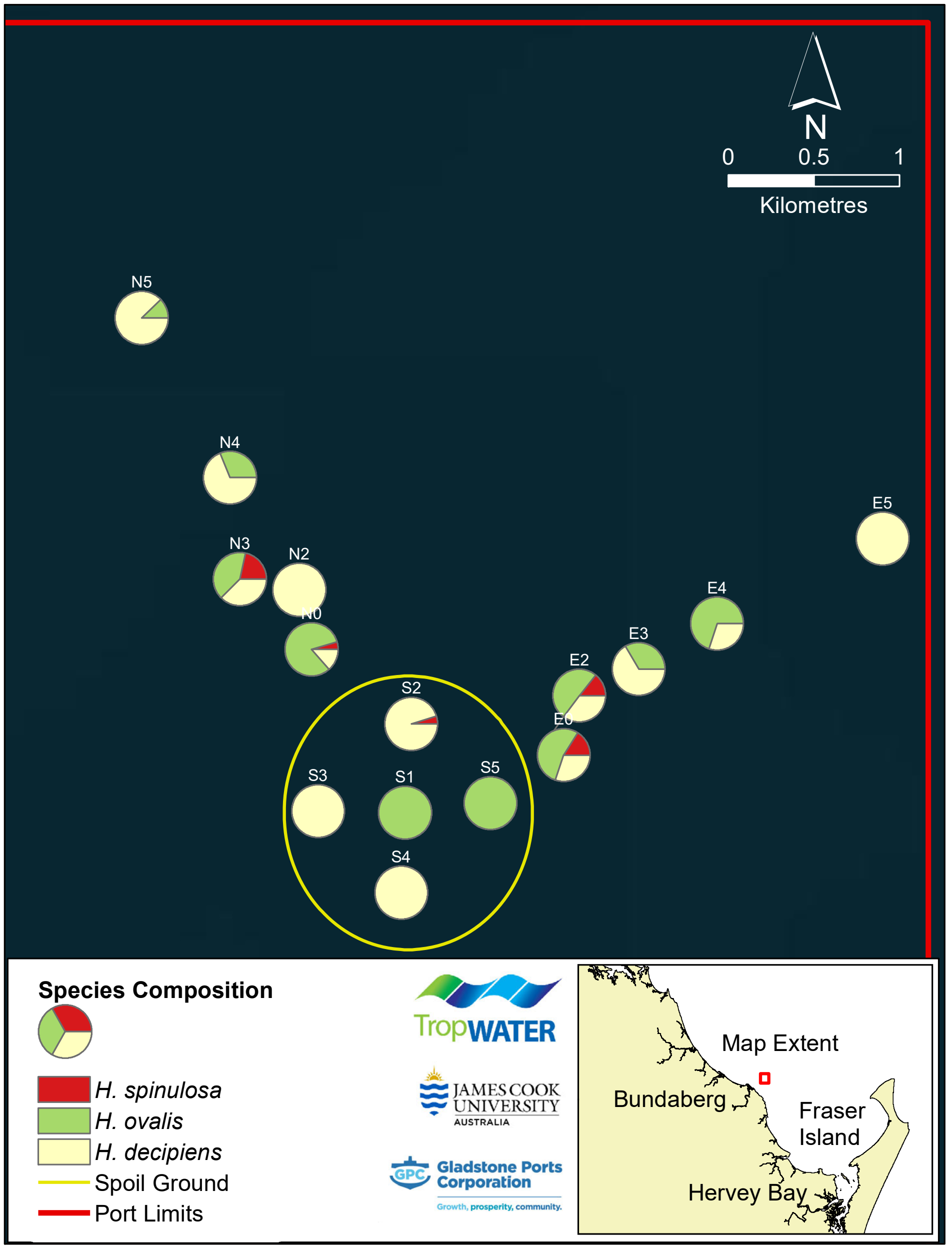

**Figure 7**. Seagrass species composition at each sampling site at the Port of Bundaberg spoil ground survey area.

**Table 2.** Seagrass species, cover and biomass at each site sampled at the Port of Bundaberg spoil ground survey area.

| Site | Seagrass Species | Seagrass Cover Category | Seagrass % Cover | Mean biomass (g DW m$^{-2}$) | Biomass Standard Error | Biomass *H. spinulosa* | Biomass *H. ovalis* | Biomass *H. decipiens* |
|---|---|---|---|---|---|---|---|---|
| E0 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 20 | 1.438 | 0.16 | 0.232 | 0.770 | 0.435 |
| E2 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 20 | 1.235 | 0.12 | 0.176 | 0.625 | 0.434 |
| E3 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 20 | 1.052 | 0.14 | 0 | 0.350 | 0.702 |
| E4 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 25 | 1.537 | 0.10 | 0 | 1.076 | 0.460 |
| E5 | *H. decipiens, H. ovalis* | Sparse | 2 | 0.218 | 0.25 | 0.001 | 0.001 | 0.215 |
| N0 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 25 | 1.267 | 0.19 | 0.058 | 1.039 | 0.171 |
| N2 | *H. decipiens, H. ovalis* | Sparse | 2 | 0.145 | 0.19 | 0 | 0 | 0.145 |
| N3 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 40 | 1.635 | 0.24 | 0.354 | 0.668 | 0.612 |
| N4 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 25 | 1.452 | 0.11 | 0.013 | 0.446 | 0.992 |
| N5 | *H. decipiens, H. ovalis, H. spinulosa* | Sparse | 1 | 0.349 | 0.12 | 0 | 0.043 | 0.307 |
| S1 | *H. decipiens, H. ovalis* | Sparse | 5 | 0.118 | 0.17 | 0 | 0.118 | 0 |
| S2 | *H. decipiens, H. ovalis, H. spinulosa* | Moderate | 30 | 1.393 | 0.07 | 0.068 | 0 | 1.324 |
| S3 | *H. decipiens* | Sparse | 0.5 | 0.086 | 0.09 | 0 | 0 | 0.086 |
| S4 | *H. decipiens* | Sparse | 1 | 0.086 | 0.09 | 0 | 0 | 0.086 |
| S5 | *H. decipiens, H. ovalis* | Moderate | 15 | 0.427 | 0.11 | 0 | 0.427 | 0 |

**Table 3**. Seagrass cover at each site at the Port of Bundaberg spoil ground survey area in 2006, 2008, 2011, 2015 and 2020.

| Site | 2006 | 2008 | 2011 | 2015 | 2020 |
|---|---|---|---|---|---|
| S1 | Sparse | Nil | Nil | Nil | Sparse |
| S2 | Nil | Sparse | Nil | Sparse | Moderate |
| S3 | Sparse | Sparse | Nil | Nil | Sparse |
| S4 | Nil | Sparse | Nil | Nil | Sparse |
| S5 | Nil | Nil | Nil | Nil | Moderate |
| N0 |  | Sparse | Nil | Moderate | Moderate |
| N1 | Dense |  |  |  |  |
| N2 | Dense | Moderate | Nil | Sparse | Sparse |
| N3 | Moderate | Moderate | Nil | Moderate | Moderate |
| N4 | Nil | Nil | Nil | Moderate | Moderate |
| N5 | Moderate | Dense | Nil | Moderate | Sparse |
| E0 |  | Moderate | Nil | Dense | Moderate |
| E1 | Dense |  |  |  |  |
| E2 | Dense | Moderate | Nil | Dense | Moderate |
| E3 | Dense | Moderate | Nil | Moderate | Moderate |
| E4 | Dense | Moderate | Nil | Dense | Moderate |
| E5 | Dense | Moderate | Nil | Dense | Sparse |

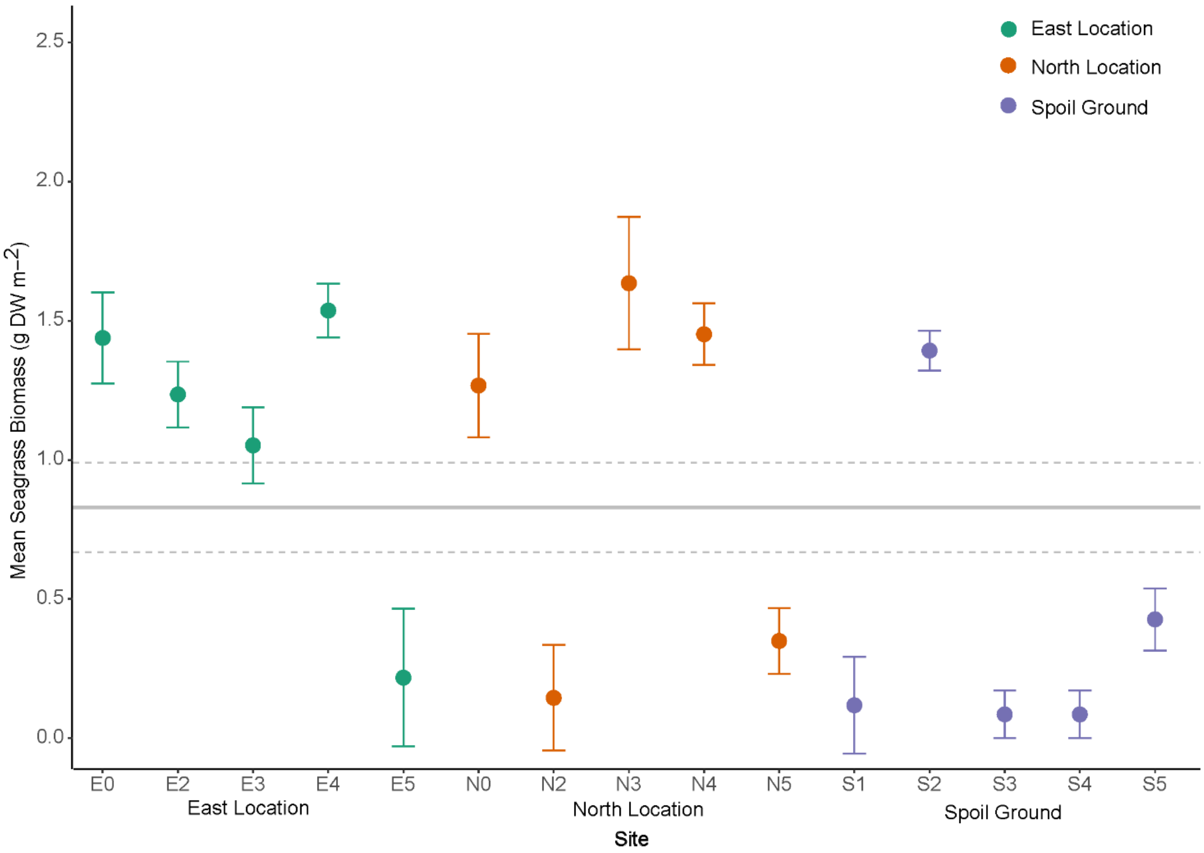

**Figure 8.** Mean seagrass biomass (± SE) at each sampling site across the survey area (east location, north location, spoil ground). Grey and dotted lines represent overall mean biomass and SE.

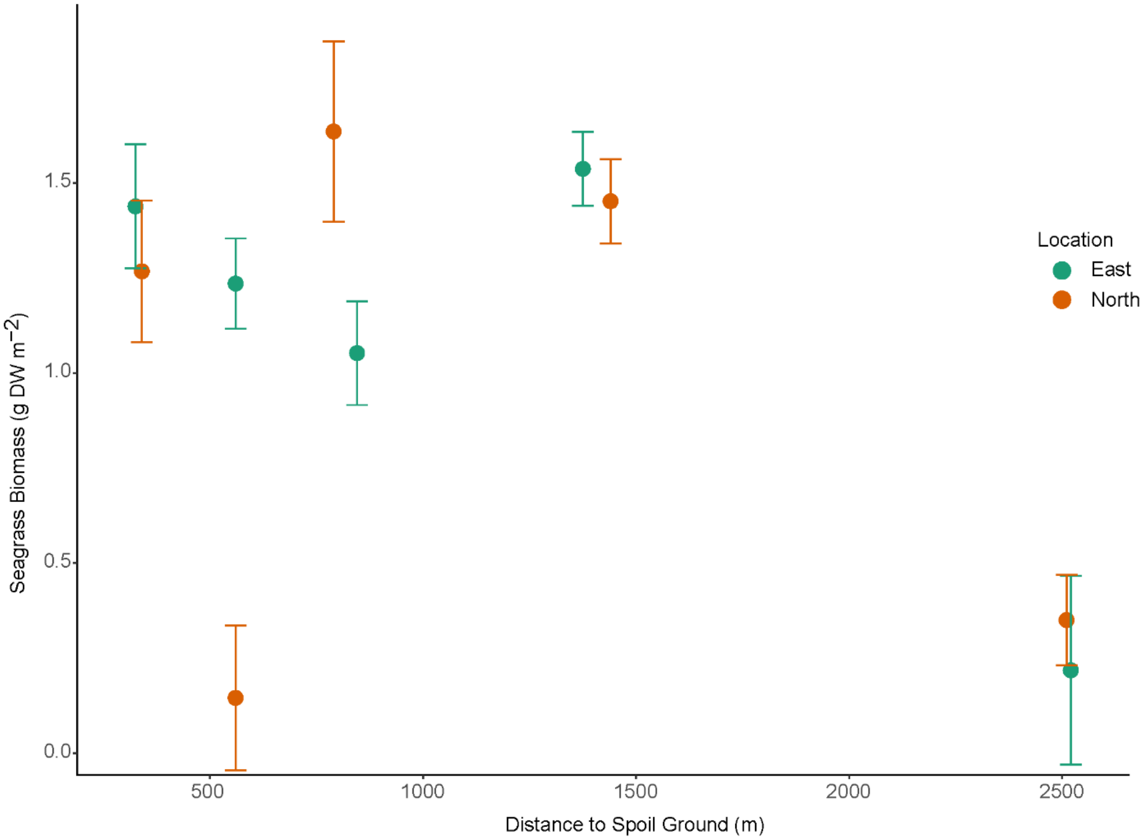

**Figure 9.** Mean seagrass biomass (± SE) at sites along transects to the north and east of the Port of Bundaberg spoil ground.

## 3.3 Infauna Invertebrate Communities in the Port of Bundaberg Spoil Ground

A total of 924 invertebrates, from 103 taxa in ten phyla, were sampled. The most commonly sampled taxa were an amphipod crustacean from the Metilidae family (101 individuals from 1 species), followed by the polychaetes *Diopatra* sp1. (83 individuals from 1 species) and *Lumbrineridae* sp1 (68 individuals from 1 species) (Table 4, Figure 10). These three species represented 27% of the invertebrates sampled. No other individual taxa represented more than 4% of the total abundance. The most common phyla sampled were Annelids (all polychaetes; 446 individuals) and Crustaceans (361 individuals). These two phyla accounted for more than 85% of the individuals sampled. At sites outside the spoil ground in the east and north locations Metilidae, *Diopatra* sp1 and *Lumbrineris* sp1 were the most common taxa (Table 4). Within the spoil ground, *Lumbrineris* sp1 was the most common taxa sampled followed by the polychaetes *Diopatra* sp1 and *Terebellides* sp1 (Table 4).

**Table 4.** Count of most numerically dominant taxa at Port of Bundaberg survey area (spoil ground, north location, east location).

| East Location | | North Location | | Spoil Ground | |
|---|---|---|---|---|---|
| **Taxa** | **Count** | **Taxa** | **Count** | **Taxa** | **Count** |
| Metilidae (crustacean) | 46 | Metilidae (crustacean) | 44 | *Lumbrineris* sp1 (annelid) | 29 |
| *Diopatra* sp1 (annelid) | 44 | *Diopatra* sp1 (annelid) | 21 | *Diopatra* sp1 (annelid) | 18 |
| *Lumbrineris* sp1 (annelid) | 25 | *Lumbrineris* sp1 (annelid) | 14 | *Terebellides* sp1 (annelid) | 14 |
| *Eunice* sp1 (annelid) | 17 | Ischyroceridae (crustacean) | 11 | Metilidae (crustacean) | 11 |
| *Terebellides* sp1 (annelid) | 14 | Deximinidae (crustacean) | 10 | Pseudozeuxoidae (crustacean) | 10 |

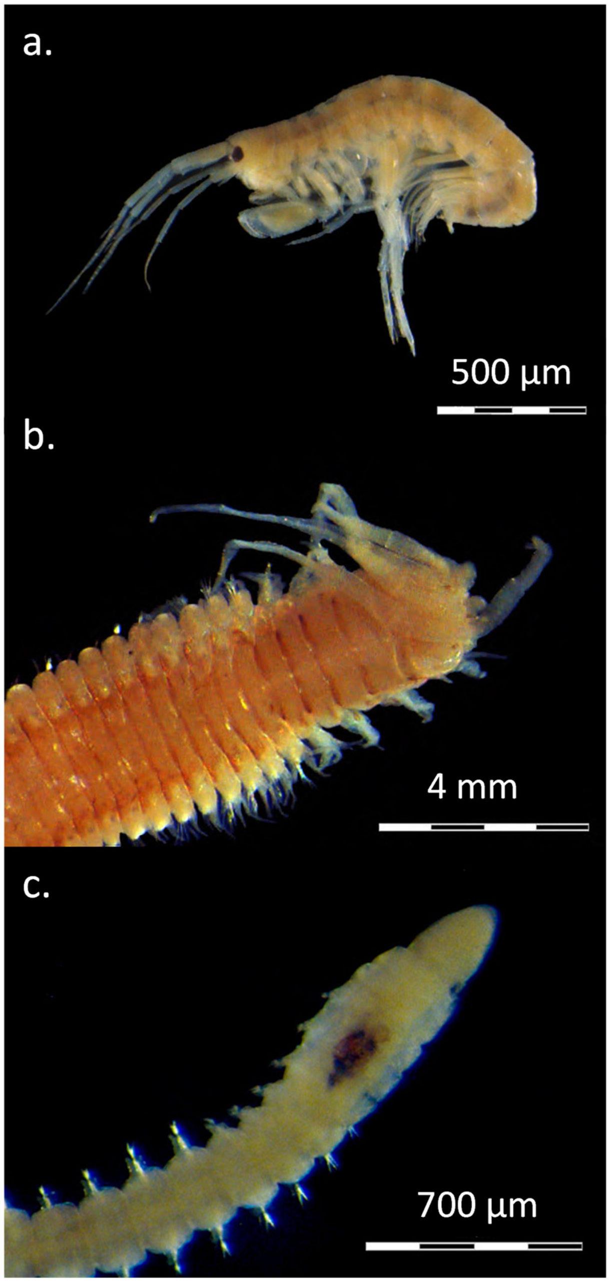

**Figure 10**. The three most common benthic invertebrate taxa sampled in the Port of Bundaberg, Metilidae sp. (a), *Diopatra* sp1 (b) and *Lumbrineridae* sp1 (c).

Infauna communities varied with location inside and outside the spoil ground, distance to the spoil ground and seagrass biomass. Species richness, diversity, and infauna and crustacean abundance all varied across locations but there was no difference for species evenness and annelid abundance (Table 5). Species richness was greater in the north (p = 0.001) and the east (p = 0.001) than the spoil ground but there was no difference between the north and east locations (Figure 11, 12). Species diversity (p = 0.001), infauna abundance (p = 0.007) and crustacean abundance (p= 0.001) was greater in the north location than the spoil ground but not between the east and the spoil ground or the east and north locations (Figure 11, 12).

Infauna communities varied inconsistently between sites along transects in the north and east locations. There was a significant interaction between location and distance to spoil ground for species richness, diversity and infauna and annelid abundance, while crustacean abundance had significant main effects but no interaction and species evenness showed no relationship (Table 5). Species richness, diversity and infauna abundance showed no relationship with distance to the spoil ground in the north transect but decreased as distance increased in the east transect (Figure 13). Annelid abundance had a positive relationship as distance increased in the north and a negative relationship in the east while crustacean abundance had a negative abundance regardless of location.

There was a positive significant relationship between seagrass biomass and infauna species richness, diversity, abundance and the abundance of annelids and crustaceans (Table 5, Figure 14)

**Table 5.** General Linear Model results for model comparing location across the survey area (A.), the relationship with distance to the spoil ground in the north and east location (B.) and seagrass biomass (C.) for each of the invertebrate variable measured (species richness, species diversity, species evenness, infauna abundance, annelid abundance and crustacean abundance. Bold = significant (<0.05). The best model for species evenness only included the null model.

| | | **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 | 2 | 40.112 | **<0.001** | 13.805 | **0.001** | 0.844 | 0.656 | 9.261 | **0.010** | 3.728 | 0.155 | 17.493 | **<0.001** |
| **B. Distance to the Spoil Ground** | | | | | | | | | | | | | |
| Location | 1 | 3.052 | 0.081 | 5.170 | **0.023** | | | 3.139 | 0.076 | 0.517 | 0.472 | 4.746 | **0.029** |
| Distance to SG | 1 | 6.959 | **0.008** | 17.631 | **0.000** | | | 1.975 | 0.160 | 1.549 | 0.213 | 3.940 | **0.047** |
| Location x Distance to SG | 1 | 8.180 | **0.004** | 15.795 | **0.000** | | | 4.083 | **0.043** | 9.122 | **0.003** | | |
| **C. Seagrass Biomass** | | | | | | | | | | | | | |
| Biomass | 1 | 53.051 | **<0.001** | 21.337 | **<0.001** | 1.21 | 0.271 | 21.647 | **<0.001** | 12.31 | **<0.001** | 21.447 | **<0.001** |

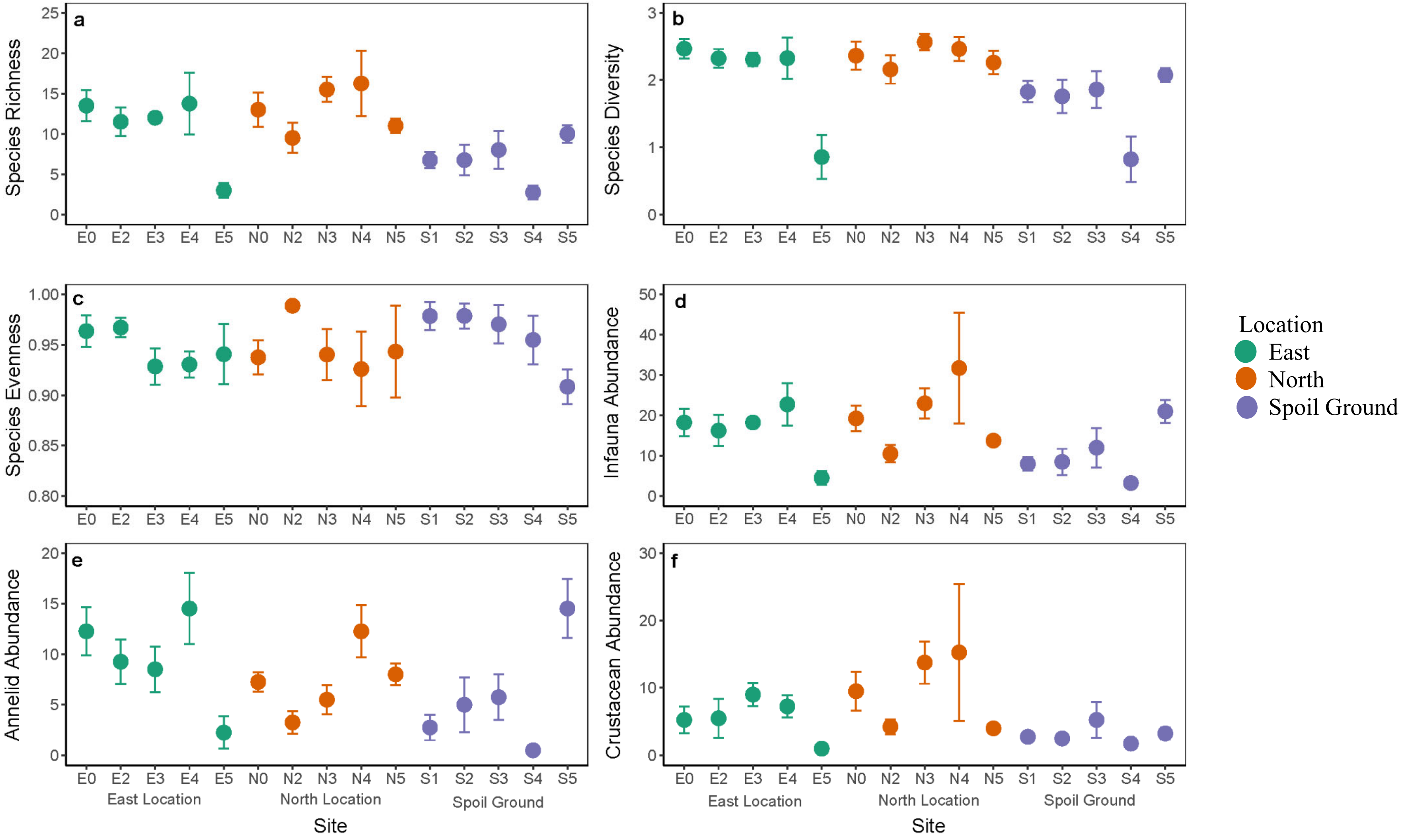

**Figure 11.** Mean (± SE) infauna species richness (a), species diversity (b), species evenness (c), abundance (d), annelid abundance (e) and crustacean abundance (f) at each site across the Port of Bundaberg survey area (east location, north location, spoil ground).

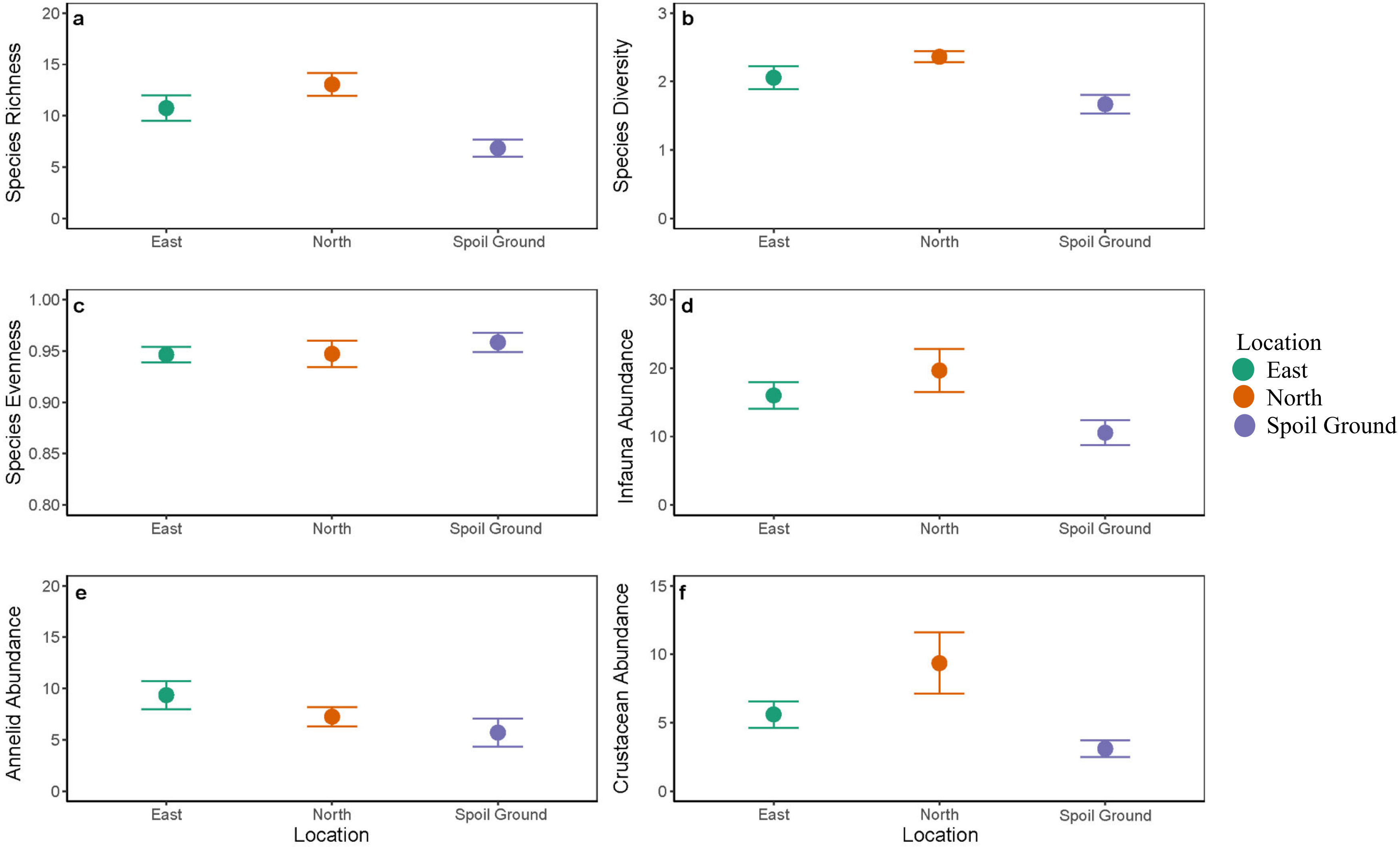

**Figure 12.** Mean (± SE) infauna species richness (a), species diversity (b), species evenness (c), abundance (d), annelid abundance (e) and crustacean abundance (f) at each location across the Port of Bundaberg survey area.

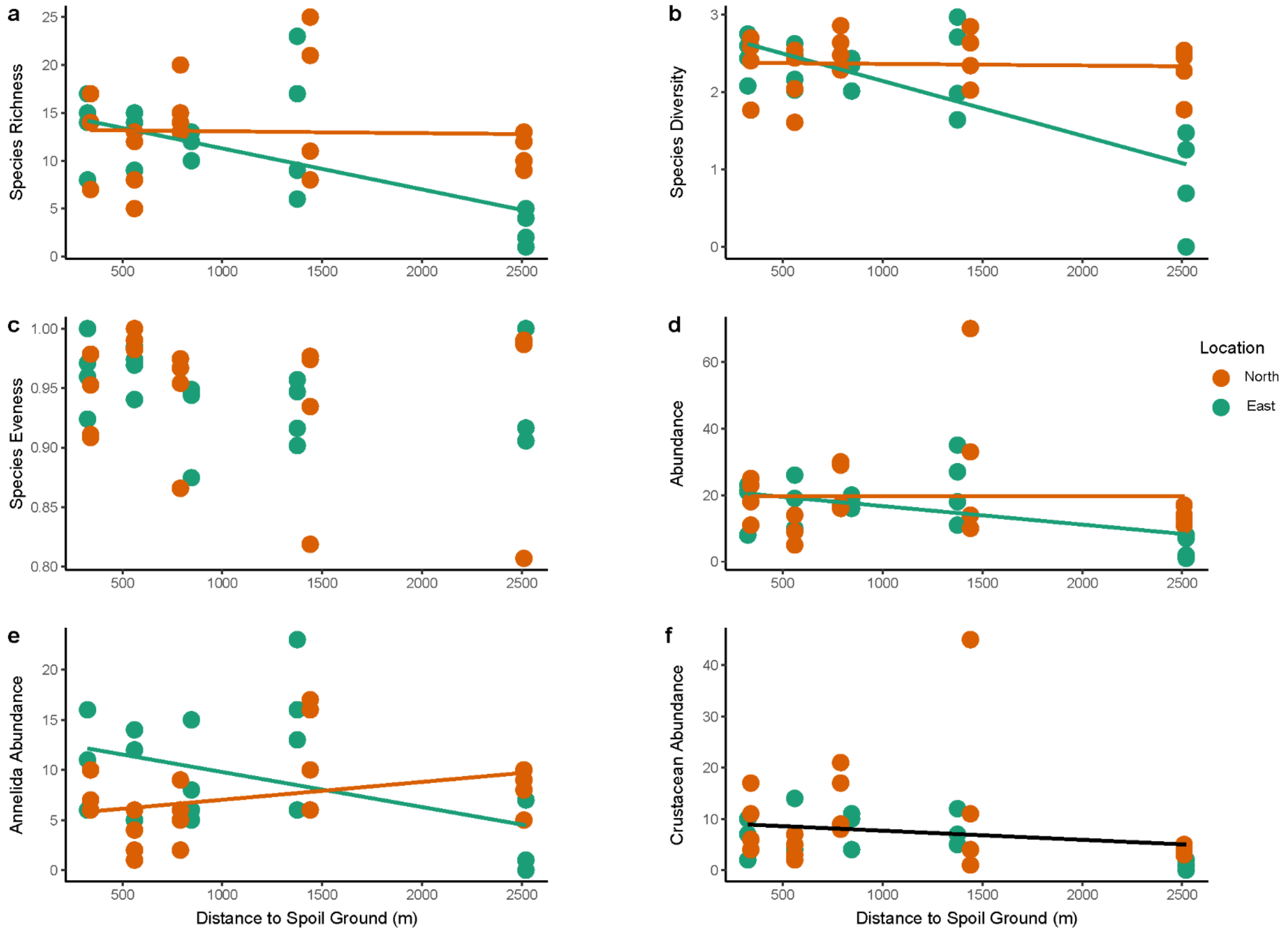

**Figure 14.** Relationship between infauna species richness (a), species diversity (b), species evenness (c), abundance (d), annelid abundance (e) and crustacean abundance (f) as distance to the spoil ground increases in the north and east locations of the Port of Bundaberg spoil ground survey area.

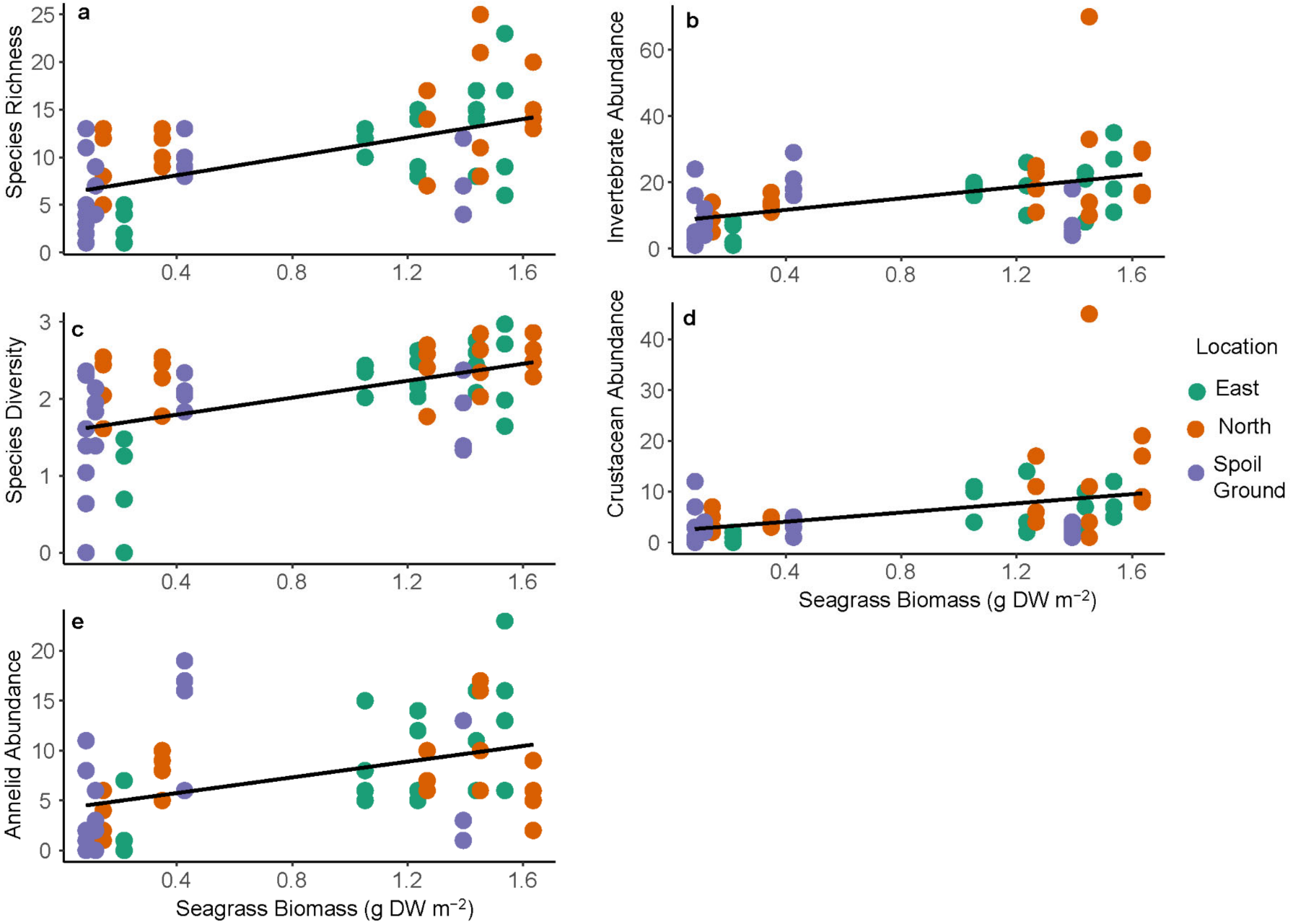

**Figure 13.** Relationship between infauna species richness (a), abundance (b), species diversity (c), crustacean abundance (d) and annelid abundance (e) as seagrass biomass increases across all Port of Bundaberg sampling sites.

**Historical Comparisons**

Infauna communities varied inconsistently over monitoring surveys in 2011, 2015 and 2020. There were significant interactions between location and sampling year for both family richness and infauna abundance (Table 6). In all years fewer families and individuals were sampled in spoil ground than either the north (family richness in 2011, 2015, 2020 p < 0.001, abundance in 2011 p = 0.011, 2015 p = 0.043, 2020 p = 0.010) or east locations (family richness in 2011, 2015, 2020 p < 0.001, abundance in 2011. 2015 p < 0.001) outside the spoil ground (Figure 15). In 2020 however there was no difference between the east location and the spoil ground for infauna abundance (p = 0.187). There was greater family richness and infauna abundance in the east than the north in 2015 (family richness p = 0.026, abundance p = 0.021) and abundance in 2011 (p < 0.001) but there was no difference in 2011 or 2020 for family richness or abundance in 2020. The number of families sampled was higher in 2020 than the other years (Figure 15).

Distance to the spoil ground had different impacts on family richness and infauna abundance across sampling years (Table 6). In 2011 there was an increase in family richness as distance to the spoil ground increased regardless of the location but in 2015 there was a negative relationship in the north and no relationship in the east (Figure 16). In 2020 the pattern was the opposite where infauna abundance decreased in the east and there was no difference in the north (Figure 16). Infauna abundance showed a similar pattern to family richness. Abundance increased as distance to the spoil ground increased in both areas in 2011, but only in the east in 2015. There was no relationship in the north in 2015 and 2020 and abundance decreased in the east in 2020 (Figure 17).

**Table 6**. Results from GLM comparing infauna family richness and abundance across locations at the Port of Bundaberg spoil ground across monitoring years (A.) and as distance to the spoil ground increases along transects in the north and east locations across sampling years (B.). Bold = significant (<0.05).

| | | **Family Richness** | | **Infauna Abundance** | |
|---|---|---|---|---|---|
| | df | LR ChiSq | P | LR ChiSq | P |
| *Model Distribution* | | *Poisson* | | *Gaussian* | |
| **A. Location** | | | | | |
| Location | 2 | 122.970 | **<0.001** | 61.613 | **<0.001** |
| Year | 2 | 119.218 | **<0.001** | 1.506 | 0.471 |
| Location x Year | 4 | 22.768 | **<0.001** | 17.559 | **0.002** |
| **C. Distance to Spoil Ground** | | | | | |
| Location | 1 | 0.958 | 0.328 | 8.831 | **0.003** |
| Distance to SG | 1 | 0.138 | 0.109 | 2.139 | 0.144 |
| Year | 2 | 72.343 | **<0.001** | 2.765 | 0.251 |
| Location x Distance to SG | 1 | 2.531 | 0.111 | 0.299 | 0.584 |
| Location x Year | 2 | 15.344 | **<0.001** | 12.881 | **0.002** |
| Distance to SG x Year | 2 | 25.038 | **<0.001** | 9.911 | **0.007** |
| Location x Distance to SG x Year | 2 | 15.468 | **<0.001** | 7.023 | **0.029** |

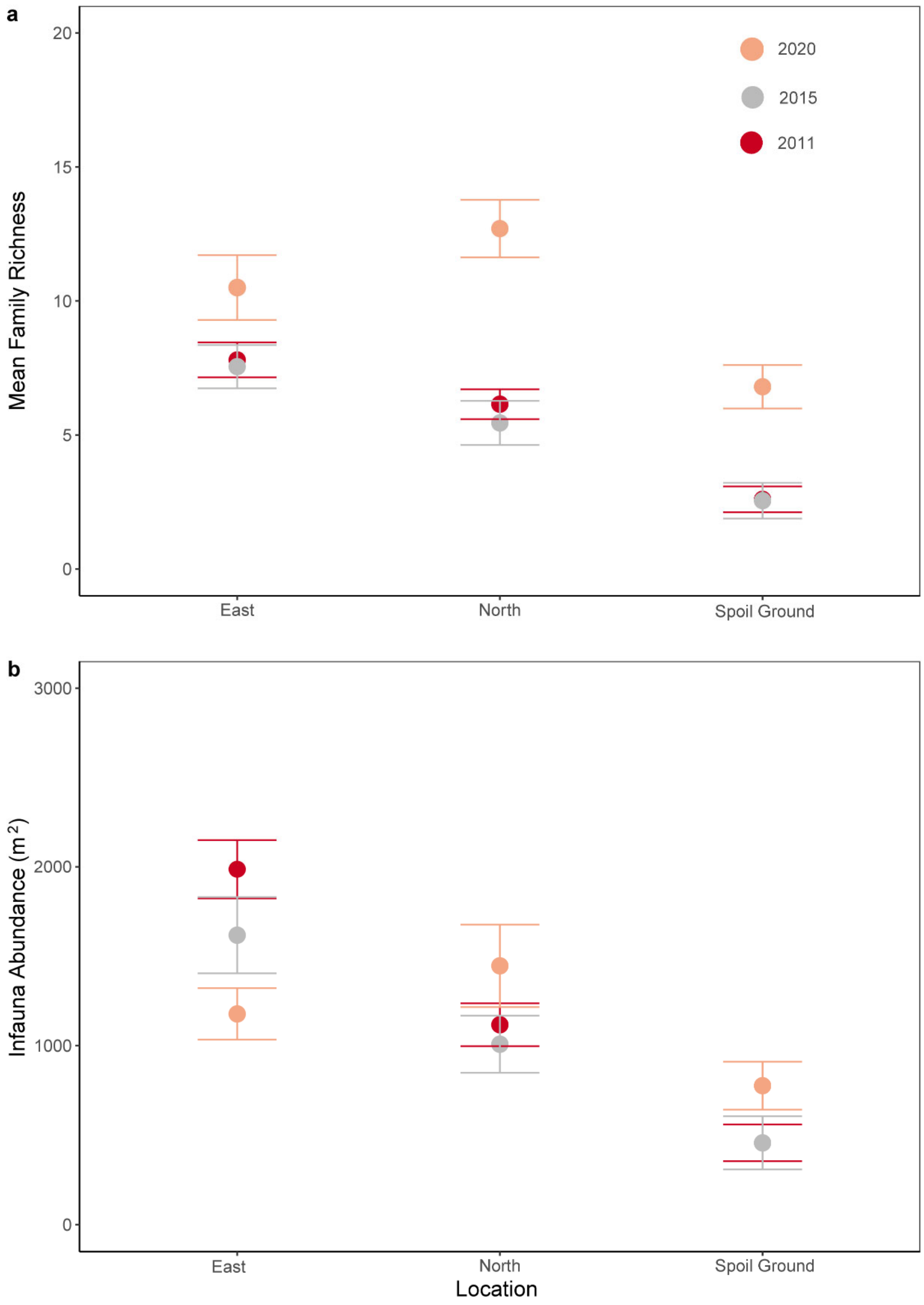

**Figure 15.** Mean (± SE) of family richness (a) and total infauna abundance (b) at locations inside (spoil ground) and outside (North and east locations) the Port of Bundaberg spoil ground in each survey year (2011, 2015, 2020).

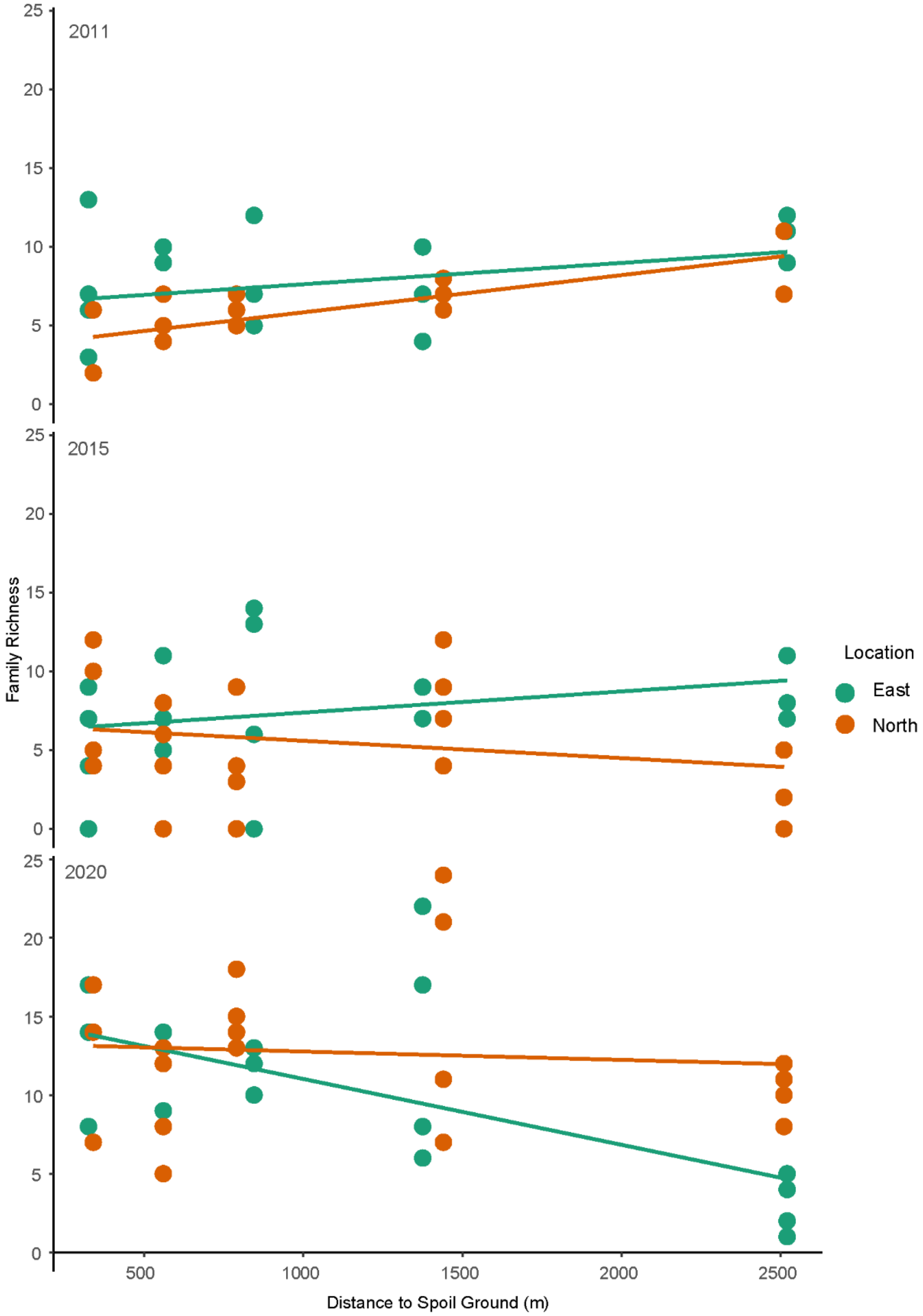

**Figure 16.** Family richness as distance to the spoil ground increases to the east and north locations in each monitoring survey year (2011, 2015, 2020).

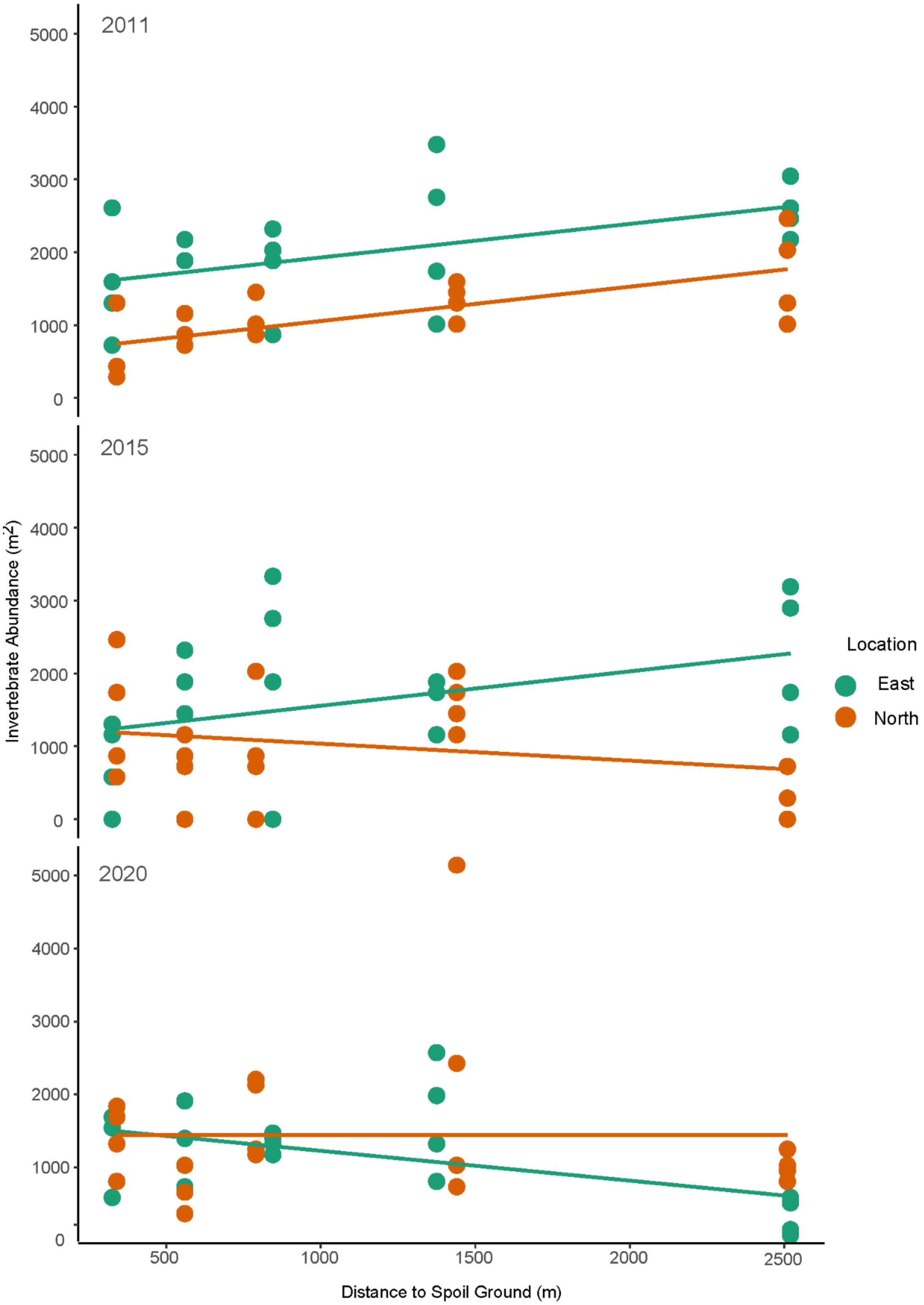

**Figure 17.** Total infauna abundance at each sampling sites at distance to the spoil ground in the north and east location in each monitoring survey (2011, 2015, 2020).

## 3.4 Community Assemblages

Multivariate analysis found no difference in benthic infauna communities sampled from locations across the PoB spoil ground survey area ($F_{2, 12} = 1.11$, $p = 0.300$, Figure 17). There was no clustering of sites in the spoil ground or to the north or east, although sites in the spoil ground had a greater spread. A dendrogram based on similarity across sites shows high similarity between four of the five sites from each of the north and east locations (Figure 18). Sites E5 and N2 however were more similar to sites in the spoil ground.

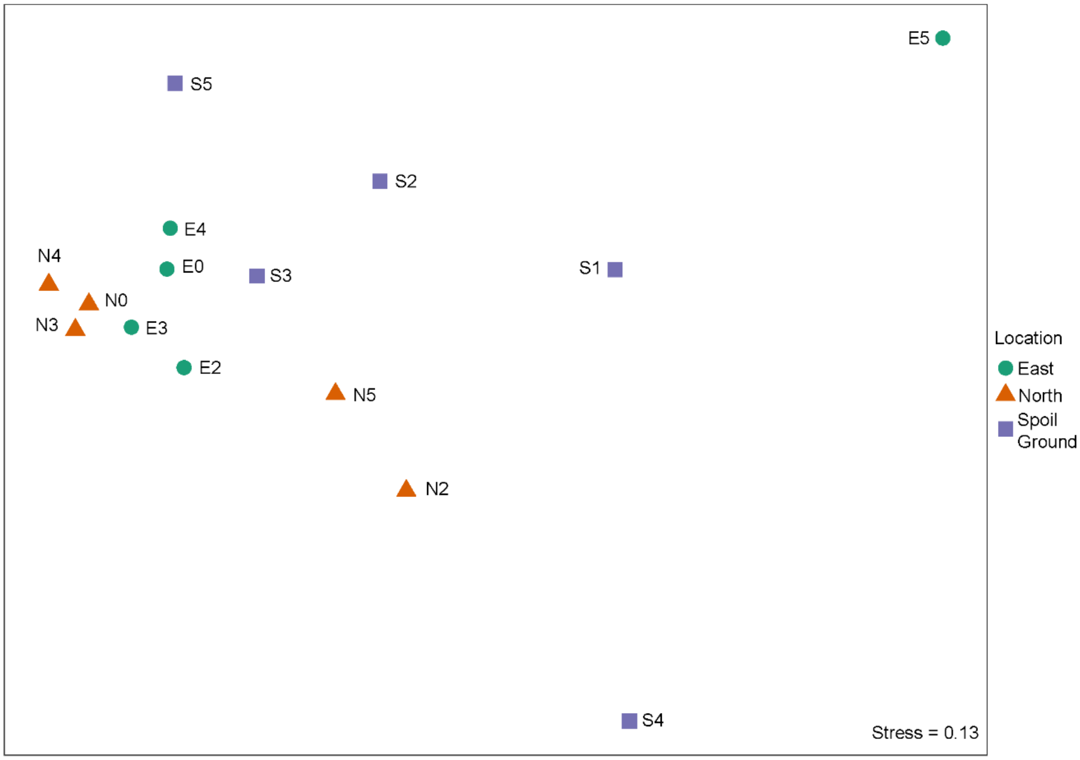

**Figure 17.** nMDS plot based on Bray Curtis dissimilarity for sites across the Port of Bundaberg survey area. (S = spoil ground; N –north locations; E – east locations).

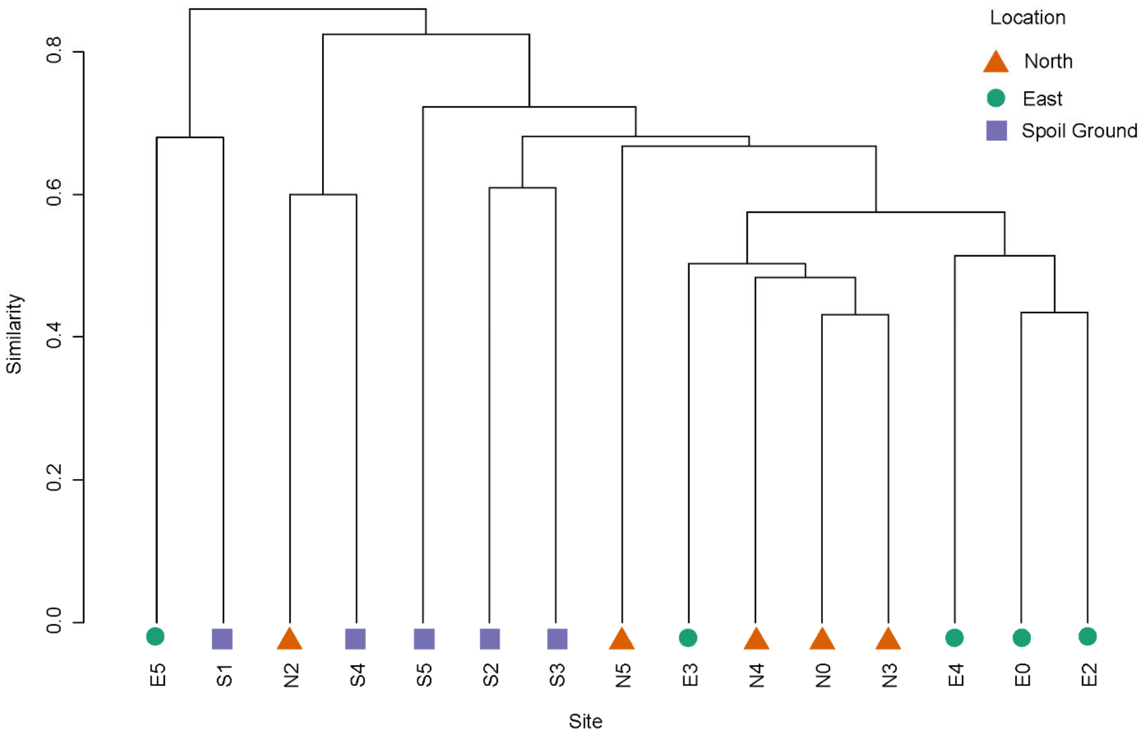

**Figure 18.** Similarity of sites across the Port of Bundaberg survey area based on Bray Curtis dissimilarity (S = spoil ground; N – north location; E – east location).

# 4 DISCUSSION

Seagrass was found throughout the PoB spoil ground survey area and there was no pattern to indicate a gradient effect on seagrass, sediment or benthic infauna. Species richness, diversity and abundance of infauna were lowest in the spoil ground but did not appear to spread in any significant way outside of the spoil ground.

## 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). There was little difference in sediment grain size across sampling sites and sediment consisted of primarily of sand. The dominance of sand across all sites suggest there is little observable impact of spoil deposition on the sediment at the PoB spoil ground survey area. The absence of any increase in fine sediment along transect moving away from the spoil ground indicate that there is little transport of sediment out of the spoil ground. The small decrease in gravel as distance increases from the spoil ground suggest any heavier spoil remains with the spoil ground. The changes were however subtle (~10%) and the low sampling replication at each distance to the spoil ground means that any results need to be considered with caution.

Previous surveys have found low fine sediment contributions across sampling sites similar to our results. There was a positive relationship with distance to the spoil ground in 2015 but the percent of fine sediment remained low along the transect. Higher gravel content in previous surveys (up to 30% in 2015, 2008) were not observed in this survey. Variability in the sediment grain size across survey may be related to the timing of dredging relative to sampling or the type of spoil deposited. Large flooding events such as those in the Burnett River in 2010/11 and 2013 may also influence sediment grain size throughout the PoB. The influx of sediment from these floods may have impacted the distribution of sediment size in the 2011 and 2015 surveys as finer sediment drifts further from shore. The influence of the floods maybe have dissipated over time as no differences were detected in this survey.

## 4.2 Seagrass

Seagrass was found throughout the PoB spoil ground survey area and at all 15 of the sampled sites. There was no significant difference between the spoil ground and surrounding locations. While mean biomass in the survey area was low (0.8 g DW $m^2$) it was similar to the overall mean biomass of the meadow (1 g DW $m^2$).

The PoB spoil ground benthic survey in 2020 was undertaken concurrently with a larger PoB whole port seagrass survey (Smith and Rasheed 2021). The surveyed area forms part of a large meadow covering more than 5500 ha stretching past the port limits. While mean biomass in the spoil ground survey area was low (0.8 g DW $m^2$) it was similar to the overall mean biomass of the larger meadow (1 g DW $m^2$). Seagrass biomass in the PoB spoil ground survey area was typical of deep-water *Halophila* species and high when compared to other deep-water seagrass areas surveyed recently in Queensland. Biomass ranged from 0.08 to 1.39 g DW $m^{-2}$ in the spoil ground and 0.14 to 1.63 g DW $m^{-2}$ in the surrounding survey area. Biomass was much greater than 2019 deep-water surveys in Gladstone (0.01 – 0.77 g DW $m^{-2}$, Smith et al. 2020) and similar to those in Hay Point (0.96 – 1.35 g DW $m^{-2}$, York and Rasheed 2020) and Abbot Point (0.55 – 2.64 g DW $m^{-2}$, Van

De Wetering et al. 2020). The relatively high seagrass biomass recorded within the PoB spoil ground suggest that seagrass there are in good condition relative to other similar seagrass in north Queensland.

Previous surveys have found little seagrass in the spoil ground and this was the first time seagrass occurred at all sites. Four of the five spoil ground sites in this survey however had below average biomass relative to sampling sites across the survey area. Deep-water *Halophila* species are largely ephemeral colonising species that change rapidly in response to light conditions (Chartrand et al. 2018). While most sites in the spoil ground had low biomass suggesting there may be subtle effects of spoil deposition it may also reflect natural variation as light conditions vary. Improved seagrass area, although not density, in this survey relative to previous surveys may reflect improved conditions for seagrass establishment and growth. Greater seagrass area seen in 2020 reflects broader trends in coastal and deepwater seagrass across North Queensland over the previous 5 years that have seen high seagrass biomass and meadow area in response to below average rainfall and improved water clarity (Reason et al. 2020; Smith et al. 2020).

While seagrass cover was lower at the PoB spoil ground in 2020 than 2006, 2008 and 2015 it was greater than in 2011 when no seagrass was recorded. Queensland seagrass communities are seasonal, with maximum distribution and abundance usually occurring in late spring/early summer (Smith et al. 2020). Monitoring during this time of year is important to capture seagrass distribution and abundance at their annual peak. The 2011 survey was undertaken in early Autumn directly after the wet season when seagrass is in senescence and prior to the normal annual recruitment of *Halophila* species and is the likely explanation of why no seagrass was recorded in that survey. We recommend that all future PoB spoil ground benthic surveys are conducted between August and December when seagrass biomass is likely at its peak and allowing direct comparison to previous surveys and other North Queensland ports.

Deep-water seagrasses like those in the PoB spoil ground are ephemeral and highly variable in both space and time adding an additional level of difficulty for monitoring and interpreting changes (Chartrand et al. 2018; York et al 2015). The intent of monitoring the PoB spoil ground is to determine any impacts of spoil deposit on seagrass and benthic infauna. Effects of spoil deposition will be difficult to detect given the ephemeral nature of deep-water seagrass and benthic communities and changes need to be interpreted with caution. Results from the larger port wide survey undertaken in conjunction with this survey (see Smith and Rasheed 2021) allowed benthic habitats to be compared over a broader area and provide a greater ability to detect change within the spoil ground. We recommend that future PoB spoil ground surveys include a broader port wide survey to improve our ability to interpret seagrass condition and detect any changes in the spoil ground.

Previous benthic surveys of the PoB spoil ground have used diver swum transects to broadly classify seagrass density as sparse, moderate or dense as specified in the LTMMP. Broad classifications make comparisons across surveys difficult and are prone to observer biases. The addition of seagrass biomass in this survey adopts a standardised method used across Queensland and is calibrated to measured standards and therefore allows direct comparisons across years in the future as well as a broader understanding of benthic habitats in the spoil ground and how they compare to similar habitats elsewhere in Queensland within a given year.

### 4.3 Infauna Composition

Benthic infauna communities are regarded as indicators of ecosystem health and provide a number of important functions such nutrient cycling and the basis of marine food webs (Ieno et al 2006). Dredge spoil deposition 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). In the PoB spoil ground infauna species richness, diversity and abundance was lower than at sites to the north and east but there was no difference in community assemblages. These results follow a consistent pattern to surveys in 2011 and 2015. Low diversity and abundance in the spoil ground was directly attributed to the impacts of spoil deposition in these surveys but other environmental factors may be playing a role. In this report seagrass biomass was included in the analysis of infauna and there was a strong positive relationship with infauna diversity and abundance. Seagrass presence may therefore be a more important predictor of infauna distribution than location in the survey area per se.

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 (Barnes 2020, Casares and Creed 2008). While there was no significant difference in seagrass biomass inside and outside the spoil ground the three lowest biomass sites in the study were inside the spoil ground leading to low infauna diversity and abundance there. Historically there has been very little seagrass recorded in the spoil ground and the absence of seagrass may explain in part the lower infauna diversity and abundance in the spoil ground in previous surveys. The impact of spoil deposition on seagrass may therefore be having a greater impact on benthic infauna than the spoil deposition directly on infauna. Ensuring healthy seagrass communities is therefore imperative to maintaining healthy benthic infauna communities.

There was no detectable affect of spoil deposition and movement on benthic infauna assemblages outside the spoil ground. In fact, there was a decrease in diversity and abundance in the east transect at more distant sites, with no difference in the north transect. Patterns in the east transect were driven by low diversity and abundance at E5 the most distant site. This site also had the lowest seagrass biomass along the transect. These results contrast those from previous surveys that found increases in invertebrate abundance as distance to the spoil ground increased and higher abundances in the east transect. Variation in infauna abundance patterns in the north and east of the survey area may be related to changes in seagrass distribution. In 2015 dense seagrass was recorded across the east transect where the infauna abundance was also higher. Seagrass was absent in 2011 but sampling occurred during the seagrass senescent season and infauna may reflect the previous high season seagrass distribution.

Taxa diversity in this study was greater than previous surveys. Higher taxonomic diversity may be related to the difference in sampling methods across surveys. In this survey we used a sediment grab which sampled a greater surface area than cores used in previous surveys. While abundances were similar in 2020 to other years after samples were standardised for sampling area, family richness was not standardised because it would lead to a large over estimation of the number of species present. Greater family diversity in 2020 was therefore more likely an artefact of the differing sampling methods and area sampled rather than any actual changes.

### 4.4 Conclusions and Recommendations

There was no evidence that sediment deposition in the Port of Bundaberg spoil ground was having a measurable effect on benthic habitats surrounding the spoil ground. There was no difference in sediment grain size condition or seagrass biomass inside and outside the spoil ground, although seagrass biomass was low at most sites inside the spoil ground. Infauna was less diverse and abundant inside the spoil relative to nearby locations indicating some direct impact of spoil deposition within the spoil ground. However, there was no evidence of impacts of spoil on sediment infauna or seagrass occurring outside the spoil ground regardless of the proximity to the spoil ground. This survey showed strong links between seagrass biomass and increased fauna diversity. Given the high level of seasonal and inter-annual spatial variability in deep-water seagrasses, we suggest that future spoil ground assessments incorporate a broader survey area for seagrasses to ensure a clearer picture of seagrass change. In addition as deep-water seagrasses are highly seasonal sampling times should be standardised to occur during the peak growing season (August-November) in the future to enable comparable results.

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## Appendix 1. Queensland ports seagrass monitoring program

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

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.

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