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REPORT

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Phosphorus supply for atoll biological productivity

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Abstract The origin of phosphorus for atoll productivity is discussed using biogeochemical data from Tikehau atoll (French Polynesia) and taking into account new concepts of the role of the coral reef fractal dimension on P uptake. The horizontal P flux from surface oceanic water is three orders of magnitude higher than the estimated outer reef new production and three times higher than the lagoon new production. Therefore, the nutrient paradox for atoll production is definitively obsolete.

Keywords Atoll · Phosphorus · Excess production · Nutrients requirement

Introduction

Scientists studying coral reefs were faced with the paradox of the high productivity of such ecosystems despite low nutrient levels in the surrounding waters (Webb et al. 1975). D'Elia (1977) thought that symbiotic corals could not obtain all the phosphorus they require by means of reactive phosphorus uptake at typical environmental concentrations. Different theories have tried to explain this paradox by identifying potential nutrient sources: coastal upwelling along the Great Barrier Reef (Andrew and Gentien 1982) and endo-upwelling in the platform of atolls (Rougerie and Wauthy 1986; Rougerie et al. 1992). However, Smith (1988) further sharpened our understanding of productivity and nutrient relationships in reef ecosystems by pointing out that the net productivity of the whole-reef system is low. Indeed, Kinsey (1985), Smith (1988), and Crossland et al. (1991) demonstrated that the high photosynthetic production of reefs is nearly completely offset by high rates of respiration and that net production is comparable to that found in oligotrophic plankton communities. With low net productivity and efficient recycling, whole-reef ecosystems should not be expected to require large inputs of new nutrients (Marsh 1987).

The aim of the present paper is to discuss the apparent paradox of high-productivity reef systems in the midst of nutrient-poor waters by using data obtained for a whole atoll, i.e. outer reef and lagoon, by taking the Tikehau atoll (15°S, 148°W; French Polynesia, South Pacific Ocean) as an example (Fig. 1). Indeed, Polynesian atolls represent an excellent vehicle for discussing this paradox because:

1. They are located in southern oligotrophic tropical waters which involve a great anticyclonic gyre (Blackburn 1981) with low nutrient levels in the mixing layer, i.e. $P\text{-}PO_4$ 0.2–0.3 μM and $N\text{-}NO_3$ < 0.1 μM (Rancher and Rougerie 1992).
2. Surface currents are in a constant westward direction, with speeds between 0.1 and 1 m s^{-1} (Tabata 1975).
3. The flat areas of the land crown of the atolls and their remoteness from high islands (e.g. Tahiti) make terrestrial nutrient input zero.

Due to the complexity of the nitrogen cycle in reefs, we use the phosphorus budget to estimate new production following Smith (1984, 1988) and Hatcher (1997). We will try to demonstrate that the horizontal oceanic surface water flows are able to supply phosphorus requirements for the whole atoll ecosystem: reef flat, outer reef slope, and lagoonal communities. In this paper, we use the definitions of Hatcher (2000) applied to phosphorus in atoll ecosystem and illustrated in Fig. 2: (1) atoll excess (i.e. net) production (EP) is defined by inorganic carbon and nutrient fluxes; and (2) atoll new P production (NP) is the proportion of atoll excess primary production that utilizes allochthonous P in the synthesis of organic material plus the capture and remineralization in situ of particulates. We will consider separately: (1) the outer reef flat communities with the outer reef slope, which are directly under the influence of

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