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CARBON FLUX AT THE WATER-SEDIMENT INTERFACE OF TROPICAL LAGOONS

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Scientific topic :

Tropical ecosystem understanding is related to reef compartment functioning and to a lesser extent to mangrove systems. Reef metabolic budget is considered to be approximatively balanced with a very weak net production in spite of a large gross production (Crossland *et al.*, 1991 ; Gattuso *et al.*, 1993) when carbon export of mangroves to adjacent systems appears more and more problematic (Alongi & Christoffersen, 1992). As a consequence, structuring mechanisms of the vast stretch of sedimentary bottoms found in most lagoons is still misunderstood. These biogenic accumulation of particules, up to now considered as the result of reef exportation, and to a lesser extent to mangrove input, have focussed little attention as far as the carbon budgets are concerned (Sorokin, 1993). Rare studies were obtained from oxygen measurements transformed in carbon by the way of metabolic quotients previously calculated in temperate ecosystems or even on planctonic organisms. Such an approach is conceivable in preliminary studies but needs an improvement to balance coral reef budget. Our research constitute an adaptation of carbon budget investigations undertaken in temperate marine sediments by Hargrave & Phillips (1981) to coral systems.

Aims of the study

Our research deals with energetic budgets of tropical lagoon taking into account the actual metabolic quotients and the proportion of aerobic and anaerobic metabolisms in marine sediments. These investigations use CO₂ flux measurements and oxygen flux measurements at the water sediment interface. Until now, our investigations have been undertaken on three sites in the Pacific i.e. two high island sites : the SW lagoon in New Caledonia and the Moorea lagoon in French Polynesia, and one atoll site : the Uvea lagoon in Loyalty islands. Two workshops initiated by the french National Program on Coral Reef (PNRCO) cope with an



integrated study of New Caledonia lagoons undertaken by ORSTOM (Lagoon Program). The Polynesia site was selected to ensure a closer cooperation with the second team of our national program on carbon and carbonate fluxes (J.P. Gattuso). Comparison of the various results collected on these lagoons should help to a better understanding of large scale spatial variability of the fluxes.

Our main objective is the estimation of carbon budget in sedimentary area of lagoons. The benthic compartment is thus considered as autotroph when the amount of carbon produced by primary producers is equal or greater than metabolic needs ; it is considered as heterotrophic in the reverse situation (Hopkinson et al., 1991). Energetic budget can be obtained by carbon flux calculation using oxygen uptake measurements (Boucher & Clavier, 1990 ; Garrigue *et al.*, 1992a) or by a direct measurements of carbon fluxes related to photosynthesis and to respiration (Uvea lagoon). This approach needs to calculate actual community respiratory quotients ($CRQ = \Delta CO_2 / \Delta O_2$) and community photosynthetic quotients ($CPQ = \Delta O_2 / \Delta CO_2$) of the whole benthic community. CRQ has also been analysed by partitioning carbon fluxes due to aerobic and anaerobic metabolisms at the water-sediment interface (SW lagoon of New Caledonia and Moorea). CO_2 being the end product of quiet all metabolisms (oxic respiration, sulfate and nitrate reduction, fermentations and even methanisation when CH_4 diffuses in the water column : Marty et al., 1988), this flux can be considered as the sum of oxic and anoxic metabolisms. Carbon flux related to anoxic metabolism is calculated by subtracting oxic metabolism from total flux. Oxic metabolism is obtained by correcting oxygen consumption using one aerobic respiratory quotient whose value depends from the oxidised metabolic substrate.

Technical design

Simultaneous measurement of oxygen uptake and pH/TA changes were performed in triplicated enclosures deployed at the water-sediment interface by SCUBA diving. A pH logger, built by AIMS Laboratory in 1991, has been tested and adapted using technics previously deployed on corals and calcareous algae (Barnes, 1983 ; Chisholm et al., 1990 ; Gattuso et al., 1993). A threeway oxygen logger was built by the ORSTOM center from Noumea using YSI oxymeters. Incubations were performed in ca 50 liters enclosures isolating 0.2 m² of undisturbed sediment from the water column, first at light for four hours in order to measure joint effects of primary production and respiration. Dark conditions were then simulated for 2

hours by either covering the enclosures with a black sheet, nor by injecting an inhibitor of photosystem II (DCMU : Garrigue et al., 1992) in order to measure respiration.

Total CO₂ flux (ΔCO_2) are calculated from the difference between TCO₂ at the beginning and at the end of the incubation using pH, TA, temperature and salinity measured in enclosed water. ΔCO_2 is corrected from the variation of alkalinity (ΔTA) to take into account CaCO₃ changes (ΔCaCO_3) and oxydoreduction processes (Anderson et al., 1986). Calcification/decalcification processes are prevailing in aerobic conditions when other pathways occur for anaerobic degradation of organic matter ie sulfatoredution, a metabolism which prevails in most tropical sediments (Skyring & Chambers, 1976 ; Kristensen *et al.*, 1991). ΔO_2 is calculated with and without correcting from sediment non-biological oxygen demand (NBOD) obtained by poisoning living organisms (formalin 4%). NBOD corresponds to oxidation of reduced compounds accumulated into the sediment during anaerobic respiration.

Results

Soft bottom energetic budget has first been studied at mesoscale in the SW lagoon of New Caledonia. A spatio-temporal random sampling allowed to estimate carbon flux on the whole lagoon area (2000 km²) during one year. The lagoon is globally a carbon sink with a ratio production/respiration (P/R) of 0.88 (P = 0.40 g C m⁻² and R = 0.45 g C m⁻²) but the assumption has to be blent in space and time. The three types of bottom communities previously defined in the SW lagoon (Chardy et al., 1988) display different types of characteristics. Muddy bottoms (MB) along the seashore present the lowest metabolism and a P/R ratio significantly far lower than one. On the other hand, grey-sand bottoms (GSB) in the central part of the lagoon and white-sand bottoms (WSB) back to the barrier reef have a significantly higher metabolism but their P/R ratio (0.94 and 1.08 respectively) do not significantly differ from 1 and both can be considered as autotrophic biotops.

The global heterotrophy of the SW lagoon is thus exclusively related to the large MB carbon sink (35% of lagoon surface), far away from the barrier reef, which needs an external input to operate. This deficit is covered by particulate matter sedimentation (terrigenous origin) which has a rate 2 time greater over this bottom (1.05 g C m⁻² d⁻¹) than in other part of the lagoon : 0.55 and 0.59 g C m⁻² d⁻¹ in GSB and WSB respectively (Clavier et al., 1995). Over the year, metabolic activity follows an seasonal cycle with lower rates at the beginning of the cold season and higher rates when temperatures are the highest. Production and respiration vary in the the same way so P/R remains constant over time.

These results shows that in the SW lagoon, the backreef carbonate sands are a source of energy and thus can be independent from the reef input. In order to test this assumption, we performed a similar study on an atoll lagoon in Uvea (Loyalty Islands) devoided of any terrigenous influence. Sampling has concerned the whole soft-bottom area of the lagoon (800 km²) in junc. Annual production (0.88 g C m⁻²d⁻¹) and respiration (0.84 g C m⁻²d⁻¹), estimated by using the same annual fluctuation of production than in the SW lagoon of New Caledonia, are more than two time higher than in the previous lagoon. The P/R ratio = 1.05 confirms the autotrophy of coral sands and their potential functional independence from the reef which represents only a physical barrier for lagoon bottom. However, the two studied ecosystems display fundamental differencies : the SW lagoon needs 40 000 tons of carbon per year to operate when the Uvea lagoon exports 8000 tons C y⁻¹ from soft bottom area.

During the course of these studies, the metabolic quotients (QRC and QPC) and the contribution of anaerobic metabolism to total metabolism were also investigated. In the SW lagoon, QRC calculated by geometric regression of 61 dark incubations reach 1.14 for the whole lagoon. Considering an aerobic respiratory quotient of 0.85, the proportion of anaerobic/total metabolism equals 40%. QPC value calculated from 18 light incubations is 1.03. The excellent linearity between oxygen flux and carbon dioxide flux allows to consider these values as a characteristic of the whole lagoon. A similar study in the lagoon of Moorea on 7 stations sampled on the Tiahura transect indicates a QRC of 1.27 and a ratio anaerobic/total metabolism equal to 56%. These values are greater than the previous data obtained in New Caledonia but do not significantly differ suggesting a functional analogy of benthic ecosystem functioning. Finally, in the Uvea lagoon, a QRC of 1.17 was obtained, a value which does not significantly differ from other sites. This is not the case for the very low value of QPC (0.41), which indicates a fundamental difference among the benthic primary producers operating photosynthesis in Uvea atoll. These results demonstrate the necessity to calculate metabolic quotient for different communities whose functioning rely on different taxa assemblages.

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