CHAPTER 4: DISCUSSION

3.1 WATER QUALITY PARAMETERS

The spatial and temporal variability of individual water quality parameters and comparison to data from other studies is discussed below. The usefulness and sampling constraints of each parameter is assessed.

4.1.1 Nitrite + Nitrate

Large scale location differences were the only significant source of variation. Values ranged between 0.13 and 0.54 μM with an overall mean of 0.32 $\pm$0.01 μM. Between locations mean values ranged from 0.23$\pm$0.02 μM (location C, hereafter C) to 0.38$\pm$0.03 μM (D). Locations D,E and F were significantly higher in mean concentration, than the other 3 locations. Over 24 hours mean values ranged between 0.25$\pm$0.03 μM (T4) and 0.34$\pm$0.04 μM (Time 3, hereafter T3) with an overall pooled mean of 0.30$\pm$0.01 μM. A pooled mean from the diel study of 0.33 $\pm$ 0.02 μM was obtained.

The range of values found in this study are similar to those found by Brady (1989) in a transect from the Barron River (0.33-0.51 μM), and to other studies in the GBRL, at Magnetic Island (0.28 μM, Brodie *et al.* 1989), Hayman Island (0.27 μM, Steven and van Woesik 1989), and shelf waters in the Whitsundays (0.38 μM, Furnas, *et al.* 1988). At John Brewer reef Jones *et al.* (1989) found that sampling in the presence of *Trichodesmium* blooms gave significant differences in nitrite + nitrate concentrations (0.26 μM) compared to sampling in the absence of such phenomena (0.45μM). This clearly indicates that sampling studies need to consider a range of biological and physical phenomena.

4.1.2 Ammonium

Ammonium was the most labile nutrient species with values ranging from 0.01 to 3.71 μM, indicating high small scale patchiness. Spatial variation between locations and temporal differences between days were significant sources of variation. However, the high variability between replicates may have masked the significance of other factors. Mean values between locations in the spatial study varied between 0.39$\pm$0.18 (E) and 1.33$\pm$0.28 μM (E) with an overall mean of 1.14$\pm$0.09 μM. Temporal variation over 24 hours was similar ranging from 0.30$\pm$0.11 μM (T1) to 1.24$\pm$0.52 μM (T2). Pooled mean values for the 3 studies were similar (Table 4.1).

In comparison Brady (1989) found relatively low levels (0.04-0.14 μM) of ammonium in a transect out from the Barron river. However, most studies on the GBR have noted a great range of ammonium concentrations; Magnetic Island (0.07-2.8 μM, Brodie *et al.*, 1989), Hayman island (1.0-15.0 μM, Steven & van Woesik, 1989) and Hamilton Island (0.2-1.6 μM, Blake and Johnson, 1988). Jones (1989) noted high levels of ammonium during a 24 hour survey at John Brewer reef (ca. 0.74 μM). He attributed these high ammonia concentrations to a combination of increased tidal mixing, rough weather and also releases from sediments. Increased turbulence resulting from zero tides during the present study most probably released ammonia from sediment pore waters resulting in occasional high ammonia and nitrite + nitrate concentrations. The extremely patchy distribution of ammonium can pose problems in statistical analysis as the often high within sample (between replicate) variance can result in non significant results despite the apparently wide range of concentrations (Boto and Wellington, 1988). Care is needed in interpreting arithmetic means for ammonium and factors such as *Trichodesmium* blooms and other sources of ammonification should be considered.

4.1.3 Dissolved inorganic nitrogen (DIN)

DIN concentrations varied temporally with respect to day and time of day, and spatially between locations and between habitats. Between locations DIN values ranged from 0.78 ± 0.16 μM (E), and 1.68 ± 0.27 μM (D), with a pooled mean concentratation of 1.14 ± 0.09 μM. DIN levels on day 1 were significantly less (0.57 ± 0.13 μM) than on days 2 and 3 (1.19 ± 0.13 μM, 1.24 ± 0.17 μM). Over 24 hours mean values ranged from 0.57 ± 0.02 μM (T1) to 1.48 ± 0.30 μM (T7). Overall mean values for the 24 hour and the Diel study were similar (1.02 ± 0.12 μM and 1.03 ± 0.11 μM respectively).

Brady (1989) noted concentrations of 0.63 μM around Green Island. The range of DIN values recorded at Green Island (0.24-3.91 μM) are also similar to values recorded in other studies on the GBR (Steven & van Woesik, 1989; Blake & Johnson, 1988; Brodie *et al.*, 1989).

4.1.4 Orthophosphate

Orthophosphate concentration did not vary significantly ($P < 0.05$) with respect to any of the temporal or spatial factors measured. Values ranged from 0.01 to 0.41 μM with an overall mean of 0.17 ± 0.01 μM. Over 24 hours means ranged from 0.11 ± 0.02 μM (T2) to 0.28 ± 0.08 μM (T5), with an overall mean of 0.18 ± 0.01 μM. A pooled mean of 0.22 ± 0.02 μM was calculated in the diel study. Between locations mean orthophosphate concentration was greatest at B (0.21 ± 0.02 μM) and least at E (0.13 ± 0.04), with an overall mean of 0.17 ± 0.01 μM.

Brady (1989), found orthophosphate concentrations decreased in a transect from the mouth of the Barron river (0.22 μM) to Green Island (0.11 μM) with an overall mean concentration of 0.17±0.05 μM. Other studies at Magnetic Island (0.20 ±0.02 μM, Brodie *et al.*, 1989) and the Whitsundays (0.23 uM, Furnas et al., 1988) have found similar concentrations. Jones *et al.*, 1989 noted during Trichodesmium bloomsthere was a 23% increase in dissolved inorganic phosphate.

4.1.5 Total Phosphorous

TP concentrations differed marginally between days (F = 3.83; 2,16 df; P = 0.075), but the loss of a number of samples due to contamination, makes these results speculative. Mean TP values ranged from 0.3 μM (D, 1 sample) and 0.5±0.1 (E) between locations with an overall mean of 0.38±0.03 μM. Over 24 hours values ranged from 0.2±0.0 (T1) to 0.45±0.15 (T8) with a pooled mean of 0.29±0.03 μM. A similar mean of 0.3±0.02 μM was found for the diel study.

Levels of TP were approximately twice that of orthophosphate. This is similar to results found elsewhere (Brodie *et al.*, 1989 and Furnas *et al.*, 1988). Brady (1989) found a range of TP concentrations from 0.94 to 1.12 μM in a transect from the Barron river to Green Island, but also noted blooms of the blue green algae *Trichodesmium*. Few other estimates of TP exist for the GBR.

Jones *et al.*, (1989) found a range of 3.42 to 4.27 μM at John Brewer reef

4.1.6 Total Nitrogen

Apart from a marginally significant depth by location interaction effect (P = 0.042) there were no other detectable differences in TN over any spatial or temporal scales. Mean concentrations over 24 hours ranged from 4.7±0.7 μM (T4) to 9.6±0.2 μM (T8) with a pooled mean of 7.05±0.59. Similarly in the spatial study values ranged from 5.1±0.9 μM (C) to 9.0±1.1 μM (F) with an overall mean from the spatial study of 7.06±0.43 μM. A mean of 7.01±0.43 was calculated from the diel study.

Few measurements of total nitrogen have been made on the GBR. Jones *et al.*, (1989) found a range of 3.6 to 8.2 μM at John Brewer reef.

4.1.7 Particulate Nitrogen

No significant differences were found at any spatial or temporal scales. Pooled mean values were 1.78±0.41 μM for the spatial study and 1.53±0.6 μM for the diel study. However, there was low power for detecting differences between depths ($P < 0.66$) and locations ($P < 0.3$) for moderate changes (50%) in ambient conditions. The values obtained are however similar to values found by Furnas *et al.* (1988) in the Whitsundays (2.0 ± 0.5 μM) and in the Central and Southern GBR (1.6 ± 0.4 μM), and by Crossland and Barnes (1983) at Lizard Island (1.2 ± 0.4 μM).

Differences in the measurement technique used in different studies makes comparisons difficult.

4.1.8 Dissolved Oxygen and Temperature

Short term temporal differences were the major source of variation for oxygen and temperature. Mean dissolved oxygen and temperature were greater over sampling times T2 to T4 (Table 2.3.b.) consistent with increases in solar irradiation, and surface water mixing due to strengthening wind conditions (i.e sea breezes). No significant spatial difference either between depth or location were recorded. Marginal habitat differences ($P < 0.05$) are ambiguous (Table 2.3.b).

4.1.9 Suspended Solids

Suspended sediment concentration varied significantly between time periods, consistent with resuspension during low tide. Mean values ranged from 1.58 mg/l (T5) to 2.63 mg/l (T4) with an overall mean of 1.98±0.09 mg/l.

Brodie *et al.* (1988) found a mean suspended sediment level of 3.95±4.29 mg/l at Magnetic Island. Results from John Brewer reef lagoon (2.64 mg/l) are more comparable (Jones *et al.*, 1988) to Green Island.

4.1.10 Clarity

Water clarity data, measured with a secchi disk was greater than the total depth of water on the reef, and consequently provided no useable information. Further, suspended sediment measurements cannot be strongly correlated with clarity. Nephelometric turbidity instruments aren't sensitive enough to give reliable readings. The use of multi-level light sensors at different depths which give instantaneous extinction coefficient readings may help to overcome some of these problems in future sampling programmes.

4.1.11 Chlorophyll *a*

No significant spatial or temporal variation was identified in the study, as samples varied widely. Values of Chlorophyll *a* ranged from 0.4 μg/l to 8.4 μg/l with an overall value of 3.48$\pm$1.11 μg/l. The high range of values and suggest that high within sample variance and insufficient replication may have resulted in the non-significance of these results.

Brodie *et al.*, 1989 noted a large range (0.05-2.0 μg/l) of Chlorophyll *a* values at Magnetic Island with significant inter site variation. Furnas *et al.*, (1988) noted a difference in chlorophyll *a* between coastal waters in the Whitsundays (1.17$\pm$0.25 μg/l) and shelf waters (0.68$\pm$0.13 μg/l). Jones *et al.*, (1989) found a mean of 0.58 μg/l at John Brewer reef and noted a 56% decrease in Chlorophyll *a* in the presence of *Trichodesmium* blooms.

4.1.12 Biological Oxygen Demand

No significant spatial or temporal variation was identified in the study. Values ranged from 0.1- 2.5 mg/l with an overall value of 0.47$\pm$0.16 mg/l around the sewage pipe and 0.78$\pm$0.18 mg/l averaged over all locations. This is within the range of value reported by other workers on the GBR (1.1 mg/l, Brodie *et al.*, 1989 ;0.5 mg/l, Jones *et al.*, 1989). Bell *et al.* (1987) notes a value of 0.7 mg/l for unpolluted Carribean reefs. Measurement difficulties with BOD levels as low as this make comparisons, either within the present study or with other workers results, problematic.

Table 4.1. Summary of mean values from the Spatial and Temporal Study.

		Spatial Study				24 Hour Study				Diel Study		
Parameter	**N**	**Mean**	**S.E.**	**Range**	**N**	**Mean**	**S.E.**	**Range**	**N**	**Mean**	**S.E.**	**Range**
Nitrite + Nitrate (μM)	45	0.32	0.01	0.17-0.51	63	0.29	0.01	0.13-0.54	23	0.33	0.02	0.17-0.51
Ammonium (μM)	39	0.82	0.09	0.03-2.28	34	0.73	0.12	0.00-3.71	19	0.69	0.09	0.00-1.35
DIN (μM)	37	1.14	0.09	0.46-2.61	34	1.02	0.12	0.24-3.91	18	1.03	0.11	0.24-1.73
Phosphate (μM)	45	0.17	0.01	0.01-0.41	36	0.17	0.01	0.06-0.54	19	0.22	0.02	0.01-0.38
Total Nitrogen (μM)	46	7.1	0.4	2.8-15.0	61	6.72	0.59	3.6-37.4	24	7.01	0.41	4.1-12.3
Total Phosphorous (μM)	21	0.38	0.03	0.2-0.9	16	0.29	0.03	0.2-0.6	17	1.14	0.02	0.2-0.4
Particulate N (μM)	12	1.8	0.4	1.0-6.6	-	-	-	-	12	1.5	0.1	12.0-18.0
Dissolved Oxygen (mg/l)	12	8.45	0.13	7.7-10.5	32	7.51	0.23	4.8-10.9	12	7.6	0.3	6.8-8.6
Temperature (^{o}C)	12	26.3	0.1	26.1-26.7	32	25.1	0.2	24.0-27.6	11	25.1	0.2	24.3-26.8
Chlorophyll *a* (μg/l)	-	-	-	-	10	3.48	1.11	0.49-8.66	7	1.14	0.66	0.4-5.1
BOD_5 (mg/l)	12	0.7	0.2	0.1-2.5	-	-	-	-	6	0.41	0.17	0.0-1.2
Suspended solids (mg/l)	-	-	-	-	24	2.0	0.1	1.4-3.4	-	-	-	-

4.2 GENERAL DISCUSSION

This study demonstrated that there were significant differences in concentrations of inorganic nutrients between locations around Green Island. Higher concentrations of DIN were recorded at locations on the windward side of the reef (D & F), and a significantly lower concentration of DIN at location E on the north-eastern side of the reef in an area of patch reefs. There was also some evidence of potential difference in DIN concentration by habitat in the temporal study. However, habitat differences were only tested on the leeward side of the reef. However, given the study was undertaken over a very small time frame it is impossible to draw any firm conclusions regarding the source of these enhanced levels of nitrogen. A detailed understanding of both large and local scale hydrodynamics is required to adequately test such hypothesees. These findings are however, consistent with observations by other workers (Webb *et al.* 1975; Andrews and Muller, 1983; Crossland, 1983; Entsch *et al.* 1983; Hatcher and Frith, 1985). In a recent review Hamner and Wolanski (1988) suggest that water flowing over the reef crest is qualitatively different from the water seaward of the reef because it is it is modified by biological processes (e.g. fish feeding and defaecating) and physically through wave energy (e.g. resuspension of sediments and detritus). Other workers (Webb *et al.* 1975; Andrews and Muller, 1983; Crossland, 1983; Entsch *et al.* 1983; Hatcher and Frith, 1985) found that DIN levels on portions of the reef complex were found to alter as water flows across the reef.

Differences were significant between days but not over smaller time frames. It is considered that seasonal differences would be substantial as a number of studies have noted seasonal differences (Andrews and Muller, 1983; Crossland, 1983; Hatcher and Frith 1985). Hatcher and Frith (1985) found the relative influence of advection across the the windward reef crest changed with season and differed for the two forms of DIN. The relative magnitudes of fluxes are more similar to each other in summer than in winter indicating the potential for shifts in the dominance hierarchy at small time and space scales. They further note this variability between nitrogen species has implications for sampling strategies. i.e. different time frames.

Differences in phosphate concentration were apparent between locations only.
Changes in the concentration of phosphorous across the reef are difficult to measure because rates of phosphorous uptake from the water column by reef communities is slow (ca. 1-2 %) relative to to the flux of water (Atkinson and Smith 1987). No significant diurnal changes of phosphate have been noted although changes with time of year were detected (Pilson and Betzer, 1973).

No effects attributable to the discharge of sewage were detected, though it should be emphasized this was not an objective of the pilot study. It was noted sewage was discharged on the the 2nd

June at ca. 1500 hours. A pulse of increased phosphate concentration was detected in a few samples at time 4 (1645, flooding tide, 0.81 μM) on the slope at location B, but it did not give a significant difference in concentration.

4.3 SAMPLING AND MEASUREMENT PROBLEMS

Care is needed in interpreting and comparing data from nutrient and energy flux studies. Sampling design often limited by cost and time constraints, differing sampling techniques, analytical uncertainties and statistical interpretation all are potential sources of error. Burton (1973) notes that our knowledge of the distribution of nutrients in tropical waters is limited by the number of data sets, the small number of samples taken and the effects due to analytical uncertainties regarding sample collection and storage, and the way in which different nutrient species in sea water respond to different analytical techniques. For example the use of filtering samples on site before freezing for nutrient analysis has been a common procedure (Ryle *et al.*, 1981), but problems with loss of analyte may occur depending on filter type (Jones et al. 1989). Filtration through filters of a pore size of ca. 0.45 μm is an arbitrary division of material into 'particulate'and 'dissolved'. For nitrogen the distinction between dissolved inorganic forms, dissolved organic forms (< 0.45 μm) and particulate forms (> 0.45 μm) is relatively clear, however, which of these forms is bio-available is not. For phosphorous the situation is more complex since some of the fine colloidal phosphorous reacts in the molybdate method used for the analytical determination of orthophosphate. Consequently the operational term 'reactive dissolved phosphorous' better describes what is being measured. What fraction of this phosphorous is bio-available is also not clear. Future work needs to research for which nutrients the use of filters is suitable and for which unfiltered samples are preferable (Jones *et al.*, 1989).

The results of a sampling study are often not readily interpretable without understanding the influence of processes, both natural and anthropogenic, which occur at a range of scales. These complicate our ability to measure ambient conditions in an areas and to make comparisons between areas. Andrews and Muller (1983) note the space and time scales on which a study is performed will determine the relative influence of the physical environment and chemical and biological interactions on the results; much of the variance is caused by the changing physical environment and can be resolved with adequate sampling. Ideally the influence of regional processes such as river runoff from the Barron River, planktonic blooms (i.e *Trichodesmium*), coastal upwelling and oceanic intrusions, as well as local processes both natural and anthropogenic (hydrodynamic and biotic processes, dredging and sewage discharge) on nutrient levels need to be considered. Jones *et al.* (1989) have drawn attention to the fact that *Trichodesmium* blooms can substantially alter the relative concentrations of dissolved nutrients and chlorophyll.

Due to the potential sources of error mentioned above it is not necessarily correct to present the mean and variance of a set of chemical data as an adequately determined result (Andrews and Muller, 1983). Talbot and Simpson (1983) note for skewed data geometric means may be a better estimator than arithmetic treatment of the data. The use of univariate statistics which are suddenly regarded as being significant at a magical number (0.05) is incorrect. Further, Boto and Wellington (1988) note high within sample variance can lead to non significant results an apparent wide range of concentrations. Multivariate statistics can provide a good method of demonstrating processes that may not be apparent using a univariate approach.