# Ocean Barramundi Project - Baseline Marine Environmental Quality Study

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| Customer | Marine Produce Australia |
| Project | 175801.000 |
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# Document Control

## Document Identification

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## Amendment Record

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# 1 Approach

A baseline water and sediment quality monitoring program was conducted between February–August 2021. The purpose of the program was to capture ambient temporal (seasonal) and spatial data for marine quality across leases in the Buccaneer Archipelago. This will enable the setting of boundary conditions for water quality and particle tracking models. The ambient data will also provide a baseline for comparison against the EPA's criteria for maximum, high and moderate ecological protection. Field work associated with the program was undertaken by MPA staff, with data analysis and interpretation undertaken by BMT.

## 1.1 Program design

Water samples were collected from 29 sites, comprising 16 lease sites and 13 reference sites, located on the outer or inner boundary of the study area (Table 1.1). Sediment samples were collected at the 16 lease sites, only. Sites were positioned to provide coverage of all proposed leases, and to determine if gradients in water quality from offshore to nearshore regions exist, which in turn, may affect baseline conditions. During the field program, water temperature and dissolved oxygen data were also collected at the seabed, using a CTD profiler.

The water and sediment quality parameters that were collected in this program are detailed in Table 1.1, with the sampling schedule detailed in Table 1.2.

Table 1.1 Water and sediment quality parameters collected for chemical analysis

| Water quality parameters | Sediment quality parameters |
|---|---|
| Chlorophyll 'a' | Copper |
| Phaeophytin-a | Zinc |
| Particulate Organic Carbon | Total Kjedahl Nitrogen |
| Ortho-phosphate ($PO_4$-P) | Total Phosphorous |
| Ammonia ($NH_4$-N) | Total Organic Carbon |
| Nitrate and Nitrite ($NO_x$-N) | Particle Size Distribution |
| Total Nitrogen | Infauna |
| Total Phosphorous | |
| Silicate | |

Water quality samples were collected using an electric submersible pump from 0.5 m below the surface, at each of the 29 water quality sites, six times within both the wet and dry seasons (Table 1.2). Once retrieved, water samples were divided into the aliquots required for each analysis. Once each required sub-sample was obtained, the sample bottles were stored chilled during transportation to the laboratory.

Sediment samples were collected using a modified sediment corer. At each site, four cores (equating to four replicate samples) were collected, from which the top 5 cm of each core was used to form a composite and homogenised sample. Following sample processing, each sample was stored chilled during transportation to the laboratory.

Infauna samples were collected using a Petite Ponar grab. Four replicate grabs were collected at each site. The content of each grab was carefully rinsed through a series of graded sieves (to a minimum of 1 mm). Any material greater than 1 mm was stored in calico bags then fixed in formalin during transportation to the laboratory, where they were identified to the lowest taxonomic level possible.

### Table 1.2 Water and sediment quality sampling program schedule

| | Wet | | | | | | | Dry | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb 1 | Feb 2 | Mar 1 | Mar 2 | Apr 1 | Apr 2 | Jun 1 | Jun 2 | Jul 1 | Jul 2 | Aug 1 | Aug 2 |
| **Water quality parameters** | | | | | | | | | | | | |
| Dissolved Oxygen (in-situ) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Temperature (in-situ) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chlorophyll 'a' | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Phaeophytin-a | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Particulate Organic Carbon | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ortho-phosphate ($PO_4$-P) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ammonia ($NH_4$-N) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Nitrate and Nitrite ($NO_x$-N) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Total Nitrogen | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Total Phosphorous | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Silicate | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Sediment quality parameters** | | | | | | | | | | | | |
| Copper | ✓ | | | | | | | ✓ | | | | |
| Zinc | ✓ | | | | | | | ✓ | | | | |
| Total Kjedahl Nitrogen | ✓ | | | | | | | ✓ | | | | |
| Total Phosphorous | ✓ | | | | | | | ✓ | | | | |
| Total Organic Carbon | ✓ | | | | | | | ✓ | | | | |
| Particle Size Distribution | ✓ | | | | | | | ✓ | | | | |
| Infauna | ✓ | | | | | | | ✓ | | | | |

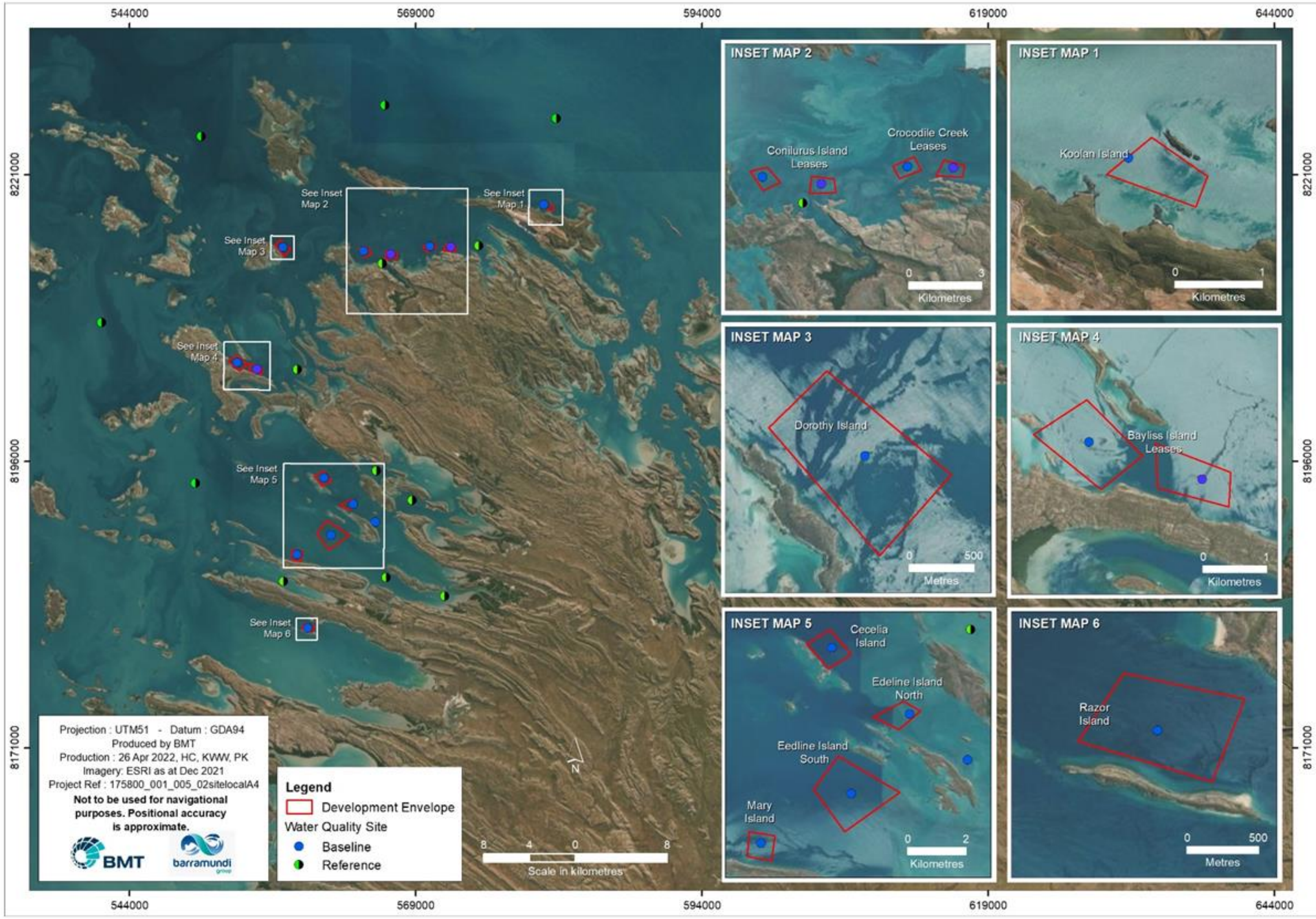



Figure 1.1 Water and sediment quality baseline monitoring sites

# 2 Statistical analysis

Water quality data were analysed statistically using PERMANOVA. Separate univariate analyses tested the relative importance of four main sources of variance, known as factors: (1) Season (fixed factor, orthogonal with 2 levels [wet & dry]; (2) Lease vs Reference [LvR] (fixed factor, orthogonal with two levels [lease & reference]; and (3) Location (fixed factor, nested within LvR, with three levels [boundary reference, inner reference, lease]) and (4) Site (fixed factor, nested within Location).

For all univariate tests, a Euclidean resemblance matrix was applied on untransformed data prior to analysis with PERMANOVA (non-parametric analysis of variance, Version 7.0.21, Primer-E Ltd) (Anderson et al. 2008). Post-hoc pair wise comparisons were then used to test for differences among levels within significant factors. Results from univariate analyses were presented using graphs of medians and standard errors for either time or location.

All sediment quality parameters were analysed to identify potential patterns between two factors: (1) Season (fixed factor, orthogonal with two levels [wet & dry]); and (4) Site (fixed factor, nested within Location). All statistical analyses, including post-hoc tests on significant factors, were undertaken using PERMANOVA (Anderson et al. 2008). This method enabled analysis of univariate and multivariate datasets, while not explicitly requiring normalised data or homogeneous variances. All analyses were run using permutations of residuals under a reduced model (n = 9999 permutations).

For percent particle size distribution, data were square-root transformed following Underwood (1997). A Bray-Curtis dissimilarity matrix was generated and the data were analysed using PERMANOVA. Multivariate statistical outputs were presented graphically using a nonmetric Multidimensional Scaling plot (nMDS). Vector overlays of the particle size groups were plotted on the nMDS to show correlations with the patterns in the multivariate data.

Separate univariate analyses were performed on sediment nutrient concentrations. No transformations were necessary for the nutrient data. Euclidean distance was used as a dissimilarity measure for all univariate analyses. By using the Euclidean measure, PERMANOVA returns an equivalent test statistic to a standard ANOVA (Anderson et al. 2008). If factors were significant, they were interpreted using post-hoc pair-wise comparisons to test for differences among levels the factor. Results from univariate analyses were presented using graphs of medians and standard errors.

The trace metals were explored with separate univariate PERMANOVAs. A Euclidean distance measure was applied on untransformed data, allowing PERMANOVA to return an equivalent test statistic to a standard ANOVA (Anderson et al. 2008). Post-hoc pair wise comparisons were used to test for differences among levels within significant factors. Results from univariate analyses were presented using plot of medians and standard errors for each factor.

For the analysis of infauna, a two-factor statistical design was used: (1) Season (fixed factor, two levels [wet & dry]); (2) Site (fixed factor). The benthic infauna assemblage (multivariate dataset) were first sorted to species level, before being consolidated to the phyla level due to the generally low diversity recorded at a class or family level. Multivariate assemblage data were square-root transformed to down-weight the contribution of dominant infauna and to allow intermediate or rarer groups to play a part in the analyses (Clarke 1993). A Bray-Curtis dissimilarity matrix was generated and the data were analysed using PERMANOVA.

Results of multivariate analysis were presented graphically using nMDS. This enabled the top benthic infauna phyla that had the strongest correlations with the patterns in the multivariate data to be determined. For univariate analyses of infauna abundance and family richness, a Euclidean distance measure was applied on untransformed data, allowing PERMANOVA to return an equivalent test statistic to a standard ANOVA (Anderson et al. 2008). Post-hoc pair wise comparisons were used to test for differences among levels within significant factors. Results from family richness and abundance analyses were presented using bar graphs of medians and standard errors for each location.

To examine the relationship between infauna community assemblage and sediment parameters (grain sizes, trace metals, nutrients), a nMDS plot of the community assemblage were graphed with vectors overlayed on the nMDS plot of sediment parameters. This enabled the top sediment parameters that had the strongest correlations with the patterns in the multivariate infauna data to be determined.

# 3 Results

## 3.1 Water quality

### 3.1.1 Dissolved oxygen

Univariate analyses applied to dissolved oxygen (% saturation) confirmed differences among seasons (Table 3.1, Figure 3.1). Overall, wet season data reported higher DO concentrations than dry season data. A significant Season x Location (LvR) effect was also present, with post-hoc pairwise comparisons confirming that dissolved oxygen differed with all combinations of season and location.

Of the lease sites, Bayliss Island and Conilurus Island had the highest median dissolved oxygen in the wet season, with Bayliss Island also having the highest median dissolved oxygen in the dry season. Dorothy Island recorded the lowest median dissolved oxygen in the wet season, with all other sites recording relatively similar concentrations in the dry season.

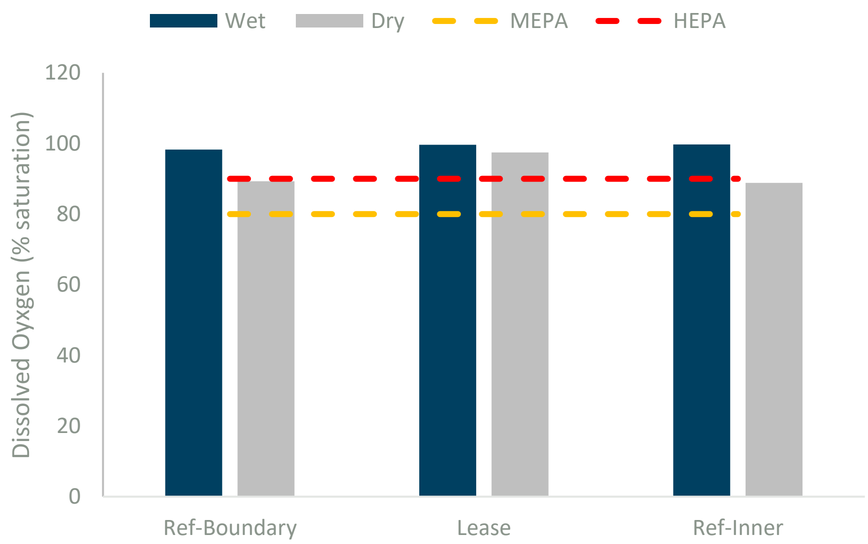



Figure 3.1 Median dissolved oxygen percent saturation at lease and reference sites for wet and dry seasons

Table 3.1 Results of a four factor PERMANOVA examining dissolved oxygen concentrations at the bottom of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **2330.2** | **0.0001** |
| LvR | 1 | 124.3 | 0.0818 |
| Location (LvR) | 1 | 54.413 | 0.2475 |
| **Season x LvR** | **1** | **584.41** | **0.0018** |
| Site (Location [LvR]) | 26 | 32.822 | 0.7129 |
| **Season x Location (LvR)** | **1** | **191.42** | **0.0295** |
| Site (Location [LvR]) x Season | 26 | 40.872 | 0.4199 |
| Residual | 275 | 40.614 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.2 Temperature

Results of univariate analysis confirmed water temperature (C°) differed between wet and dry seasons (Table 3.2, Figure 3.2), with wet season having higher median temperatures than dry season. An overall significant Season x Location (LvR) effect was not present. The highest median temperatures in both seasons were recorded at Cecelia Island, with the lowest recorded at Edeline Island North.

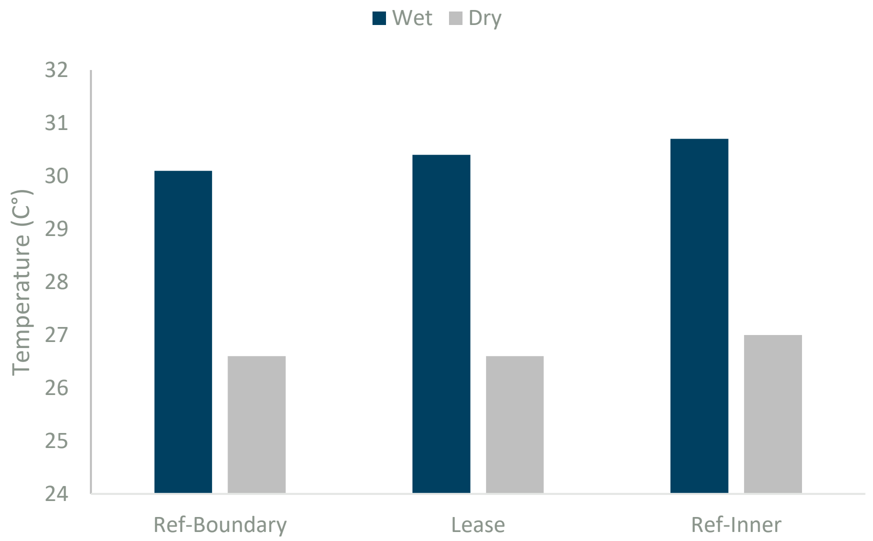



Figure 3.2 Median water temperature at lease and reference sites for wet and dry seasons

Table 3.2 Results of a four factor PERMANOVA examining temperature at the bottom of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **954.37** | **0.0001** |
| LvR | 1 | 0.1551 | 0.6852 |
| **Location (LvR)** | **1** | **6.1501** | **0.0106** |
| Season x LvR | 1 | 0.0139 | 0.8995 |
| Site (Location [LvR]) | 26 | 0.4471 | 0.9774 |
| Season x Location (LvR) | 1 | 2.0499 | 0.1264 |
| Site (Location [LvR]) x Season | 26 | 0.9497 | 0.3367 |
| Residual | 275 | 0.8915 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.3 Chlorophyll-a

The outcome of univariate analyses indicated that chlorophyll-a concentrations (ug/L) differed between wet and dry season (Table 3.3, Figure 3.3). Wet season data reported higher median concentrations across all locations than dry season data. An overall significant Season x Location (LvR) effect was not present. Of the lease sites, Bayliss Island and Bayliss Island Extra recorded the highest median chlorophyll-a concentrations in the wet season, with Bayliss Island also recording the highest median chlorophyll-a concentration in the dry season.

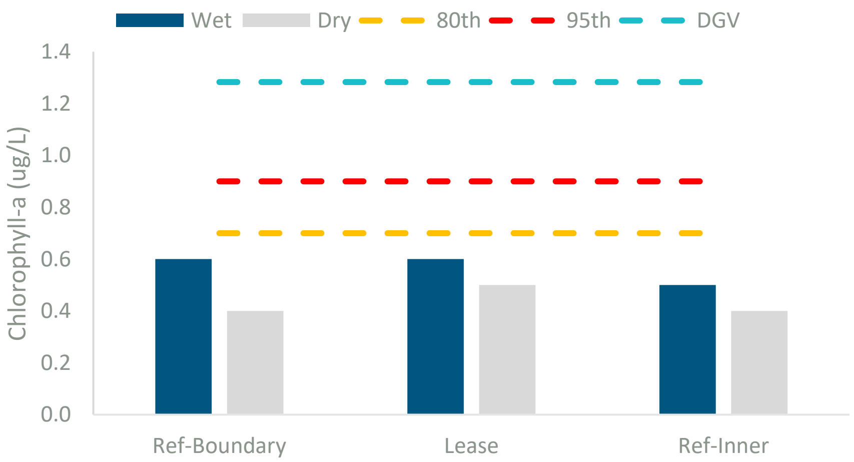



Figure 3.3 Median chlorophyll-a concentrations at lease and reference sites for wet and dry seasons against the 80th and 95th percentiles of baseline data and the default guideline value for chlorophyll-a for the north-west tropical region (ANZG 2018)

Table 3.3 Results of a four factor PERMANOVA examining chlorophyll-a concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **1.569** | **0.0001** |
| LvR | 1 | <0.00001 | 0.9555 |
| **Location (LvR)** | **1** | **0.68964** | **0.0008** |
| Season x LvR | 1 | 0.21296 | 0.0511 |
| **Site (Location [LvR])** | **26** | **0.10655** | **0.0059** |
| Season x Location (LvR) | 1 | 0.00010 | 0.9645 |
| Site (Location [LvR]) x Season | 26 | 0.02932 | 0.9657 |
| Residual | 275 | 0.05464 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.4 Phaeophytin-a

The outcome of univariate analyses indicated that phaeophytin-a concentrations (ug/L) fluctuated with season (Table 3.4, Figure 3.4). Wet season data reported lower concentrations for boundary sites than dry season data. An overall significant Season x Location (LvR) effect was not present. Of the lease sites, those within Strickland Bay (Cecelia Island, Edeline Island North, Edeline Island South, Mary Island) all recorded the greatest median phaeophytin-a concentrations during the dry season.

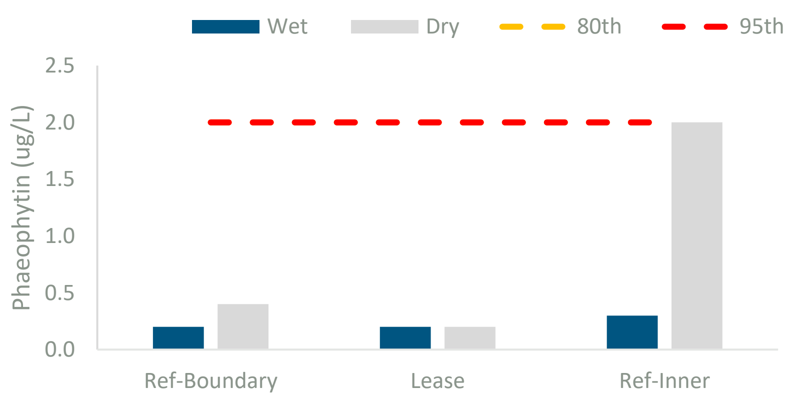



Figure 3.4 Median phaeophytin-a concentrations at lease and reference sites in wet and dry seasons against the 80th and 95th percentiles of baseline data

Table 3.4 Results of a four factor PERMANOVA examining Phaeophytin-a concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **42.8690** | **0.0001** |
| LvR | 1 | 1.05480 | 0.0884 |
| Location (LvR) | 1 | 0.44003 | 0.2718 |
| **Season x LvR** | **1** | **1.37540** | **0.0493** |
| Site (Location [LvR]) | 26 | 0.53552 | 0.0572 |
| Season x Location (LvR) | 1 | 0.93052 | 0.1054 |
| **Site (Location [LvR]) x Season** | **26** | **0.66671** | **0.0087** |
| Residual | 275 | 0.35806 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.5 Orthophosphate

Results of statistical testing for orthophosphate concentrations (ug.P/L) indicated a significant effect of season (Table 3.5, Figure 3.5). Wet season data reported lower concentrations of orthophosphate than dry season data. A significant Season x Location (LvR) effect was present, with post-hoc pairwise comparisons confirming this difference is significant for all levels of the Location factor. Boundary reference sites recorded the greatest orthophosphate concentrations, followed by the lease sites and inner reference sites.

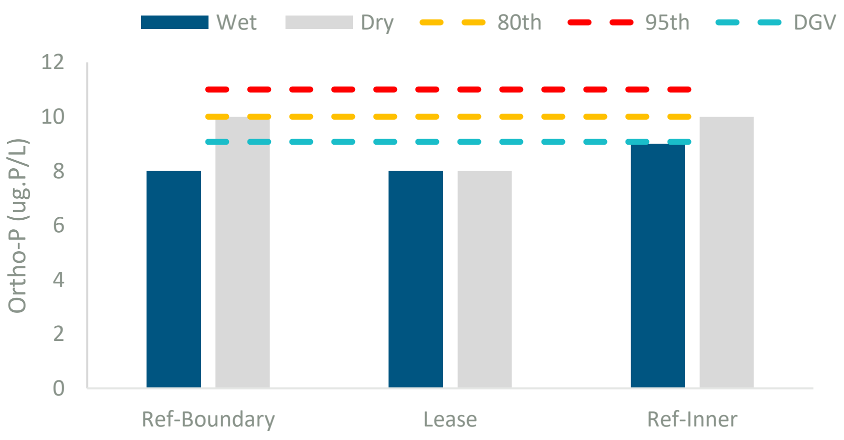



Figure 3.5 Median orthophosphate concentrations at lease and reference sites in wet and dry season against the 80th and 95th percentiles of baseline data and the default guideline value for orthophosphate for the north-west tropical region (ANZECC ARMCANZ 2000)

Table 3.5 Results of a four factor PERMANOVA examining Orthophosphate concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **131.300** | **0.0001** |
| LvR | 1 | 0.00189 | 0.9611 |
| **Location (LvR)** | **1** | **62.6000** | **0.0001** |
| Season x LvR | 1 | 1.45380 | 0.2152 |
| **Site (Location [LvR])** | **26** | **3.93610** | **0.0001** |
| **Season x Location (LvR)** | **1** | **4.15400** | **0.0340** |
| **Site (Location [LvR]) x Season** | **26** | **1.85090** | **0.0062** |
| Residual | 275 | 0.93212 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.6 Total Phosphorous

Results of statistical testing for total phosphorous concentrations (ug.P/L) indicated a significant effect of season (Table 3.6, Figure 3.6). Wet season data reported higher concentrations of total phosphorous than dry season data. A significant Season x Location (LvR) effect was not present. No site recorded consistently higher or lower concentrations of total phosphorous. Reported medians were all higher than the default guideline value for total phosphorous for the north-west tropical region (ANZECC ARMCANZ 2000).

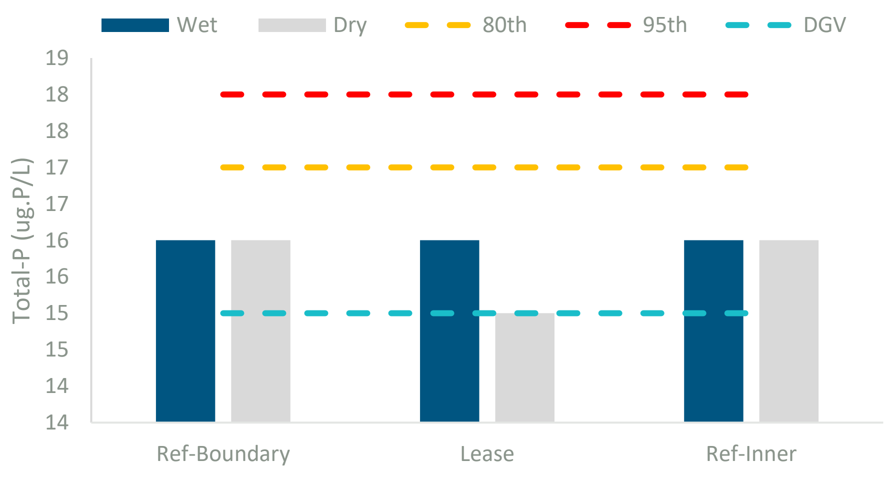



Figure 3.6 Median total phosphorous concentrations at lease and reference sites in wet and dry season against the 80th and 95th percentiles of baseline data and the default guideline value for total phosphorous for the north-west tropical region (ANZECC ARMCANZ 2000)

Table 3.6 Results of a four factor PERMANOVA examining Total Phosphorous concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **16.2000** | **0.0364** |
| LvR | 1 | 0.03009 | 0.9235 |
| Location(LvR) | 1 | 1.93910 | 0.4704 |
| Season x LvR | 1 | 0.00120 | 0.9858 |
| Site (Location[LvR]) | 26 | 3.73110 | 0.3940 |
| Season x Location(LvR) | 1 | 1.80060 | 0.4800 |
| Site (Location[LvR]) x Season | 26 | 3.95510 | 0.3226 |
| Residual | 275 | 3.61450 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.7 Silicate

The outcome of univariate analyses indicated that silicate concentrations (ug.Si/L) differed significantly between seasons and locations (Table 3.7, Figure 3.7). Wet season data reported higher concentrations of silicate than dry season data. A significant Season x Location (LvR) effect was recorded, with the inner reference sites recording a comparatively higher fluctuation in silicate concentration between seasons than the boundary reference or lease sites respectively. Post-hoc pairwise comparisons indicate that only for the boundary reference sites was this effect not significant.

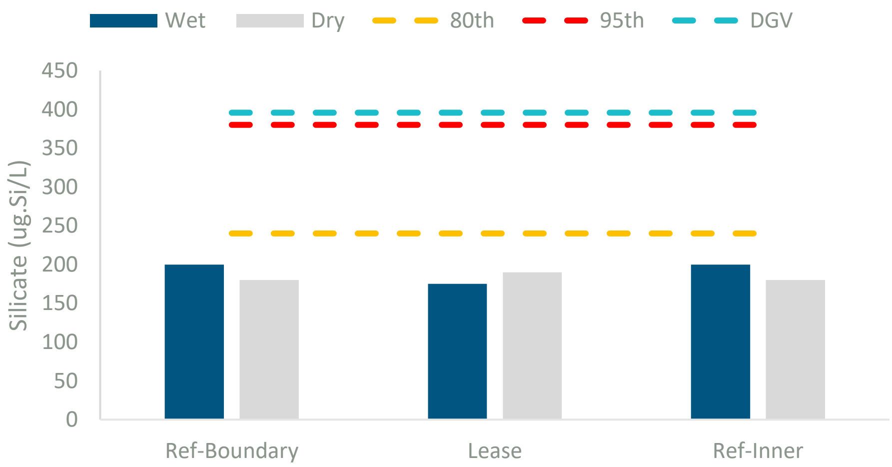



Figure 3.7 Median silicate concentrations at lease and reference sites in both wet and dry season against the 80th and 95th percentiles of baseline data and the default guideline value for silicate for the north-west tropical region (ANZECC ARMCANZ 2000)

Table 3.7 Results of a four factor PERMANOVA examining Silicate concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **192580** | **0.0001** |
| LvR | 1 | 4900.3 | 0.3635 |
| **Location (LvR)** | **1** | **37721** | **0.0118** |
| Season x LvR | 1 | 14517 | 0.1193 |
| Site (Location [LvR]) | 26 | 5981 | 0.4323 |
| **Season x Location (LvR)** | **1** | **72026** | **0.0006** |
| Site (Location [LvR]) x Season | 26 | 9626.2 | 0.0476 |
| Residual | 275 | 5949.5 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.8 Nitrate and Nitrite

The outcome of univariate analyses indicated that concentrations (ug.N/L) of nitrate and nitrite differed significantly between both seasons and locations (Table 3.8, Figure 3.8). Wet season data reported higher concentrations of nitrate and nitrite than dry season data. The results did not indicate a significant Season x Location (LvR) effect. The boundary reference sites recorded significantly greater concentrations of nitrate and nitrite than the lease or inner reference sites in both seasons.

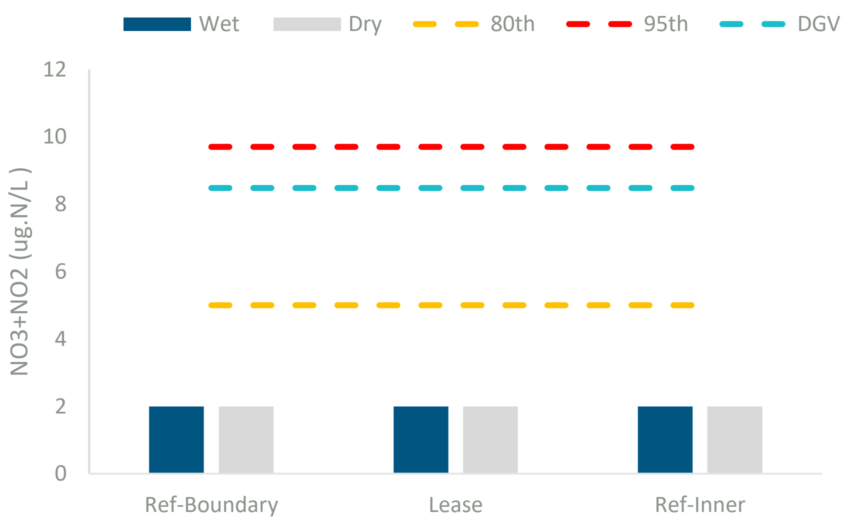



Figure 3.8 Median nitrate and nitrite concentrations at lease and reference sites in both wet and dry season against the 80th and 95th percentiles of baseline data and the default guideline value for orthophosphate for the north-west tropical region (ANZECC ARMCANZ 2000)

Table 3.8 Results of a four factor PERMANOVA examining Nitrate and Nitrite concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **75.245** | **0.0001** |
| **LvR** | **1** | **42.325** | **0.0035** |
| **Location (LvR)** | **1** | **410.26** | **0.0001** |
| Season x LvR | 1 | NA | NA |
| **Site (Location [LvR])** | **26** | **12.138** | **0.0004** |
| Season x Location (LvR) | 1 | 7.7564 | 0.2008 |
| Site (Location [LvR]) x Season | 26 | 4.045 | 0.7029 |
| Residual | 275 | 4.9339 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.9 Ammonia

Results of statistical testing indicated ammonia concentrations (ug.N/L) were not different between seasons or locations (Table 3.9, Figure 3.9), with no significant Season x Location (LvR) effect reported either.

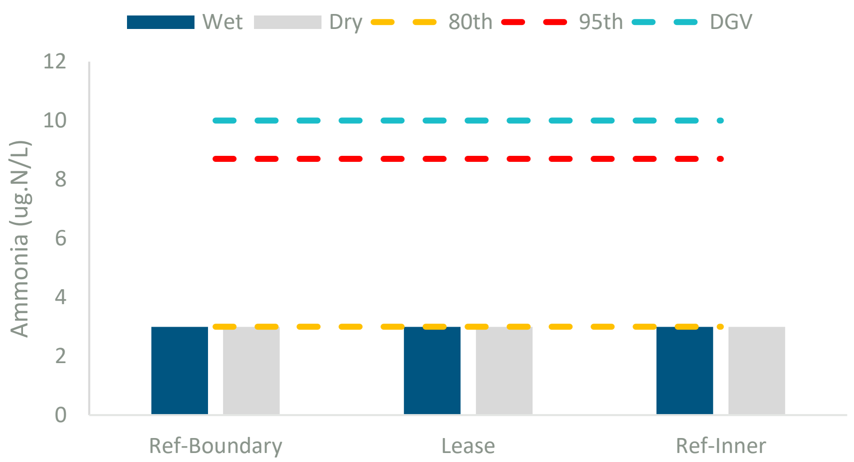



Figure 3.9 Median ammonia concentrations at lease and reference sites in both wet and dry seasons against the 80th and 95th percentiles of baseline data and the default guideline value for ammonia for the north-west tropical region (ANZECC ARMCANZ 2000)

Table 3.9 Results of a four factor PERMANOVA examining Ammonia concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| Season | 1 | 0.27761 | 0.8025 |
| LvR | 1 | 2.41090 | 0.4338 |
| Location (LvR) | 1 | 0.03140 | 0.9243 |
| Season x LvR | 1 | 0.99511 | 0.6046 |
| Site (Location [LvR]) | 26 | 1.68190 | 0.9919 |
| Season x Location (LvR) | 1 | 13.4780 | 0.0675 |
| Site (Location [LvR]) x Season | 26 | 2.9840 | 0.7511 |
| Residual | 275 | 3.8685 | |
| Total | 332 | | |

Notes:
1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.10 Total Nitrogen

Results of statistical testing indicated total nitrogen concentrations (ug.N/L) were significantly different between seasons (Table 3.10, Figure 3.10). Wet season data reported higher concentrations of total nitrogen than dry season data. The analyses did not indicate a significant Season x Location (LvR) effect. No sites had consistently higher or lower concentrations of total nitrogen.

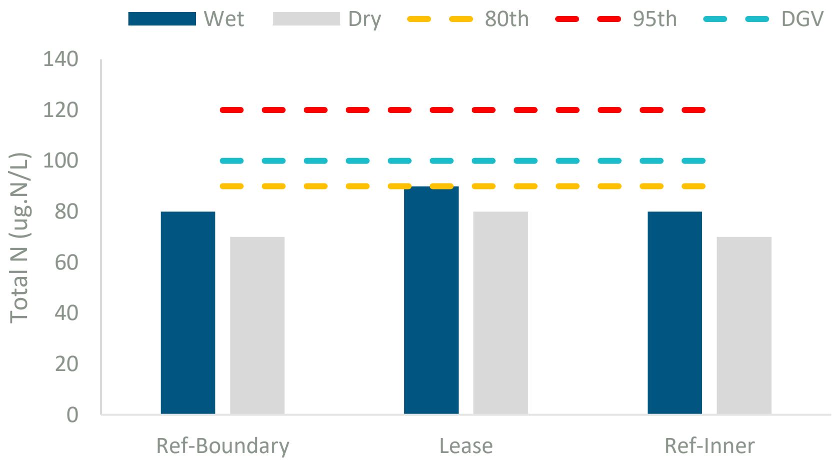



Figure 3.10 Median total nitrogen concentrations at lease and reference sites in both wet and dry seasons against the 80th and 95th percentiles of baseline data and the default guideline value for total nitrogen for the north-west tropical region (ANZECC ARMCANZ 2000)

Table 3.10 Results of a four factor PERMANOVA examining Total Nitrogen concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **8518.4** | **0.0245** |
| LvR | 1 | 1327.3 | 0.4776 |
| Location (LvR) | 1 | 270.83 | 0.6966 |
| Season x LvR | 1 | 2393.5 | 0.2913 |
| Site (Location [LvR]) | 26 | 2339.2 | 0.2261 |
| Season x Location (LvR) | 1 | 18.526 | 0.9211 |
| Site (Location [LvR]) x Season | 26 | 1787.3 | 0.7337 |
| Residual | 275 | 2175.2 | |
| Total | 332 | | |

Notes:

1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

### 3.1.11 Particulate Organic Carbon (POC)

The outcomes of univariate analyses indicated that POC concentrations were significantly different between both seasons and locations (Table 3.11, Figure 3.11). Wet season data reported higher concentrations of POC than dry season data. The results did not indicate a significant Season x Location (LvR) effect. POC concentrations were generally higher at the inner reference sites than the lease or boundary reference sites, with a decreasing gradient from nearshore to offshore locations.

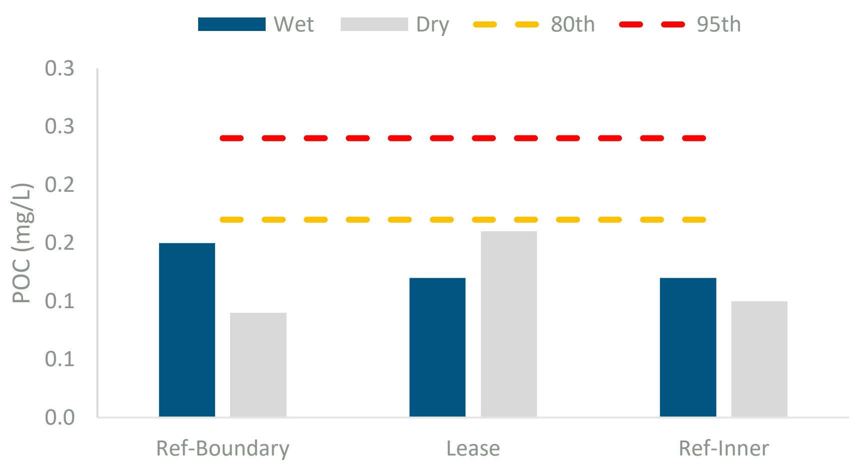



Figure 3.11 Median concentrations of POC at lease and reference sites in both wet and dry seasons against the 80th and 95th percentiles of baseline data

Table 3.11 Results of a four factor PERMANOVA examining POC concentrations at the surface of the water column

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Season** | **1** | **0.25060** | **0.0001** |
| LvR | 1 | NA | NA |
| **Location (LvR)** | **1** | **0.46830** | **0.0009** |
| Season x LvR | 1 | 0.00370 | 0.3681 |
| **Site (Location [LvR])** | **26** | **0.00730** | **0.0185** |
| Season x Location (LvR) | 1 | NA | NA |
| Site (Location [LvR]) x Season | 26 | 0.00200 | 0.8422 |
| Residual | 275 | 0.00346 | |
| Total | 332 | | |

Notes:

1. L = Lease, R = Reference, Df = Degrees of freedom, MS = Mean square

## 3.2 Sediment quality

### 3.2.1 Nutrients

Individual PERMANOVA univariate analyses for each sediment quality parameter indicated there were significant differences between sites for concentrations of total nitrogen, phosphorous and organic carbon, but no significant differences between seasons (Table 3.12, Figure 3.12). Wet season data reported lower median concentrations of total nitrogen, total phosphorous and total organic carbon than dry season data.  These reported differences between seasons were consistent for all sites.  No north-south gradient was reported in total nutrient concentrations across the lease sites.

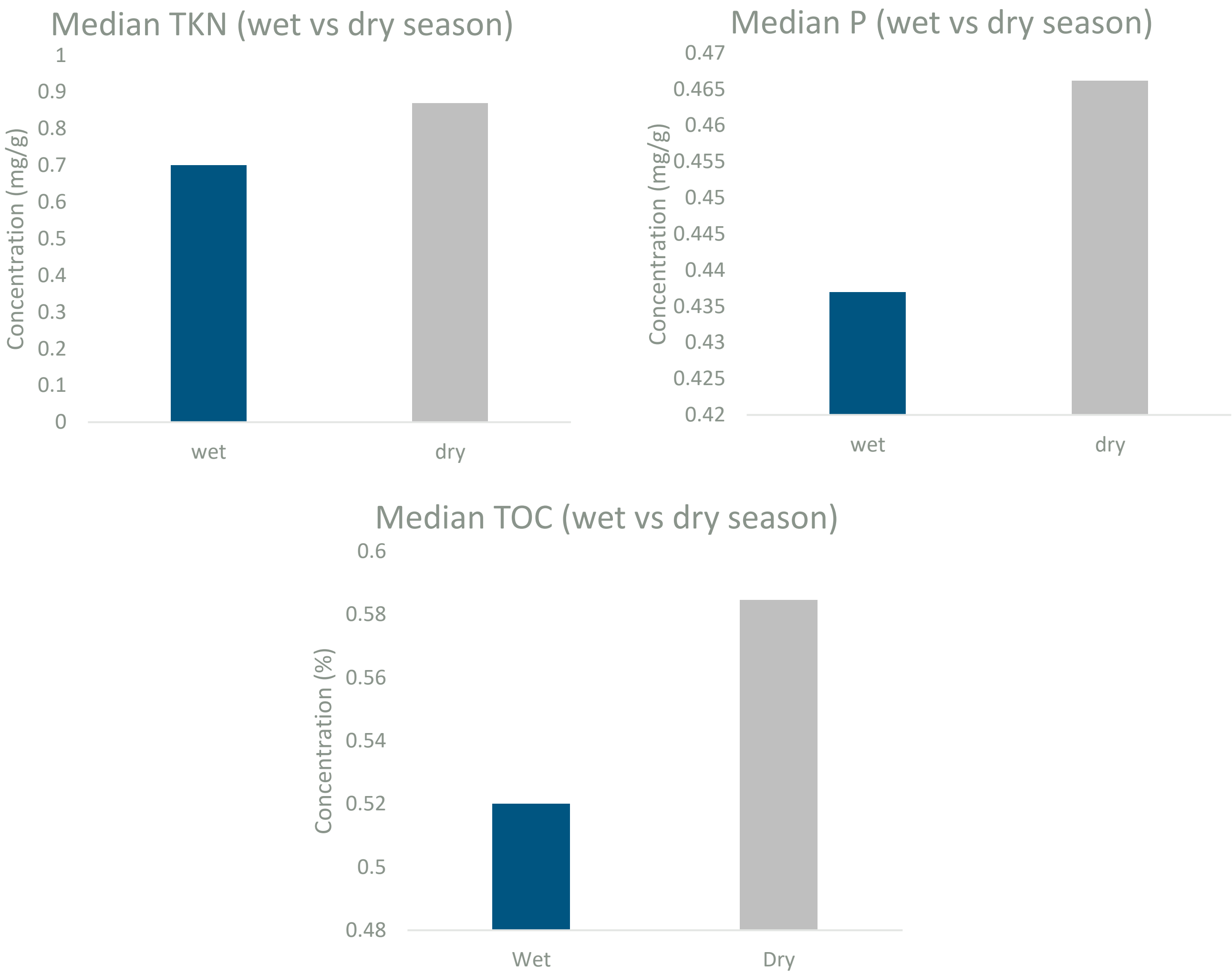



Figure 3.12 Median concentrations of total nitrogen, total phosphorous and total organic carbon across for wet and dry season across all sites

Table 3.12 Results of two factor PERMANOVAs examining total nutrient concentrations in the sediments of all lease sites

| Source | Total Nitrogen | | | Total Phosphorous | | | Total Organic Carbon | | |
|---|---|---|---|---|---|---|---|---|---|
| | Df | MS | P(perm) | Df | MS | P(perm) | Df | MS | P(Perm) |
| **Site** | **9** | **0.14022** | **0.0108** | **9** | **0.00414** | **0.0221** | **9** | **0.06111** | **0.0005** |
| Season | 1 | 0.09800 | 0.0722 | 1 | 0.00162 | 0.1153 | 1 | 0.0180 | 0.0841 |
| Residual | 9 | 0.02467 | | 9 | 0.00053 | | 9 | 0.0047 | |
| Total | 19 | | | 19 | | | 19 | | |

Notes:
1. Df = Degrees of freedom, MS = Mean square

### 3.2.2 Trace Metals

Trace metals of copper and zinc were variable temporally and spatially (Table 3.13, Figure 3.13), particularly zinc, however both were in relatively low concentrations throughout (well below ANZG guidelines of 65 mg/kg and 200 mg/kg for copper and zinc respectively). Wet season data reported for zinc were marginally higher than for dry season. Median concentrations of copper were almost the same in both seasons. There was no clear north to south gradient in trace metal concentrations.

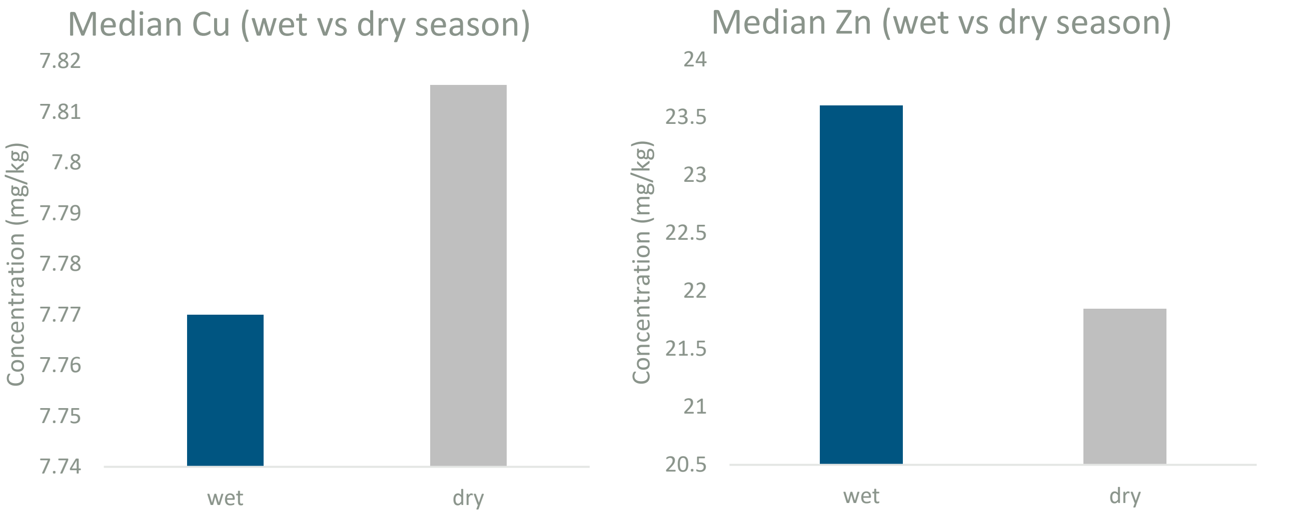



Figure 3.13 Median concentrations of copper and zinc in sediments for wet and dry season across all lease sites

Table 3.13 Results of two factor PERMANOVAs examining trace metal concentrations in the sediments of all lease sites

| Source | Copper | | | Zinc | | |
|---|---|---|---|---|---|---|
| | Df | MS | P(perm) | Df | MS | P(perm) |
| **Site** | **9** | **13.177** | **0.0001** | **9** | **87.778** | **0.0001** |
| **Season** | 1 | 0.0980 | 0.559 | **1** | **24.200** | **0.0138** |
| Residual | 9 | 0.2635 | | 9 | 2.5333 | |
| Total | 19 | | | 19 | | |

Notes:

1. Df = Degrees of freedom, MS = Mean square

### 3.2.3 Particle size distribution

Results for particle size distribution indicated that there were no overall differences between season but clear separation in distribution between some sites (Table 3.14; Figure 3.14, Figure 3.15). For example, Bayliss Island, Cecelia Island, Koolan Island and Razor Island were characterised by higher concentrations of gravel and coarse sand. All other sites reported next to no gravel or coarse sand, and instead sediments were predominantly made up of silt or fine sand. This is the case for both wet and dry seasons. The nMDS plot also showed no clear separation between seasons, nor a clear ordination of sites based on spatial proximity.

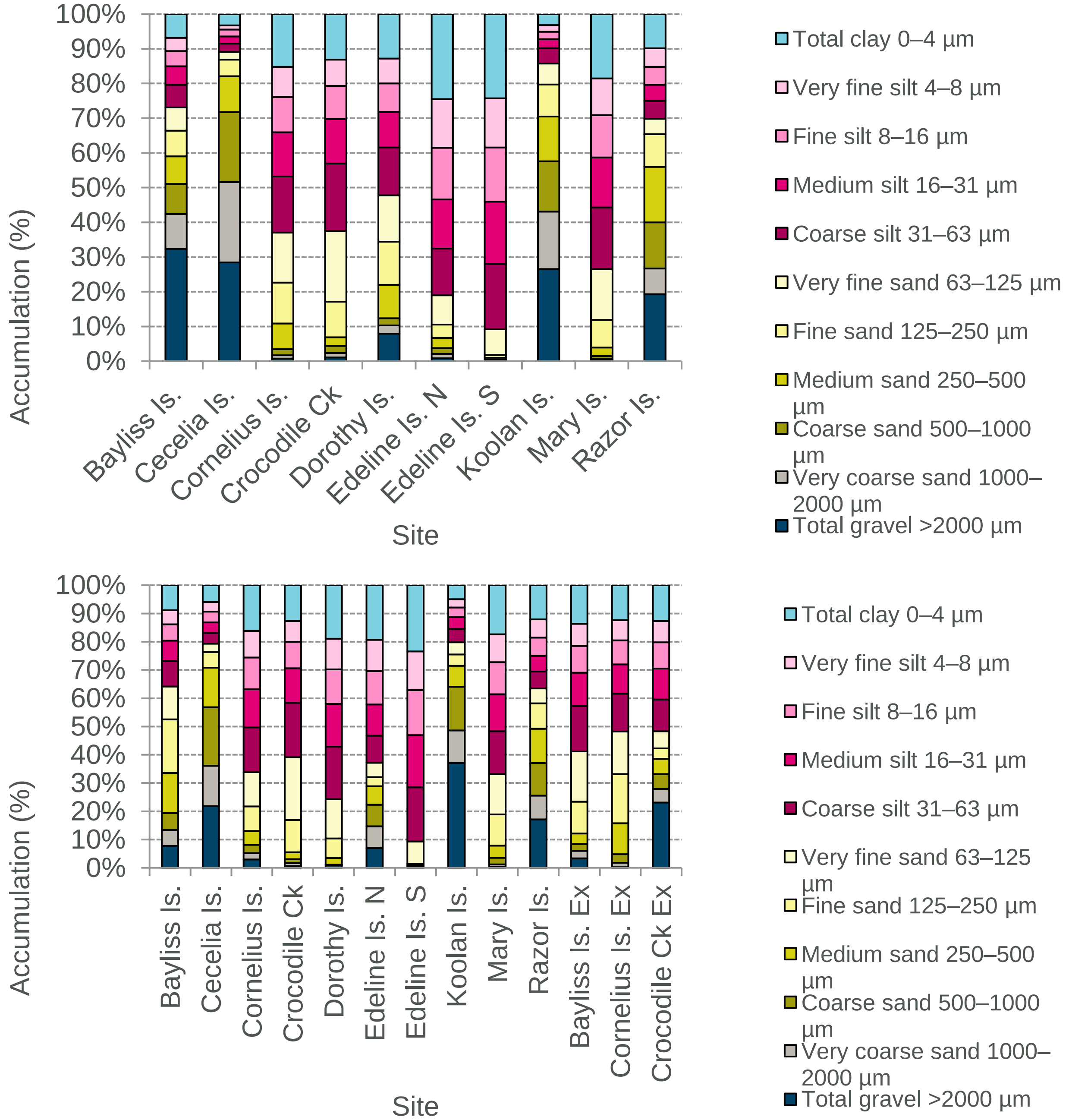
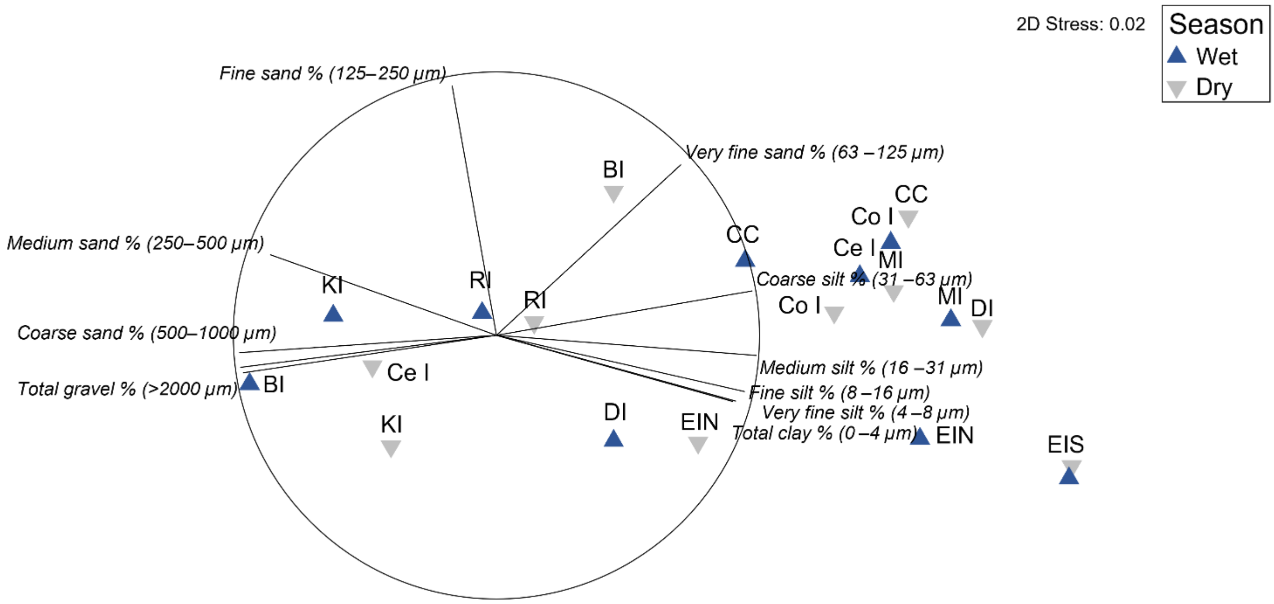



Figure 3.14 Particle size distribution results for all sites for wet and dry seasons.




Notes:
1. In nMDS, differences between sites are represented by the relative distance between points
2. 2D stress is a representation of the dimensionality of the ordination i.e. how much can be interpreted from constraining the ordination onto 3 or in this case 2 dimensions: stress <0.05 gives an excellent representation; stress <0.1 corresponds to a good ordination with no real prospect of a misleading interpretation; stress <0.2 gives a potentially useful 2–dimensional ordination, though for values at the upper end of this range, too much reliance should not be placed on the detail of the plot
3. Black line vectors indicate the relative importance of the individual trace metals in driving the separation between Sites.
4. KI = Koolan Island, EIN = Edeline Island North, EIS = Edeline Island South, RI = Razor Island, BI = Bayliss Island, CoI = Conilurus Island, CeI = Cecelia Island, MI = Mary Island, CC = Crocodile Creek, DI = Dorothy Island

Figure 3.15 Non-Metric multidimensional scaling plot showing ordination of sites with overlay of particle size distribution

Table 3.14 Multivariate PERMANOVA results for particle size distribution of sediments

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Site** | **9** | **551.43** | **0.0433** |
| Season | 1 | 19.173 | 0.8152 |
| Residual | 9 | 176.82 | |
| Total | 19 | | |

Notes:
1. Df = Degrees of freedom, MS = Mean square

### 3.2.4 Infauna

Outcomes of univariate analyses of infauna abundance and species richness indicated no differences between season but a significant difference between sites for species richness (Table 3.15, Figure 3.16, Figure 3.17). At a site level, Razor Island, Bayliss Island and Cecelia Island recorded the highest abundance and species richness overall. Mary Island and Crocodile Creek recorded lower abundances but higher species richness during the wet season and the opposite in the dry season; while at Koolan Island and Dorothy Island the inverse was true. Crocodile Creek Extra and Conilurus Island Extra recorded no infauna in the wet season.

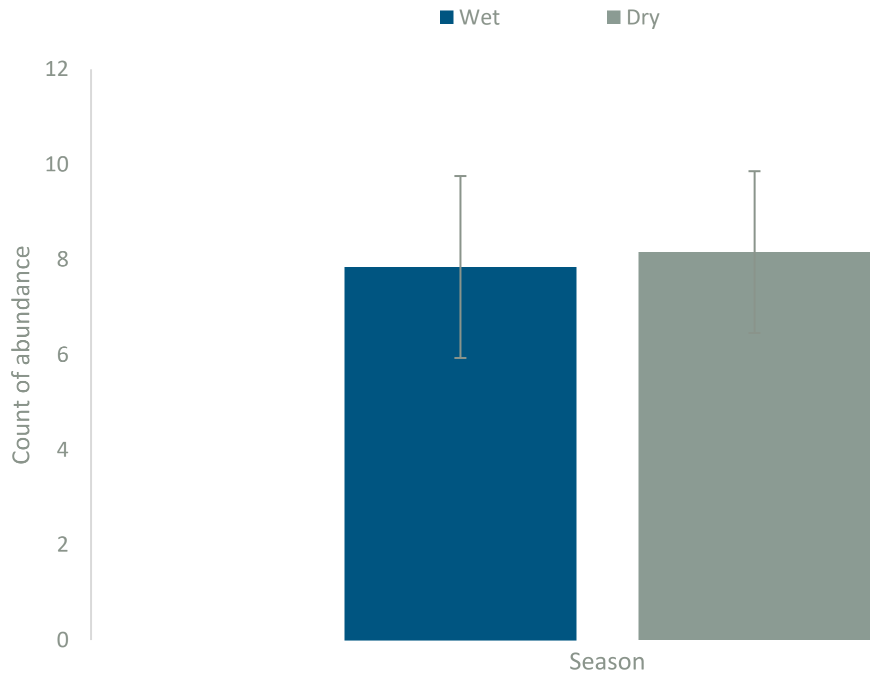



Figure 3.16 Mean (± Standard Error) abundance of infauna taxa recorded across all sites for wet and dry season

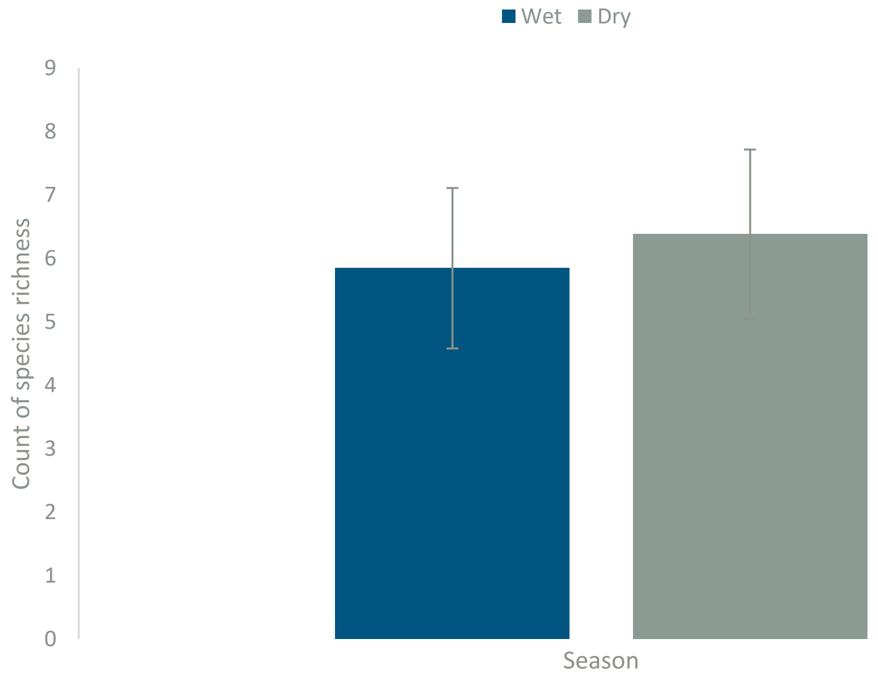



Figure 3.17 Mean (± Standard Error) counts of species richness across all sites for wet and dry seasons

Table 3.15 Results of two factor PERMANOVAs for infauna abundances and species richness for all sites

| Source | Abundance | | | Species Richness | | |
|---|---|---|---|---|---|---|
| | Df | MS | P(perm) | Df | MS | P(perm) |
| **Site** | **12** | **2305.6** | **0.0779** | **12** | **39.013** | **0.0001** |
| Season | 1 | 2179.6 | 0.282 | **1** | **1.8846** | **0.5438** |
| Residual | 12 | 1638.7 | | 12 | 4.8846 | |
| Total | 25 | | | 25 | | |

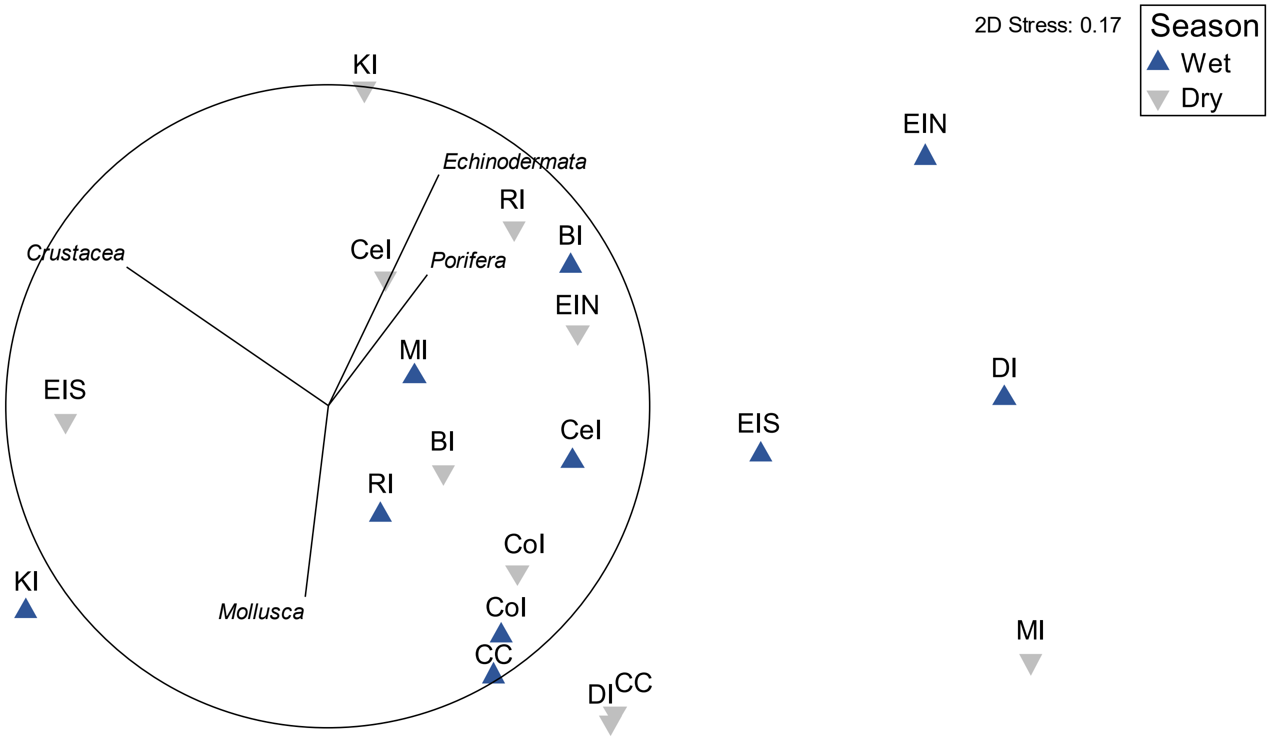
Notes:
1. Df = Degrees of freedom, MS = Mean square

Multivariate analyses of infauna data revealed a diverse community, represented by 10 phyla (Annelida, Chaetognatha, Chordata, Crustacea, Echinodermata, Mollusca, Nemertea, Porifera, Sipuncula) and 69 families. Sampling recorded 22 families of polychaetes (accounting for 34% of the infauna sampled), 25 families of crustaceans (accounting for 40% of the infauna sampled), 4 families of molluscs (accounting for 5% of the infauna sampled), 2 families of echinoderms (accounting for 5% of the infauna sampled) and 2 families of porifera (accounting for 5% of the infauna sampled). The PERMANOVA analysis indicated significant variation of community assemblage between sites but not between seasons (Table 3.16, Figure 3.18, Figure 3.19). These results are mirrored in the nMDS which shows variation at the site level, but no clear separation between seasons. Overall, polychaetes were more abundant in wet season samples, while crustaceans were more abundant in dry season samples. All other phyla had relatively similar abundances and representation in both seasons. At a site level, Bayliss Island and Cecelia Island reported the highest abundances and greatest diversity due to greater representation of polychaetes and crustaceans.

Table 3.16 Results of a two-factor PERMANOVA for the community assemblage of infauna for all sites

| Source | Df | MS | P(perm) |
|---|---|---|---|
| **Site** | **9** | **2105.2** | **0.0465** |
| Season | 1 | 929.09 | 0.5155 |
| Residual | 9 | 1188.4 | |
| Total | 19 | | |

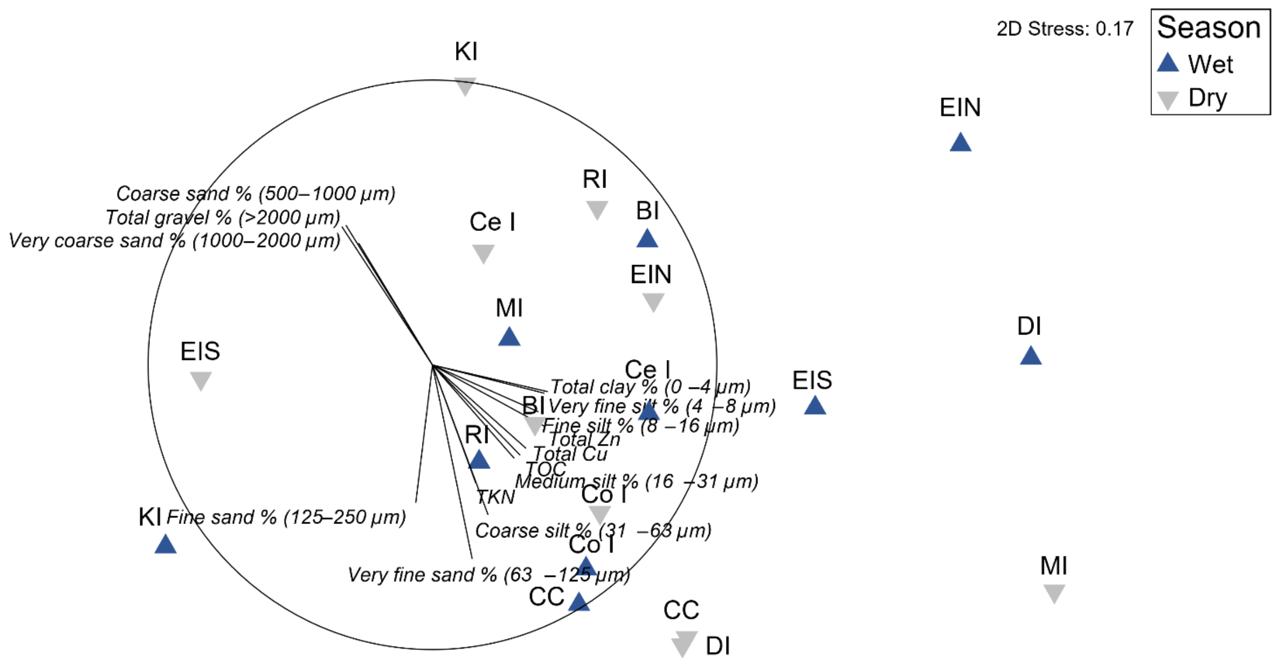
Notes:
1. Df = Degrees of freedom, MS = Mean square
2. Wet season results for Crocodile Creek Extra and for Conilurus Island Extra were removed as they recorded no counts of infauna and as such would confound the analyses.




Notes:
1. In nMDS, differences between sites are represented by the relative distance between points
2. 2D stress is a representation of the dimensionality of the ordination i.e. how much can be interpreted from constraining the ordination onto 3 or in this case 2 dimensions: stress <0.05 gives an excellent representation; stress <0.1 corresponds to a good ordination with no real prospect of a misleading interpretation; stress <0.2 gives a potentially useful 2–dimensional ordination, though for values at the upper end of this range, too much reliance should not be placed on the detail of the plot
3. Black line vectors indicate the relative importance of the individual trace metals in driving the separation between Sites.
4. KI = Koolan Island, EIN = Edeline Island North, EIS = Edeline Island South, RI = Razor Island, BI = Bayliss Island, CoI = Conilurus Island, CeI = Cecelia Island, MI = Mary Island, CC = Crocodile Creek, DI = Dorothy Island

Figure 3.18 nMDS ordination of infauna community assemblage among seasons by site with vector overlays.

Vector overlays of the sediment parameters onto the infauna nMDS ordination plot showed that the infauna assemblage at the northern part of the Archipelago (Crocodile Creek, Conilurus Island, Dorothy Island) which included generally lower counts of infauna overall inhabited fine or very fine sediments or silt with higher TKN and TOC content. Polychaetes and crustaceans, which were found in greater abundance at Bayliss Island, Cecelia Island and Koolan Island, inhabited coarse or gravelly sediments (500->2000 um).




Notes:

1. In nMDS, differences between assemblages are represented by the relative distance between points
2. 2D stress is a representation of the dimensionality of the ordination i.e. how much can be interpreted from constraining the ordination onto 3 or in this case 2 dimensions: stress <0.05 gives an excellent representation; stress <0.1 corresponds to a good ordination with no real prospect of a misleading interpretation; stress <0.2 gives a potentially useful 2–dimensional ordination, though for values at the upper end of this range, too much reliance should not be placed on the detail of the plot
3. Black line vectors indicate the relative importance of the individual sediment characteristics in driving the separation of community assemblage between Sites.
4. KI = Koolan Island, EIN = Edeline Island North, EIS = Edeline Island South, RI = Razor Island, BI = Bayliss Island, CoI = Conilurus Island, CeI = Cecelia Island, MI = Mary Island, CC = Crocodile Creek, DI = Dorothy Island

Figure 3.19 nMDS of infauna community assemblage among seasons with vector overlay of predominant sediment characteristics

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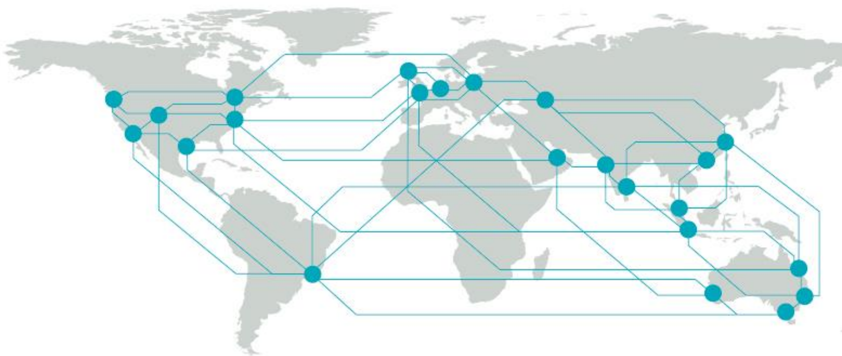

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