WATER COLUMN NUTRIENT PROCESSES IN GREAT BARRIER REEF WATERS

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INTRODUCTION

The development of rational policies for the management of inputs to and nutrient levels within a large, nominally oligotrophic ecosystem such as the' Great Barrier Reef (hereafter GBR) requires an understanding of nutrient dynamics at the system level. In developing such an understanding, the role of water column processes is central, as most nutrient additions to the GBR ecosystem through human activities will likely come via the water column, be dispersed by water movements and, be transformed by planktonic organisms.

A Schematic for a Water, Column Nitrogen Budget

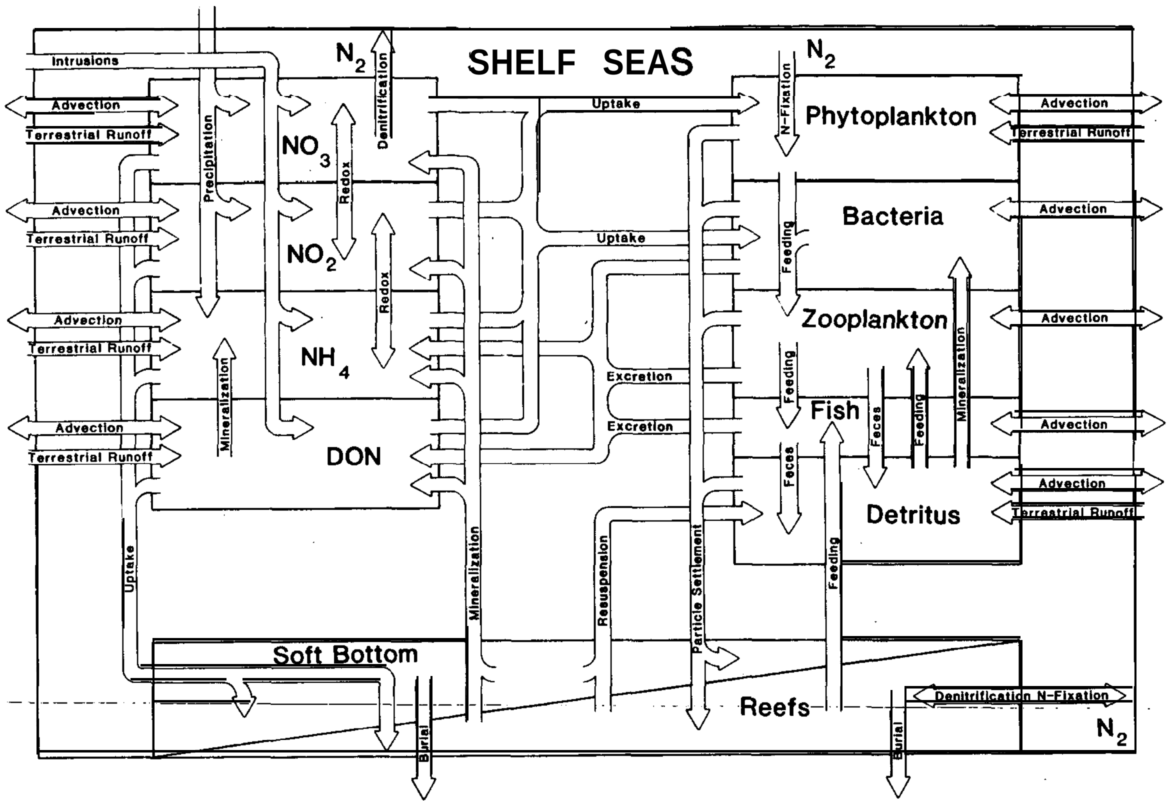
With the last several years, an attempt has begun to develop a quantitative nitrogen budget for shelf waters of the GBR. Figure 1 presents a schematic depiction of water' column pools of nitrogen, both in living and non-living forms and the pathways whereby nitrogen is added to, removed from and transformed by pelagic organisms. The focus is strictly upon water column processes. Coral reefs and the soft; inter-reefal benthos, both with equally complex nitrogen dynamics are shown as "black boxes" exchanging N with the water column. The development of models,. whether schematic as shown or numerical, provide a focus for the identification of key system pools and pathways, and a means for integrating results from a range of focused investigations.

Historical studies and data sets (eg. Andrews, 1983; Andrews and Gentian, 1982; Bellamy et al., 1982; Fumas and Mitchell, 1984; Furnas and Andrews, 1986, in prep.; Thomson and Wolanski, 1984; Wolanski and Jones, 198 1), have now established regional and seasonal variations in concentrations of dissolved inorganic nutrient species in the GBR waters, temperature-nutrient relationships in Coral Sea water masses interacting with GBR shelf waters and functional relationships whereby shelf-scale inputs of nutrients from intrusions of Coral Sea water may be estimated.

Work in progress is now directed toward quantifying seasonal and regional variability in concentrations of particulate nitrogen (PON) in shelf waters, inputs of nutrients from rainfall and coastal rivers, sedimentation of organic nitrogen from the water column, nitrogen uptake by phytoplankton and remineralization of nitrogen by water column biota (e.g. Ikeda et al., 1982).

A variety of evidence suggests that the inter-reefal pelagic ecosystem of'the GBR is nitrogen', rather than phosphorus or silicon limited. It is important, however, to note that this limitation is biomass, rather' than kinetic' limitation. Direct and indirect measurements of phytoplankton growth rates in situ (Table 1) indicate phytoplankton populations can grow at rapid rates (> 1.5 doublings day-i), despite low nutrient, particularly nitrogen concentrations. Importantly, within these populations, a number of individual phytoplankton species are frequently growing at rates in the range between 2 to 3 doublings per day and do so at DIN concentrations of 0.2 μM or less (Fumas, in prep.). Concentrations of dissolved inorganic phosphate (DIP) and silicate are almost always measurable, while concentrations of dissolved inorganic nitrogen (DIN) species

Figure 1. A schematic model for water column nitrogen pools and fluxes in GBR shelf waters.



are frequently at or below the limits of detection (now ca. 0.05 µM). Concentrations of DIN, and DIP in shelf waters generally have a DIN/DIP ratio on the order of 1, far less than the Redfield N:P ratio (15-16) characteristic of marine phytoplankton. The low DIN/DIP ratio means that in the absence of external nitrogen additions, available nitrogen will be exhausted before phosphate and silicate are depleted.

Direct comparisons between water column stocks of DIN and estimates of nitrogen present in the form of phytoplankton biomass (Figure 2) indicate that soluble inorganic pools are similar in magnitude to or smaller than biomass-N pools. As a rule of thumb, to estimate phytoplankton biomass N, 1 µg of chlorophyll is equivalent to 1 ug-at of biomass N (e.g. Fumas, 1983). Large changes in water column pools of biomass-N and DIN only occur in GBR shelf waters when-additional-amounts-of-nitrogenous nutrients are added (in the case shown), by intrusions from the Coral Sea to the ecosystem, river runoff or cyclonic disturbances of shelf sediments.

Nitrogen Uptake by Phytoplankton in the GBR

Direct measurements of nitrogen uptake by phytoplankton, made using ^{15}N tracers, indicate rapid uptake and recycling of nitrogenous nutrients. When presented with nitrate at uptake saturating concentrations (ca. 2 µM), near-surface phytoplankton from the GBR lagoon are capable of doubling their standing stock of particulate nitrogen in less than one hour (Figure 3 Top). Preliminary kinetic analyses of uptake rates in relation to nitrate concentration and light intensity indicate half-saturation coefficients, the level at which uptake occurs at half the maximal rate, are <0.5 µM NO,-N and 10% of normal surface light levels.

Time courses of ammonium uptake, as measured by ^{15}N uptake (Figure 4) confirm rapid turnover of water column ammonium pools. Where a ^{15}N-NH_4 spike considerably in excess of the ambient concentration is added to a sample (Fig 4 Top and solid lines, Bottom), linear uptake occurs for periods of at least 4-6 hours. When a spike closer to normal ambient concentrations (ca. 0.2 µM) was added to inshore samples with higher standing crop levels, uptake slows within l-2 hours, indicating either depletion of available ammonium in the sample, and/or isotope dilution of the added spike by mineralization processes within the incubation bottle.

The Role of Disturbances in Shelf-scale Nutrient Processes

Oceanographic observations made shortly after the passage of cyclone Winifred over a section of the GBR in 1986 illustrate the role of disturbances in shelf-scale and local nutrient processes and the effect of nutrient loading upon concentrations and speciation of nitrogen in particular.

A hydrographic survey conducted after the cyclone showed the presence of high dissolved nutrient and phytoplankton biomass levels (Figure 5) throughout an area on the order of 10^4 km^2. Preliminary nutrient budgets for the event indicate that most of the phosphate and silicate added to the water column could be accounted for by inputs from rainfall, river runoff and porewaters in disturbed shelf sediments. In contrast, existing nitrogen stocks plus inputs from the above sources accounted for less than 25 percent of the nitrogen present in the post-cyclone water column. Partial mineralization of organic nitrogen in the column of shelf sediments resuspended by cyclone Winifred can easily account for the discrepancy. The high concentrations of nitrite and nitrate in shelf waters are indicative of waters receiving enhanced loading of organic nitrogen (e.g. McCarthy et al., 1984); When organic nitrogenous. nutrients

Figure 2. A comparison between integrated water column stocks of chlorophyll a and DIN (NH_4 + NO_2 + NO_3) at mid- and outer shelf stations in the central GBR. Station 1 is in the GBR lagoon; station 4 at the shelfbreak. (From Fumas and Mitchell, 1986).

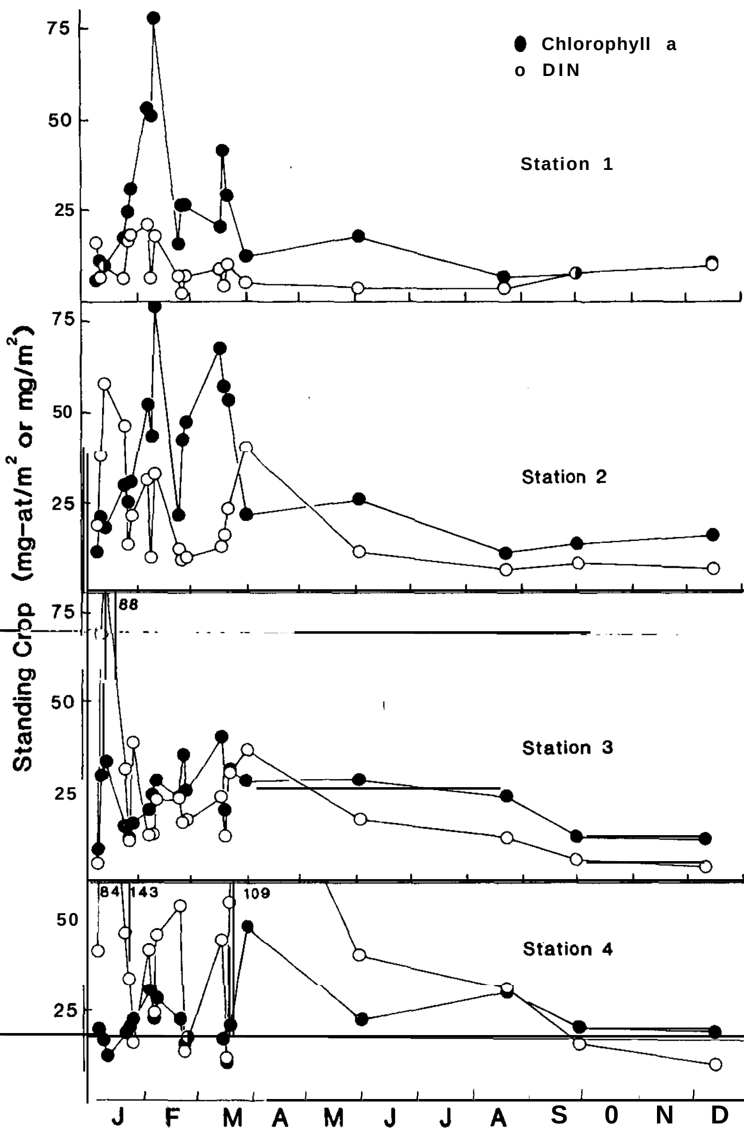


Figure 3. Uptake rates of nitrate, expressed as µM NO, taken up per µM of particulate N per hour · (hr^{-1}), in relation to nitrate concentration and ambient light intensity (as percent of surface irradiance) for near-surface phytoplankton from a mid-lagoon and an inshore site.

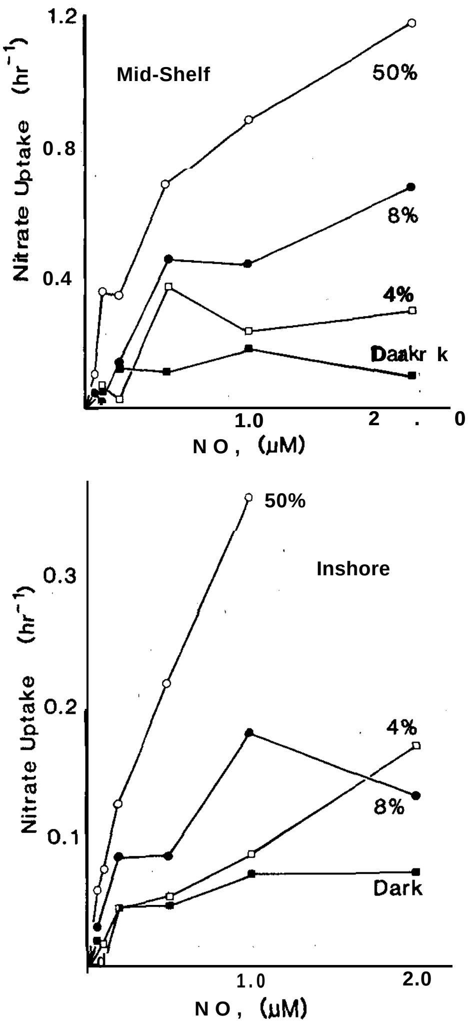


Figure 4. Time courses of $^{15}N\text{-}NH_4$ uptake, expressed as the atom percent excess of filtered particulate matter, by phytoplankton from the oceanic Coral Sea (Top, spikes > 1 μM) and from GBR shelf waters (Bottom, solid lines - midshelf and inshore experiments with spikes > 0.3 μM; dashed lines - inshore experiments with spikes < 0.2 μM).

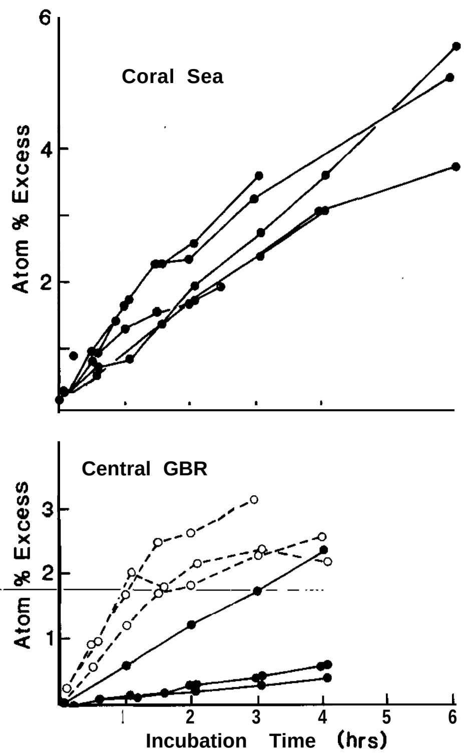
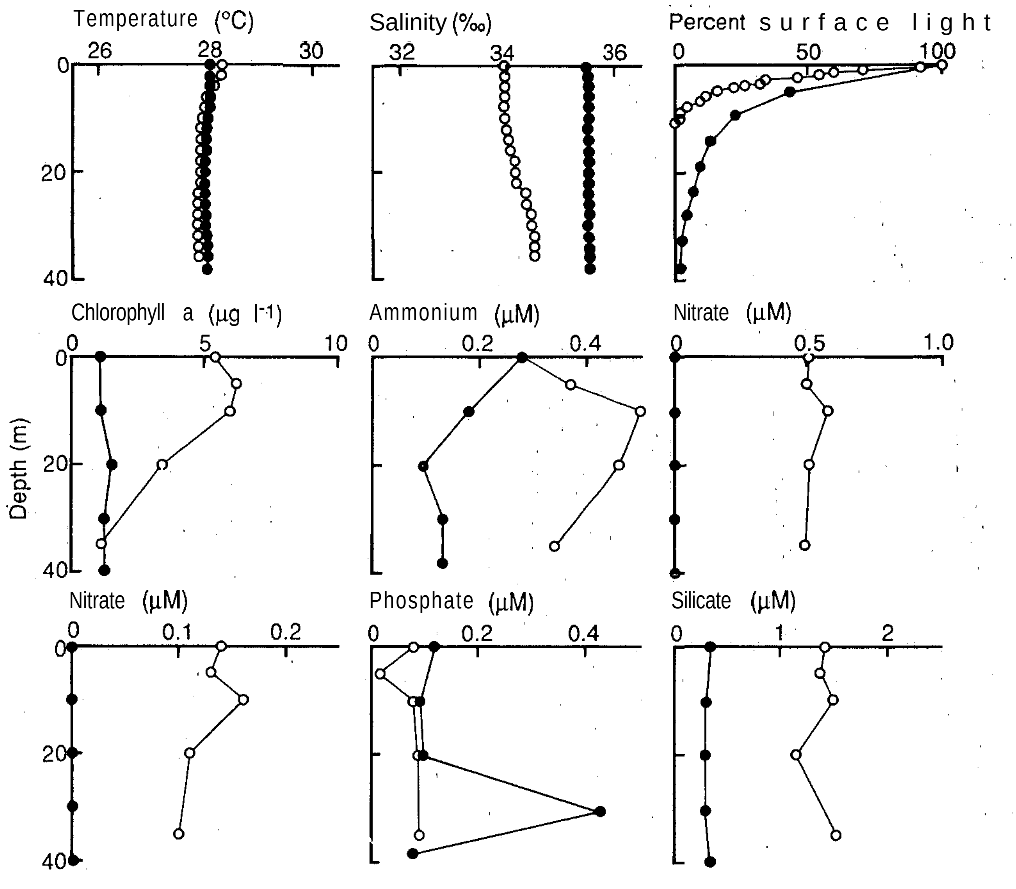


Figure 5. Representative profiles of hydrographic parameters, chlorophyll and dissolved nutrient concentrations in the cyclone affected area of the shelf (Fig. 5, 1986) and in similar mid-shelf waters in the absence of cyclonic disturbance.



are added to GBR waters, mineralization by microbial processes proceeds at a rapid rate. Where mineralization of organic N to ammonium exceeds nitrogen demand by phytoplankton, "blooms" of aerobic nitrifying bacteria appear to develop as well, converting surplus ammonium to nitrite and nitrate.

Normal seasonal storm winds can lead to localized increases of dissolved nutrient concentrations and phytoplankton biomass in inshore water by resuspension of inshore sediments (Walker and O'Donnell, 198 1; Ullman and Sandstrom, 1987). Where the nutrient and organic content of coastal sediments are enriched by nutrient discharges, this effect may be exacerbated by concurrent mineralization of resuspended organic matter.

Some Implications of Water Column Nutrient Processes for GBRMP Management Planning

Phytoplankton biomass in inter-reefal waters of the GBR is N-limited. Inputs of nitrogenous nutrients will therefore likely lead to increases in phytoplankton and hence, plankton biomass in the affected area. Because of the high water temperatures (22-30C), high in situ light levels and rapid rates of nutrient recycling within the water column, phytoplankton populations can take up nitrogen equivalent to the standing crop within hours and can develop into appreciable blooms within 2-3 days if sufficient nutrients are available. As a result, human additions of nutrients to GBR waters may not necessarily be observable as an increase, either locally, or regionally, in dissolved nutrient levels. Rather, an obvious sign would be local or regional increases in phytoplankton biomass. Localized increases in dissolved nutrient concentrations would be most apparent where ratios of nutrients entering the ecosystem are unbalanced for phytoplankton growth (e.g. Goldman, 1976), resulting in the depletion of one nutrient before all are consumed and leading to buildups of "surplus" nutrients (e.g. DIN, phosphate or silicate) in particular situations.

The ability of phytoplankton to take up nitrogen and grow at near-maximal rates at ambient nutrient concentrations less than 1 µM -n ans that nutrient discharge/dilution standards should reflect these concentrations to prevent the development of localized, possibly deleterious algal blooms. Natural DIN concentrations in excess of 1 µM do occur within the GBR (e.g. Hatcher and Frith. 1985), but such situations appear to be restricted to highly enclosed reef lagoons and reef flat tide pools with very short to moderately short residence times.

Experimental and observational evidence suggests that phosphorus, not nitrogen is the macronutrient most directly detrimental to coral reef growth and health (e.g. Kinsey and Davies, 1979). The development of enhanced phytoplankton biomass levels as a result of local or regional eutrophication would affect coral reefs in a variety of ways, either through increases in "surplus" water column phosphate concentrations, or through indirect changes in reef community structure resulting from the growth of macroalgae, increased organic sedimentation from plankton blooms, shading of benthic autotrophs and fostering the proliferation of benthic filter feeders responding to increased plankton biomass and detrital particulate concentrations.

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Table 1. Doubling rates of chlorophyll (mean ±1 S.D., range) in diffusion chambers incubated under in situ conditions at mid- and outer-shelf sites in the central GBR.

	Mid-Shelf	Outer-Shelf
Summer near-surface	0.8 ± 0.8 n = 7 0.0 - 1.6	0.2 ± 0.3 n = 5 0.0 - 0.7
Summer near-bottom	0.6 ± 0.4 n = 5 0.0 - 0.9	0.4 ± 0.2 n = 5 0.2 - 0.6
Winter near-surface	1.1 ± 0.3 n = 3 0.8 - 1.3	0.8 ± 0.2 n = 4 0.5 - 1.0
Winter near-bottom		0.5 n = 2 0.0 - 1.1