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Dissolved nutrients of a high-latitude coral reef, Houtman Abrolhos Islands, Western Australia

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ABSTRACT: Dissolved nutrients were monitored at 20 stations over a 2 yr period in the Easter Group of the Houtman Abrolhos Islands, Western Australia. Nutrient concentrations were greater inside the reef complex than concentrations in the oceanic region outside the island groups. Winter concentrations of dissolved organic phosphorus and nitrogen were high in the channels and along the islands, and reactive (inorganic) phosphate was high over the reef flats in winter. We suggest a mechanism for nutrient enrichment of the island groups whereby macroalgal material, torn by waves from the extensive algal stands along reef margins, is deposited inside the reef complex and through remineralization processes form a significant nutrient source in the lagoon.

INTRODUCTION

In the lagoonal coral reefs of the high-latitude Houtman Abrolhos Islands we have observed 4 phenomena we consider to be interrelated: (1) Macroalgal abundance is high in comparison with that of many more tropical coral reefs (Wilson and Marsh, 1979), and includes large stands of fucoid algae and kelp not typically found on coral reefs (Womersley, 1981). (2) Gross benthic community production of organic carbon is high, apparently reflecting the high algal biomass (Smith, 1981). (3) The lagoons of these reefs include large aggregations of unattached macroalgae and macroalgal fragments which undoubtedly contribute to a rich detritus-based food web, including a commercially important rock lobster fishery (1.5×10^6 kg live weight yr^{-1}, 1961–71; Morgan and Barker, 1982). (4) The dissolved nutrient concentrations in the lagoons are apparently high (Johannes et al., 1983b) both in comparison with those of surrounding waters and in comparison with those of many other coral reefs (Kimmerer and Walsh, 1981; Crossland, in press). Here, we confirm the high seasonally-sustained, nutrient levels in the Houtman Abrolhos lagoons. Further, we attempt to tie these phenomena together into a unified model of nutrient cycling in this reef system.

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Study area

The Houtman Abrolhos Islands are located between 28° and 29° S near the edge of the continental shelf of Western Australia. The biological community structure of these islands and their associated reefs has been outlined by Wilson and Marsh (1979). Most habitats of tropical coral reefs are found in the Houtman Abrolhos Islands. Compared with other reefs of similar latitude, the hermatypic coral diversity of the Houtman Abrolhos Islands is high, viz., 37 genera represented by about 70 species, *Acropora* spp. and *Montipora* spp. being most abundant. However, other faunal groups are relatively impoverished and composed of mixed southern temperate, west-coast endemic, and northern tropical species.

Fleshy macroalgae form a major component of the benthic communities of the reefs; a feature common to other high latitude coral reefs (e.g. Lord Howe Island, (Veron and Done, 1979), Bahamas, (Lighty, 1982). The high-energy outer reef slopes support rich and dense macrophyte communities characterized by large brown algae (e.g. *Dictyota, Glossophora, Sargassum*) including the kelp *Ecklonia radiata*, mixed with fleshy red and green algae (e.g. *Asparagopsis, Hypnea, Laurencia, Plocamium, Caulerpa*). Seasonally-changing macroalgal communities dominate many protected reef areas within the lagoons. Large Phaeophytes, including species of *Caulocystis, Cystophyllum, Hor-*

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mophysa, *Sargassum* and *Turbinaria*, are common in summer, with other fleshy algae (e.g. *Eucheuma*, *Laurencia*) covering shallow reef areas in spring (Rimmer, pers. comm.).

Smith (1981) measured unusually high gross primary production during both winter and summer in reef flat and lagoonal patch reef communities of the Easter Group and attributed this to a high biomass of autotrophs (both corals and fleshy algae). An annual gross production to respiration ratio average of 0.97 (0.84, winter; 1.07, summer) was calculated for the lagoonal patch reef.

The Houtman Abrolhos Islands are influenced by a strong southerly current, the Leeuwin Current, which flows along the edge of the continental shelf of Western Australia, especially during winter (Cresswell and Golding, 1980). The limited nutrient data available for the offshore waters indicate low concentrations for inorganic N and P (Rochford, 1980).

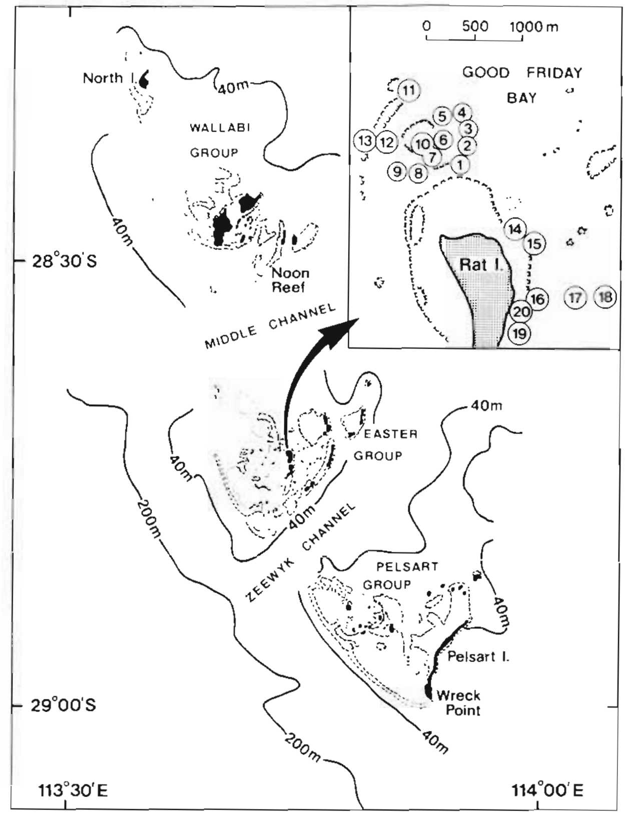

Fig. 1. Houtman Abrolhos Island Groups. Inset showing study sites and nutrient sampling stations near Rat Island

METHODS

Surface water samples were collected from 20 stations near Rat Island at 4 to 6 week intervals between November 1979 and December 1981 (Fig. 1 shows location of stations).

Each 120 ml water sample was filtered through a 0.45 µm Sartorius membrane and stored in a plastic Whirlpac bag with 1.0 ml mercuric chloride solution (2.5 g l^{-1}). Samples were transported to Perth for analysis. Each water sample was analysed for reactive phosphate (inorganic, RP), dissolved organic phosphorus (DOP), nitrate (NO_3), nitrite (NO_2), dissolved organic nitrogen (DON), and silicate (Si). Standard methods for nutrient analyses (Strickland and Parsons, 1972) were modified for small sample volumes (5–10 ml). DOP and DON were determined by persulfate oxidation (DOP, Menzel and Corwin, 1965; DON, D'Elia et al., 1977).

Additional samples were collected in winter (June 1979) from the lagoon and reef flat areas west of Rat Island and from the Wallaby and Pelsart Groups (Fig. 1). These 1 l samples were analysed for particulate organic carbon (POC), nitrate-nitrite ($NO_3^- + NO_2^-$), ammonium (NH_4^+), and reactive phosphorus (RP) (Strickland and Parsons, 1972).

RESULTS

Mean concentrations of dissolved inorganic and organic nutrients showed no significant seasonal pattern in the 2 yr of sampling (Fig. 2, 3 and 4). In general, there were no clear seasonal trends at specific sites – except that DOP and DON were higher during winter in the reef channels and along the eastern front of Rat Island, and RP was higher during this period over the reef flats.

Temporal variations in nutrient concentrations did occur over time scales other than seasonal, for example, long-term (year-to-year) and short-term (minutes-to-hours) (Johannes et al., 1983a). The short-term variability probably reflects spatial inhomogeneities resulting from complex mixing of waters within the reef system.

The 1981 summer and winter mean concentrations of RP, DOP, and DON were significantly higher than the 1980 mean values ($p < 0.05$, from 1-way ANOVA and Welsch Step-up procedure; Sokal and Rohlf, 1979). These higher concentrations in 1981 (year-to-year variations) were not significantly correlated with obvious physical factors such as storm frequency, storm intensity or rainfall. Table 1 is a summary of dissolved inorganic nutrient and POC concentrations during June 1979 for the 3 island groups.

The overall results of the monitoring program reveal that the nutrient concentrations in the island groups are consistently higher than those in the nearby ocean viz., 0.05 to 0.25 µM NO_3 in offshelf and continental

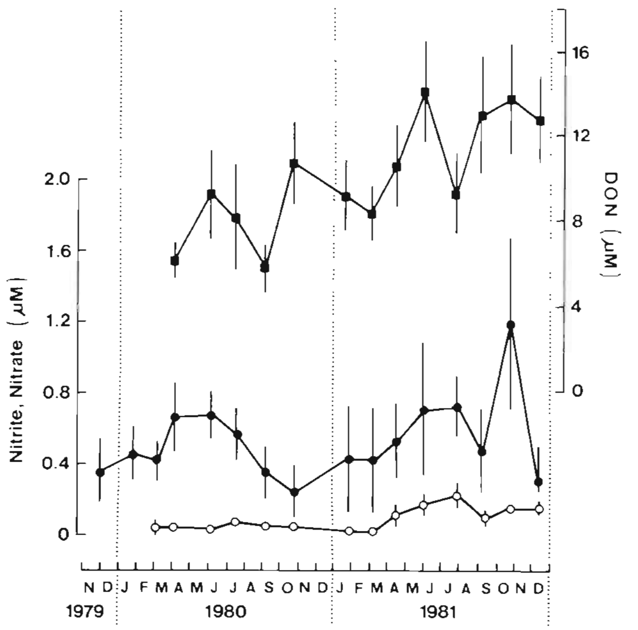

Fig. 2. Dissolved nitrogen concentrations in surface waters at Rat Island. Nitrate, nitrite and dissolved organic nitrogen (DON) shown as mean values ± standard deviation (n = 20)

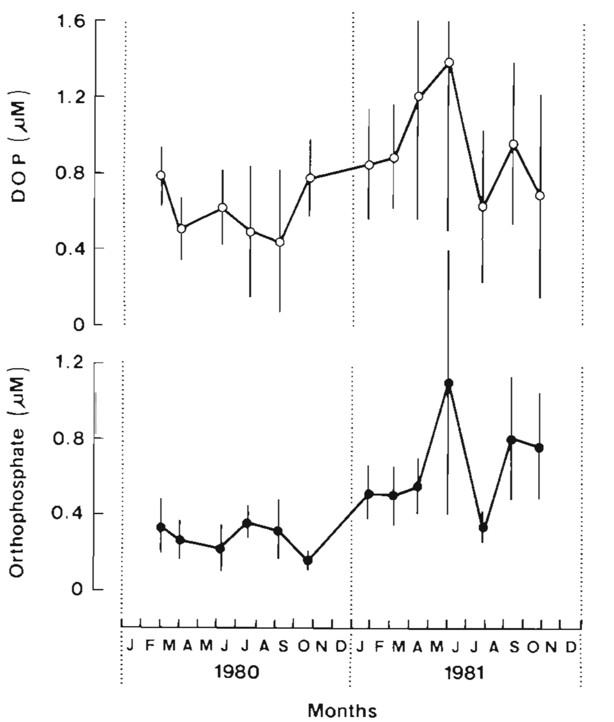

Fig. 3. Dissolved phosphorus concentrations in surface waters at Rat Island. Reactive phosphorus and dissolved organic phosphate (DOP) shown as mean values ± standard deviation (n = 20)

shelf waters (France, pers. comm.; CSIRO Hydrographic Station, Geraldton, unpubl.) and <0.2 μM RP in offshelf waters (Rochford, 1962, 1967, 1980).

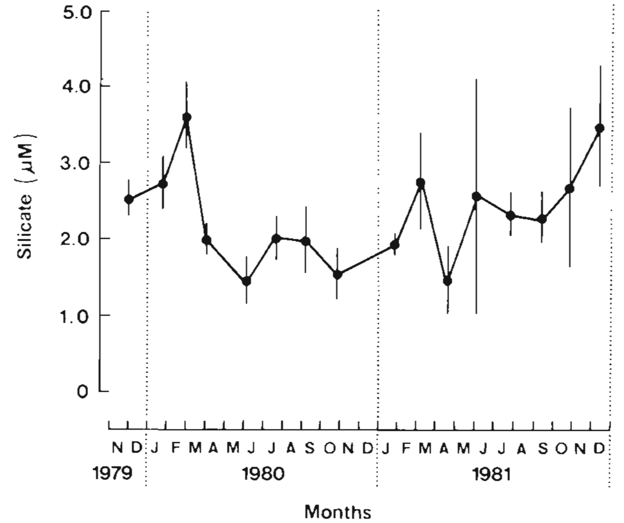

Fig. 4. Silicate concentrations in surface waters at Rat Island. Mean values ± standard deviations (n = 20)

Table 1. Dissolved inorganic nitrogen, reactive phosophorus (RP), and particulate organic carbon (POC) concentrations in Houtman Abrolhos Island waters, June 1979. Mean values of triplicate samples from each site

Sample site	NH_4^+ (μM)	$NO_3^-+NO_2^-$ (μM)	RP (μM)	POC (mg l^{-1})
Pelsaert Group (W. of Wreck Pt.)				
Front reef flat	0.17	0.83	0.26	1.52
Back reef flat	0.22	0.86	0.26	0.53
Lagoon slope	0.28	0.91	0.31	0.87
Easter Group (Western reef)				
Front reef flat	0.21	1.02	0.22	0.87
Back reef flat	0.28	0.96	0.24	0.76
Lagoon (W. of Rat Is.)	0.32	0.93	0.29	0.33
Wallabi Group ((W. of Noon Reef)				
Reef flat (Three Sisters)	1.95	1.50	0.50	0.94
Reef flat (N, Noon Reef)	0.23	1.04	0.41	1.50
Lagoon	0.30	1.19	0.43	0.62

DISCUSSION

The high concentrations of nutrients inside the lagoons of these island groups, relative to the outside oceanic concentrations, indicate that there must be sources of nutrient delivery to the lagoons other than ocean water.

Enrichment of surface waters by deep-layer nutrients along the island shelf, land runoff, and net nutrient flux from the benthos to the water column have been identified as factors leading to localized high nutrient concentrations in inshore waters of other islands (see Sanders, 1981). However, there is no evidence of localized upwelling along the Western Australian shelf margin (Rochford, 1980), so we can dismiss the possibility that ocean water entering the lagoons of the Houtman Abrolhos Islands differs significantly from that of offshelf surface water conditions. Nutrient enrichment resulting from seasonal runoff is unimportant adjudged from the lack of any seasonal changes in the surface water nutrient concentrations near Rat Island and the limited emergent land mass of the islands. Groundwater delivery occurs along much of the Western Australian coastline (Johannes, 1980), but from his observations (pers. comm.) it does not appear to account for a significant nutrient delivery to the Houtman Abrolhos Islands.

As nutrient concentrations are higher inside the lagoons than outside, horizontal mixing must deliver nutrients from the lagoons back to the ocean. To gain an order of magnitude estimate of nutrient flux we have assumed a circular configuration of 20 km diameter with 5 m average lagoon depth for the Easter Group and evaluated RP. Phosphorus is a useful parameter for budgeting long-term net production in marine communities (Atkinson, 1982); nitrogen is not, mainly due to variable nitrogen fixation activity (Smith and Atkinson, in press). Calculations suggest that at least 10^3 moles P d^{-1} are lost from the Easter Group. If this loss were to occur without renewal, we estimate that the P trapped in sediments and biota of the reefs (of the order of 10^6 moles P) would be depleted in about 3 yr. We must turn to alternative explanations for nutrient supply to, and maintenance within the Houtman Abrolhos Island groups.

We suggest another mechanism to account for the biotic-nutrient observations. Net macroalgal growth on the forereef slopes of these island groups is supported by large oceanic advection of nutrients (at low concentrations, but large water flow). Many of these algae are continuously eroded by wave action (e.g. Mann and Kirkman, 1981) and are torn loose during storms, particularly during late autumn and winter. The pattern of water movement across these reefs ensures that much of this algal material is transported into the lagoons. Large fragments of macroalgae are common in the water traversing the reef crest to the lagoons and algal particulates are commonly observed in the lower water column of the windward reef flats of the Pelsaert and Easter Groups (c.f. POC values, Table 1). A series of 6 particulate traps (0.25 m^2, 1 mm mesh; c.f. Johannes and Gerber, 1974), deployed on the western reef crest of the Easter Group during October 1982, yielded 180 to 460 (mean 300) g dry weight m^{-1} crest d^{-1} input to the lagoon. This represents an excess of 10^2 moles P d^{-1} imported to the lagoon over the reef crest in this particulate fraction alone. Floating rafts of algae are common in protected areas. While some of these rafts are lost to the surrounding continental shelf waters (especially those comprised of *Caulocystis, Cystophyllum* and *Sargassum;* algae produced on the reef flats and lagoonal patch reefs), many of the rafts eventually sink to the bottom of the lagoons where extensive accumulations of algae may be found (up to 1 m deep). We assume this material decomposes and releases nutrients back to the water column. Thus, the production of algal material on the reef slopes, transportation to the lagoons where it is trapped and remineralized, and the oceanographic transfer of nutrients back to the sea characterize the nutrient cycle of this system. The lagoons may be viewed as heterotrophic components of the system responding to autotrophic activity on the reef slopes.

The high lagoonal nutrient concentrations may well stimulate the specific growth rates of algae in the lagoon (Steffersen, 1976; De Boer et al., 1978; Topinka, 1978; Prince and O'Neal, 1979). However, our model suggests that these high nutrient levels are indicative of net community heterotrophy for the lagoonal subsystem of the total forereef-lagoon system. Two features distinguish the system from other, superficially similar systems which have been more extensively studied, i.e. coral reefs and coastal kelp beds. First, most coral reefs apparently lack a large macroalgal biomass (Cribb, 1981). In fact, the large fucoid algae and kelp, which are abundant on the forereef slopes of the Houtman Abrolhos Islands, are typically temperate water algae (Womersley, 1981). Furthermore, the bulk of algal production on coral reef slopes enters grazing rather than detrital food webs (Bakus, 1967, 1972; Hatcher, 1982). Therefore, high rates of algal detritus generation with subsequent dispersal, remineralization, and nutrient elevation are unlikely to be conspicuous features of most coral reefs (Marsh, 1976). Second, areas with a large biomass of fucoids and kelps often lack distinctive basins like reef lagoons in which to localize and accumulate detritus. Thus, the spatial separation of autotrophy and heterotrophy (exemplified by low and high nutrient concentrations in this instance) is not as conspicuous for many macroalgal-dominated ecosystems as it is in the Houtman Abrolhos Islands.

We conclude that this large-scale separation of autotrophic and heterotrophic communities, though more conspicuous in the Houtman Abrolhos Islands than in many other systems, is an important characteristic of ecosystem metabolism. It may also account in part for the sustained high yield of the lobster fishery at the Houtman Abrolhos Islands. Such fisheries are rare on most tropical coral reefs (Morgan, 1980).

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