

# CHAPTER 3: SPATIAL STUDY OF VARIATION

## 3.1 MATERIAL AND METHODS

### 3.1.1 Objectives

To assess spatial variation in water quality around Green island with respect to depth and over a range of nested horizontal scales.

### 3.1.2 Variables

- . Dissolved Inorganic Nutrients,  $\text{NO}_2 + \text{NO}_3$ ,  $\text{NH}_4$ ,  $\text{PO}_4$
- . Total Phosphorous and Total Nitrogen
- . Dissolved oxygen
- . Clarity
- . Chlorophyll *a*
- .  $\text{BOD}_5$
- . Suspended solids

Section 1.4.2 details the sampling procedures, whilst Appendix 2 gives the analytical procedures used for the determination of these parameters.

### 3.1.3 Experimental Design

Sampling was undertaken to assess the contribution of the following factors to variability in water quality around at Green Island. Sampling was undertaken only in the reef slope environment. Figure 3.1.b. represents the sampling of these factors schematically.

**Depth:** Variation between 2 depths. Surface samples were taken at 0.2 m below the surface, and depth samples were taken 1 metre above the bottom (ca. 7-10 metres).

**Location:** Variation between 6 locations (Figure 3.1), each location a minimum of 500 metres apart. Locations were selected to cover the range of environmental conditions around Green Island.

**Site:** Variation between 2 sites within each location, ca. 75-100 metres apart.

**Replication:** Variation between 2 replicate samples, ca. 5-10 metres apart, taken at each combination of site and depth.

#### 3.1.4 Site Selection

Sampling locations were selected to quantify the range of ambient conditions around the island. On the western side of the island, locations A and B from the temporal study were utilised. Locations C and D were located at the southern end of the island, location C being in an embayment. Locations E and F were located on the eastern side of the island (Figure 3.1).

**Table 3.1.** Description of sampling locations

Location	Description
A	250 metres north of the sewerage pipe and some 100m south of the jetty in line with the outer lead light.
B	250 metres to the south of the sewerage pipe. Both flats and slopes sampled.
C	On the western side of the reef away from the influence of the cay. In an embayment along the consolidated reef edge at ca. 7 metres.
D	At the southern end of the reef in a bommie field at ca. 7 metres depth.
E	Located at the north-eastern end of the reef amongst patch reefs at ca. 8 metres depth.
F	Located at the south eastern end of the reef amongst patch reefs at ca. 8 metres depth.

#### 3.1.5 Timing

The spatial sub-programme was undertaken on the the 3rd of June 1989 from 1010 to 1710 hours.

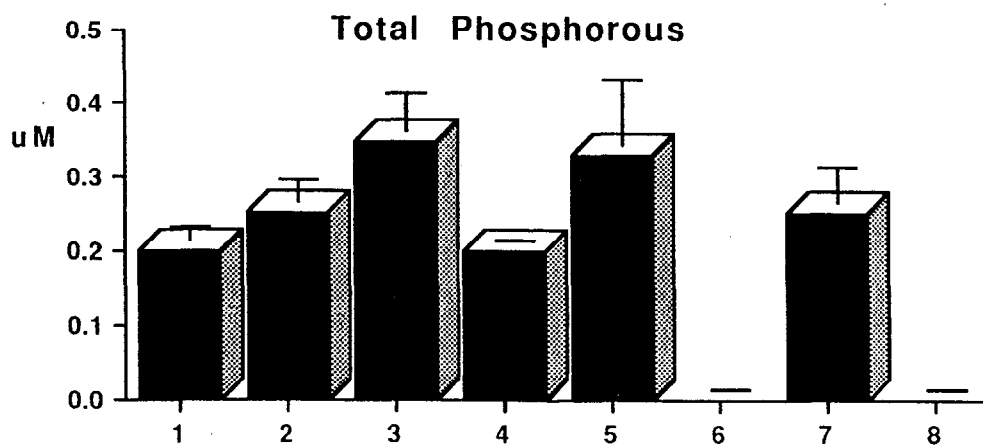
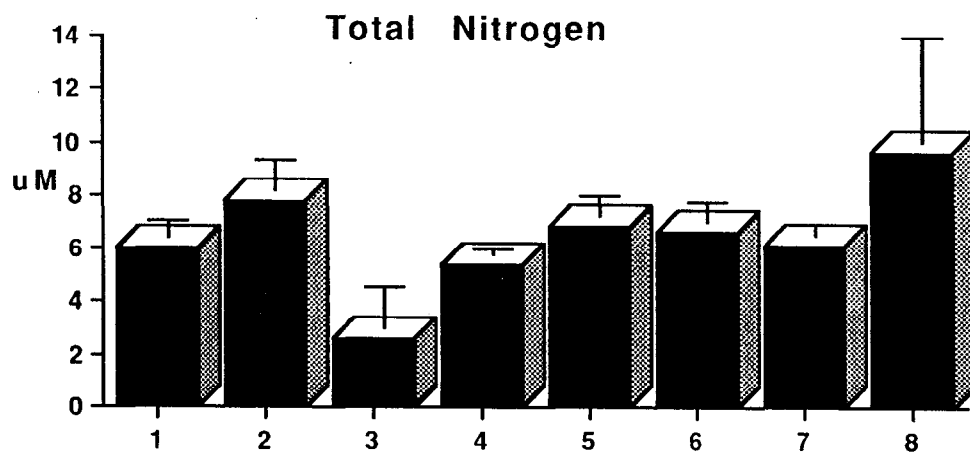
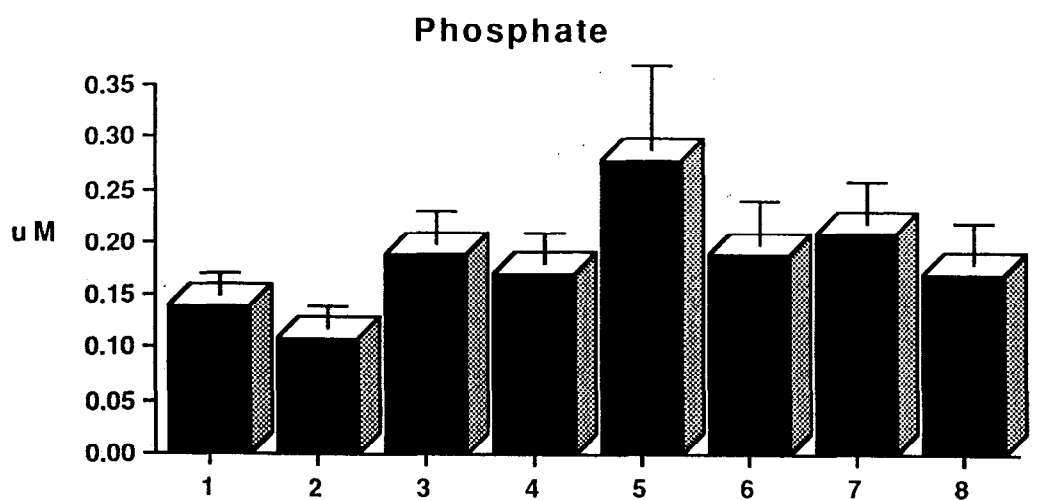
#### 3.1.6 Constraints

As this study was not repeated on any other days due to cost constraints it must be assumed that conditions on June 3, 1989 were typical. The extent to which temporal variability may have confounded the apparent spatial patterns was qualitatively examined using the temporal study results.

#### 3.1.7 Analysis

The analysis of spatial variation constituted a three factor design, (location x depth x site). Location and depth were treated as fixed orthogonal factors, whilst sites was considered a random variable and was nested within location.

Figure 2.4. Pooled Mean concentration ( $\mu\text{M}$ ) of Phosphate, Total Nitrogen and Total Phosphorous over the eight sampling periods in the 24 hour temporal study around Green Island.



**Figure 2.3. Pooled mean concentration (uM) of Nitrite + Nitrate, Ammonium and Dissolved Inorganic Nitrogen over the eight sampling periods in the 24 hour temporal study around Green Island.**

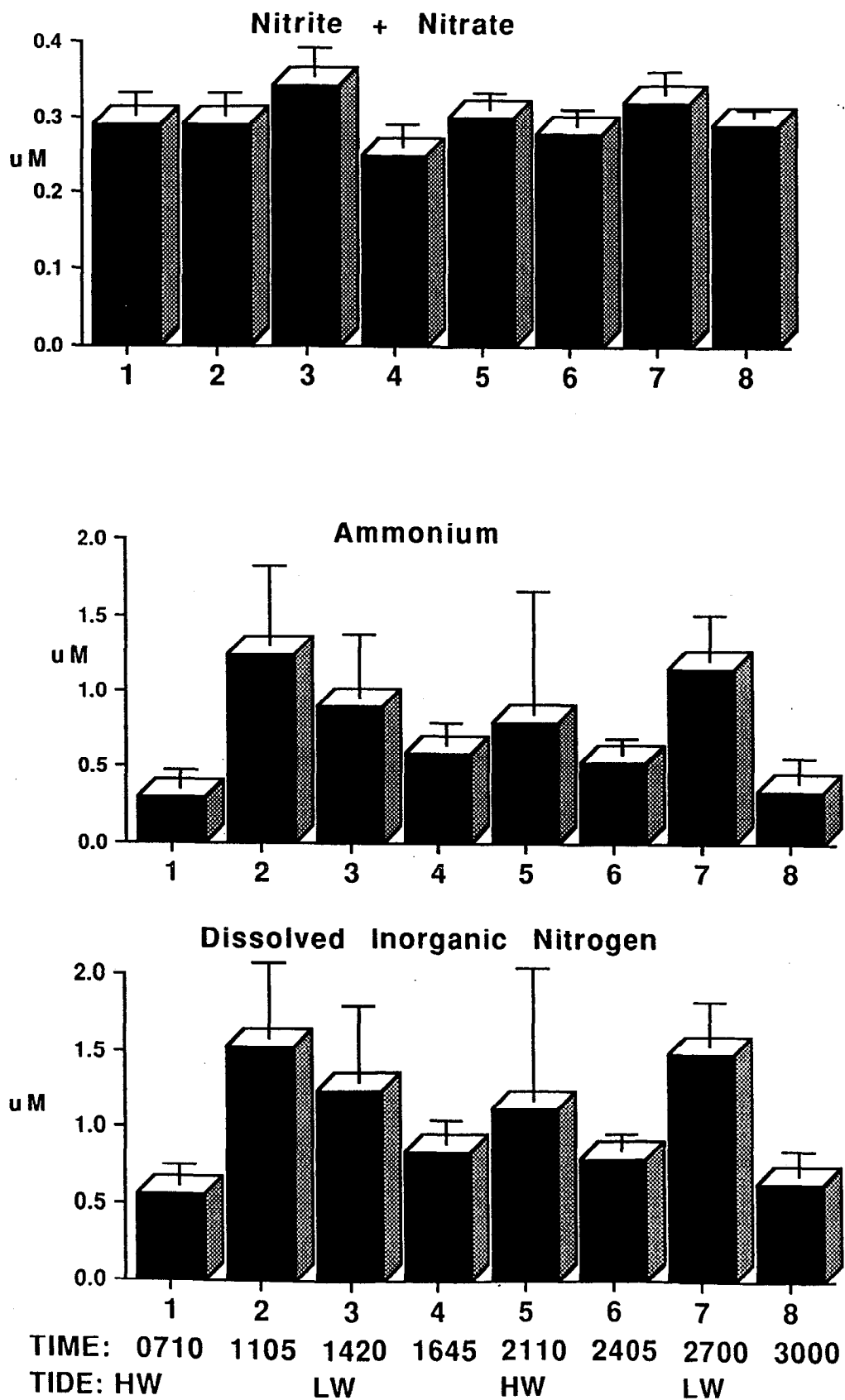
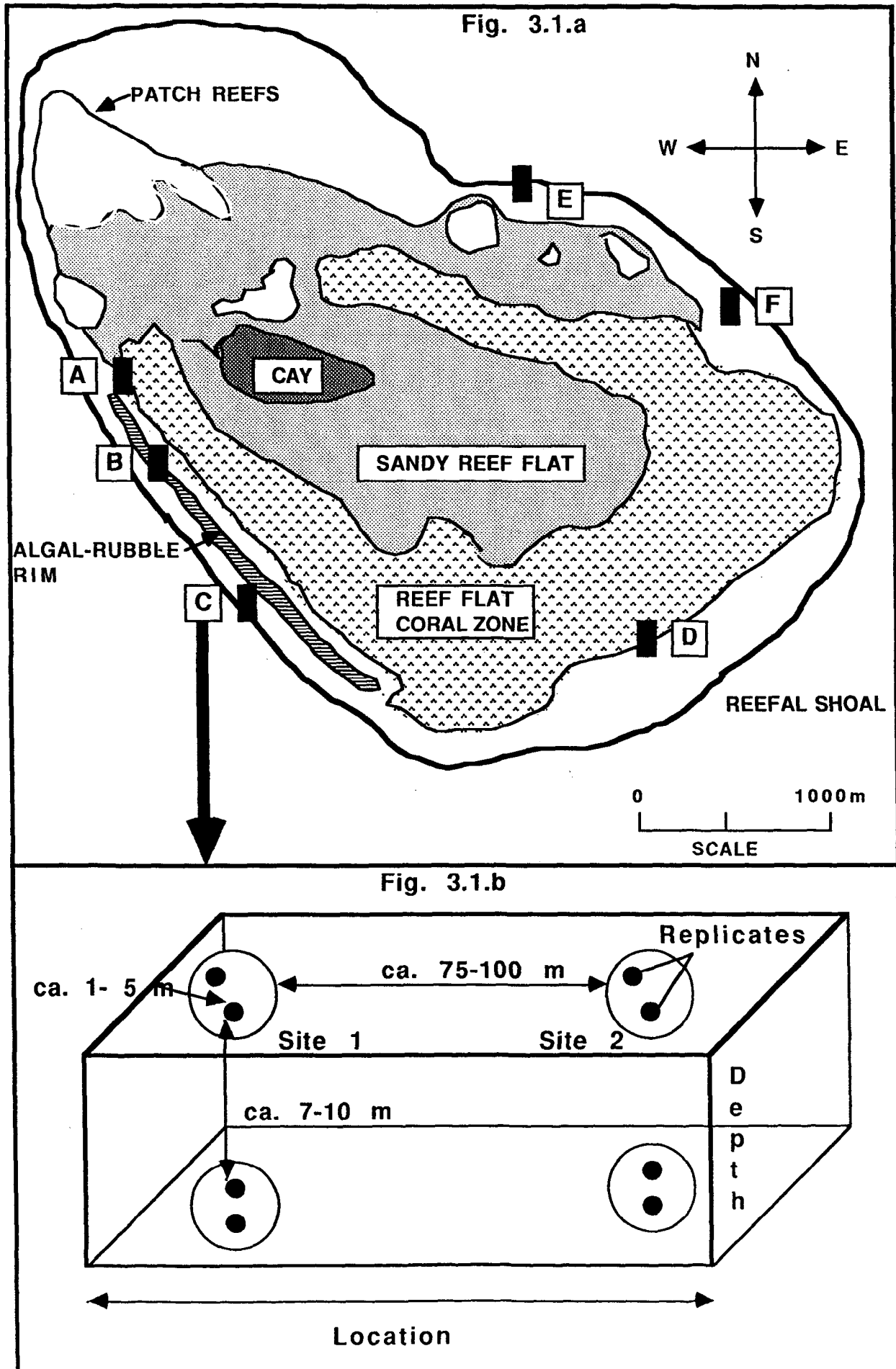


Figure 3.1. Map of Spatial study sampling locations around Green Island (3.1.a.) and a schematic representation of the sampling design (3.1.b).



## 3.2 RESULTS

### 3.2.1 Components of Variation

#### Depth Effects

Ammonium was the only parameter to potentially vary, albeit marginally ( $F = 14.02$ ; 1,22 df;  $P = 0.056$ ) between samples taken on the surface ( $0.90 \pm 0.15 \mu\text{M}$ ) and at depth ( $0.76 \pm 0.06 \mu\text{M}$ ). Data for depths were subsequently pooled to analysis of other factors. Table 3.3 summarises mean values of water quality parameters by depth.

#### Location Effects

Location was a significant source of variation for all inorganic nutrients, but not for total phosphorous, total nitrogen or particulate nitrogen (Table 3.2.a.). Pooled mean values are summarised in Table 3.4.a. Nitrite + nitrate mean concentrations at locations A ( $0.27 \pm 0.01 \mu\text{M}$ ) and C ( $0.23 \pm 0.02 \mu\text{M}$ ) were both significantly less ( $F = 5.37$ ; 5,6 df;  $P = 0.032$ ) in mean concentration from locations D ( $0.38 \pm 0.03 \mu\text{M}$ ) and E ( $0.37 \pm 0.02 \mu\text{M}$ ). Location F ( $0.35 \pm 0.03 \mu\text{M}$ ) was also significantly different from location C. Differences in ammonium concentrations between locations were only marginally significant ( $F = 5.49$ ; 5,6 df;  $P = 0.079$ ) and consequently were not detectable using Tukey's test. Dissolved inorganic nitrogen concentration were significantly ( $F = 5.61$ ; 5,6 df;  $P = 0.021$ ) higher at location D ( $1.69 \pm 0.27 \mu\text{M}$ ) than at locations A ( $0.89 \pm 0.09 \mu\text{M}$ ) and E ( $0.78 \pm 0.16 \mu\text{M}$ ). The mean orthophosphate concentration at location B ( $0.21 \pm 0.02 \mu\text{M}$ ) was significantly ( $F = 8.58$ ; 5,6 df;  $P = 0.010$ ) higher than location E ( $0.13 \pm 0.04 \mu\text{M}$ ). Differences in location were not a significant source of variation for dissolved oxygen, temperature and  $\text{BOD}_5$ .

#### Site Effects

Sites, nested within locations, were not a significant source of variation in any cases (Table 3.2).

### 3.2.2 Analysis of Power

Power was less than 0.4 to detect differences in the spatial study for small changes (<25%) in ambient water quality parameters. However, the ability to detect moderate changes (> 50%) was good ( $P = 0.93$ ). There may have been some temporal confounding but the results of the temporal study indicated this was unlikely.

### 3.2.3 Multi-variate analysis

Classification analysis (Figure 3.2.a.) showed that locations split broadly into windward (D and F) and leeward (A,B, and C). However, location E, on the north-eastern edge of the reef was highly dis-similar. The MDS analysis (Figure 3.2.b.) suggested that sites grouped according to DIN concentration. Locations on the windward side of Green Island had a greater concentration of DIN whilst location E had the least.

**Table 3.2.A.** Summary table of results of analysis of variance results for nutrients in the spatial study. All data was log transformed after residual analysis for heteroscedascity.  
 \* = sign. at 0.1; \*\* sign. at 0.05; \*\*\* = sign. at 0.01 level.

SOURCE OF VARIATION	DF	NO <sub>2</sub> + NO <sub>3</sub>		NUTRIENT SPECIES			TN	TP
				NH <sub>4</sub>	DIN	PO <sub>4</sub>		
(A) DEPTH	1	NS	NS		*	NS	NS	NS
(B) LOCATION	5	**	***		***	**	NS	NS
(C) SITE(LOCATION)	6	NS	NS		NS	NS	NS	NS
A*B	5	NS	NS		NS	NS	NS	NS
A*C	6	NS	NS		NS	**	**	NS

**Table 3.2.b.** Summary table of results of analysis of variance results for nutrients in the spatial study. All data was log transformed after residual analysis for heteroscedascity.  
 \* = sig at 0.1; \*\* sig at 0.05; \*\*\* = sig at 0.01 level.

SOURCE OF VARIATION	DF	Tempera- ture			
			O <sub>2</sub>	BOD5	PN
(A) DEPTH	1	NS	NS	NS	NS
(B) LOCATION	5	NS	NS	NS	NS
A*B	6	NS	NS	NS	NS



**Table 3.3.** Summary statistics of Depth Differences in the Spatial Study.  
S= surface; D = depth.

Parameter	Habitat	N	Mean	S.E.	Range
<b>Nitrite + Nitrate</b> ( $\mu\text{M}$ )	S	23	0.33	0.02	0.17-0.46
	D	23	0.31	0.02	0.20-0.51
<b>Ammonium</b> ( $\mu\text{M}$ )	S	21	0.90	0.15	0.03-2.29
	D	19	0.76	0.06	0.33-1.45
<b>DIN</b> ( $\mu\text{M}$ )	S	20	0.49	0.04	0.28-0.84
	D	17	0.45	0.02	0.35-0.63
<b>Phosphate</b> ( $\mu\text{M}$ )	S	22	0.17	0.02	0.01-0.41
	D	23	0.17	0.08	0.04-0.41
<b>Total P</b> ( $\mu\text{M}$ )	S	9	0.4	0.02	0.3-0.5
	D	12	0.4	0.05	0.2-0.9
<b>Total N</b> ( $\mu\text{M}$ )	S	23	6.6	0.5	3.2-12.3
	D	23	7.5	0.7	2.8-15.0
<b>Dissolved Oxygen</b> (mg/l)	S	11	8.44	0.24	7.7-10.5
	D	12	8.42	0.13	7.8-9.2
<b>Temperature</b> ( $^{\circ}\text{C}$ )	S	12	26.4	0.06	26.1-26.7
	D	12	26.3	0.04	26.1-26.5

**Table 3.4. Summary Table of Water Quality parameters by location.**

Parameter	Location					
	A	B	C	D	E	F
<b>Nitrite + Nitrate (<math>\mu\text{M}</math>)</b>						
Mean	0.27 $\pm$ 0.01	0.31 $\pm$ 0.03	0.23 $\pm$ 0.02	0.38 $\pm$ 0.03	0.37 $\pm$ 0.02	0.35 $\pm$ 0.03
Range	0.24-0.33	0.17-0.42	0.17-0.34	0.27-0.51	0.26-0.44	0.20-0.46
N	7	7	7	8	8	8
<b>Ammonium (<math>\mu\text{M}</math>)</b>						
Mean	0.62 $\pm$ 0.01	0.74 $\pm$ 0.06	0.82 $\pm$ 0.22	1.33 $\pm$ 0.27	0.39 $\pm$ 0.18	1.02 $\pm$ 0.31
Range	0.46-1.13	0.56-1.03	0.51-2.15	0.50-2.20	0.03-0.96	0.08-2.28
N	8	8	7	6	5	6
<b>DIN (<math>\mu\text{M}</math>)</b>						
Mean	0.89 $\pm$ 0.09	1.08 $\pm$ 0.08	1.08 $\pm$ 0.29	1.69 $\pm$ 0.27	0.78 $\pm$ 0.16	1.33 $\pm$ 0.31
Range	0.72-1.38	0.88-1.45	0.70-2.48	0.85-2.49	0.46-1.29	0.48-2.61
N	7	7	6	6	5	6
<b>Phosphate (<math>\mu\text{M}</math>)</b>						
Mean	0.19 $\pm$ 0.02	0.21 $\pm$ 0.02	0.14 $\pm$ 0.02	0.20 $\pm$ 0.03	0.13 $\pm$ 0.04	0.16 $\pm$ 0.02
Range	0.13-0.27	0.12-0.27	0.09-0.25	0.07-0.30	0.01-0.41	0.07-0.27
N	8	7	7	7	8	8
<b>Total N (<math>\mu\text{M}</math>)</b>						
Mean $\pm$ SE	7.4 $\pm$ 1.4	6.3 $\pm$ 0.8	5.8 $\pm$ 0.6	5.7 $\pm$ 0.6	7.9 $\pm$ 1.1	9.0 $\pm$ 1.1
Range	3.9-14.7	2.8-9.0	4.4-8.3	3.2-9.1	4.6-15.0	4.6-14.7
N	8	7	7	8	8	8
<b>Total P (<math>\mu\text{M}</math>)</b>						
Mean $\pm$ SE	0.4 $\pm$ 0.03	0.4 $\pm$ 0.03	0.4 $\pm$ 0.07	0.3 $\pm$ 0.0	0.5 $\pm$ 0.1	0.3 $\pm$ 0.03
Range	0.3-0.4	0.3-0.4	0.3-0.4	0.3-0.3	0.3-0.9	0.2-0.4
N	4	4	2	1	5	5
<b>Particulate N (<math>\mu\text{M}</math>)</b>						
Mean $\pm$ SE	1.5 $\pm$ 0.1	1.1 $\pm$ 0.1	1.4 $\pm$ 0.2	3.9 $\pm$ 2.7	1.4 $\pm$ 0.2	1.4 $\pm$ 0.1
Range	1.4-1.6	1.0-1.2	1.2-1.6	1.2-6.6	1.2-1.6	1.3-1.5
N	2	2	2	2	2	2
<b>BOD<sub>5</sub> (mg/l)</b>						
Mean $\pm$ SE	0.3 $\pm$ 0.2	1.4 $\pm$ 1.1	0.5 $\pm$ 0.2	0.9 $\pm$ 0.2	1.1 $\pm$ 0.1	0.5 $\pm$ 0.1
Range	0.1-0.5	0.2-2.5	0.3-0.7	0.1-1.1	1.0-1.2	0.4-0.6
N	2	2	2	2	2	2
<b>Dissolved Oxygen (mg/l)</b>						
Mean $\pm$ SE	7.78 $\pm$ 0.05	9.03 $\pm$ 0.55	8.33 $\pm$ 0.16	8.40 $\pm$ 0.13	8.40 $\pm$ 0.14	8.53 $\pm$ 0.28
Range	7.7-7.9	8.0-10.5	8.1-8.8	8.2-9.7	8.1-8.6	8.0-9.1
N	4	4	4	4	4	4
<b>Temperature (<math>^{\circ}\text{C}</math>)</b>						
Mean $\pm$ SE	26.3 $\pm$ 0.03	26.4 $\pm$ 0.14	26.3 $\pm$ 0.12	26.3 $\pm$ 0.11	26.4 $\pm$ 0.0	26.5 $\pm$ 0.0
Range	26.2-26.3	26.1-26.7	26.1-26.6	26.1-26.6	26.4-26.4	26.5-26.5
N	4	4	4	4	4	4

Figure 3.2.a. Non-metric Multidimensional scaling (MDS) plot in 2 dimensions of mean nutrient concentrations at 6 locations (A-F) from the spatial pilot study. Between sample similarities were calculated using the Bray-Curtis coefficient. Stress for the MDS is low at 0.03.

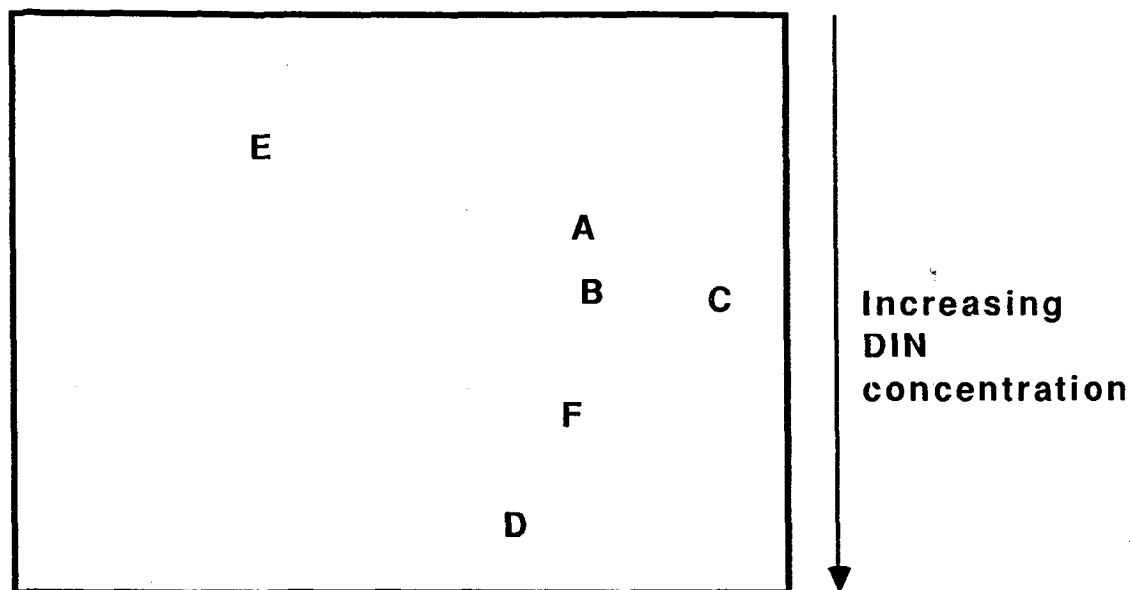


Figure 3.2.b. Dendrogram of classification of locations in the spatial study by mean concentration of inorganic nutrients. Between sample similarities were calculated using the Bray-curtis coefficient, and an unweighted group mean sorting strategy was applied.

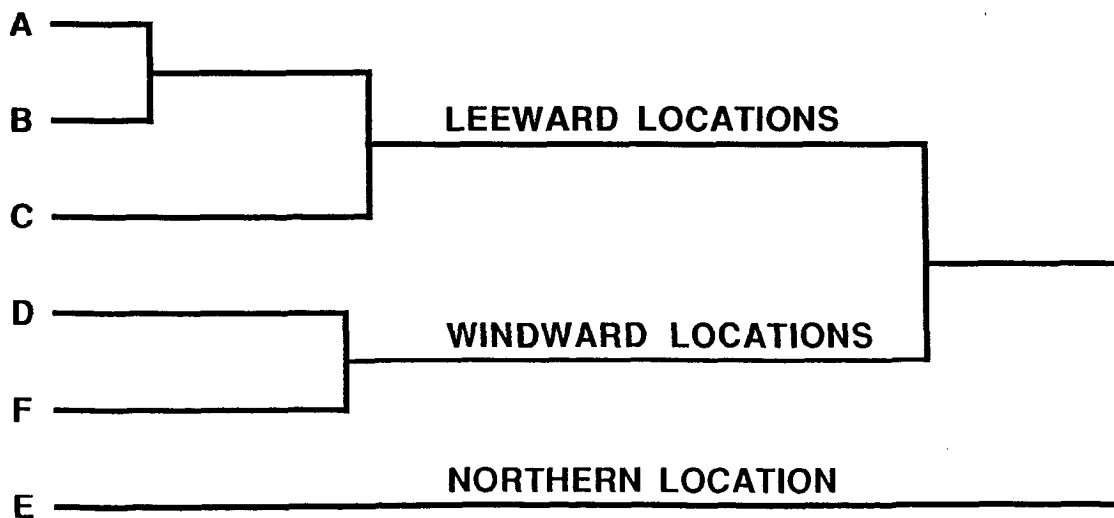


Figure 3.3. Pooled mean concentration ( $\mu\text{M}$ ) of Nitrite+Nitrate, Ammonium and Dissolved Inorganic Nitrogen between locations in the Spatial study of variation around Green Island.

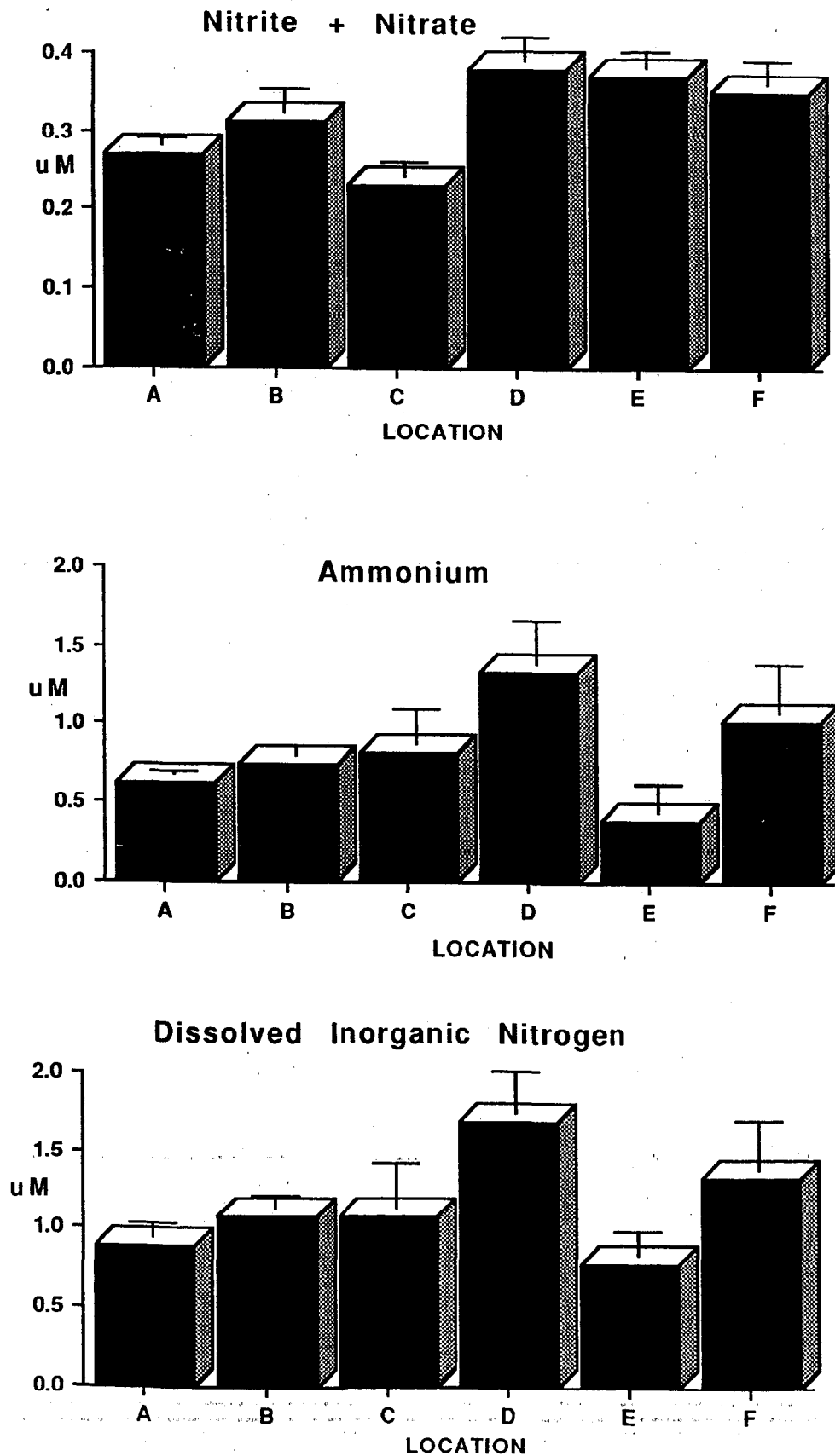


Figure 3.4. Pooled mean concentration ( $\mu\text{M}$ ) of Phosphate, Total Nitrogen and Total Phosphorous and between locations in the Spatial study of variation around Green Island.

