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AN ATTEMPT TO ESTIMATE THE CARBON BUDGET  
FOR THE SOUTH WEST LAGOON OF NEW-CALEDONIA  
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## ABSTRACT

The results of ecological studies carried out in the south western part of the New-Caledonian lagoon are integrated and summarized by means of an annual budget of carbon cycling. Pelagic production, net sedimentation of particulate organic matter, biomass and trophic structure of benthic community support the formation of a hypothetical energy flow-diagram. Despite the fact that many flow estimates are based on rough assumptions, some insight concerning the function of this ecosystem may be advanced. The major sources of energy for the benthic food web are allochthonous organic matter, macrophyte and micro-phytobenthic production, other sources are negligible. The overall balance for the benthic community suggests that the flow of organic matter through decomposers must be large and that living microbiota, rather than detritus itself, represent the principal carbon source for consumer organisms. The energy transfer between benthic compartments seems lower than that recorded hitherto in various temperate and boreal ecosystems.

## INTRODUCTION

Energy flow studies have played an important role in the development of coastal marine ecology (Mann, 1982). Although it is easy to find significant number of such approach in temperate and boreal shallow waters, there are few for coral reef and lagoonal systems. Some diagrams relating relationships between functional groups in a coral reef ecosystem have been already attempted (Lewis, 1981, Mann, 1982) without any flux and biomass quantification. More recently, the "ECOPATH" model, carried out by Polovina (1984) on the French Frigate Shoals, and considered as a tool for resource management, did provide a quantified energy budget of a coral reef environment. In this paper, the carbon budget for the south western part of the New-Caledonian lagoon has been conducted with the aim of providing a summary of the state of our knowledge about this ecosystem and giving some insight into its functioning.

Previous descriptive studies carried out in the New-Caledonian lagoon in benthic ecology and sedimentology have been reviewed in Chardy et al. (1988). Recent years, quantitative works were conducted mainly in the west southern part of the lagoon, providing a significant amount of information about this area. Sources for this paper are publications, cited in a presentation of the available data, and as yet unpublished data from on-going studies, quoted with the agreement of their authors: such original sources are acknowledged.

## MATERIALS AND METHODS

## Study area

According to its geomorphological features and scale, the south western part of the New-Caledonian lagoon may be described as a small inland sea. Bounded to the north by the southern portion of the Saint Vincent bay and to the south by a line running from Ouen Island to Mato Pass (figure 1), the area investigated covers 2066 km<sup>2</sup>, mean depth of 18 m. The major benthic communities, identified as muddy bottoms, grey sand bottoms and white sand bottoms, have been mapped on the basis of numerical dominant species (Chardy et al., 1988). The reef structures, covering 5 % of the whole area (Testau and Conand, 1983), are neglected in the present approach.

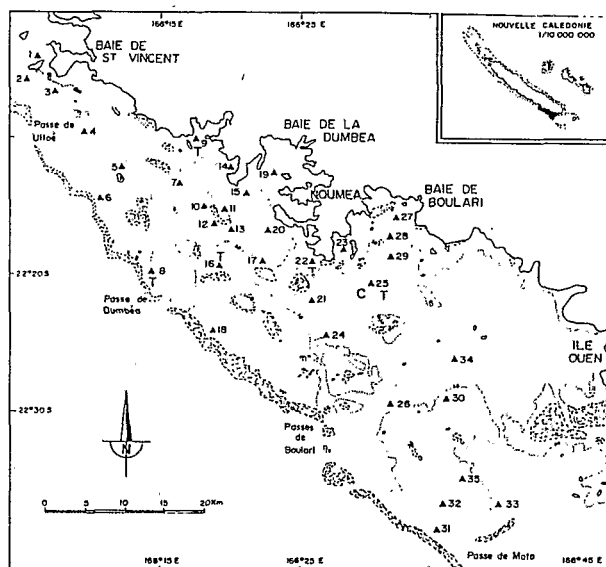


Figure 1. Map of the investigated area and location of sampling stations.

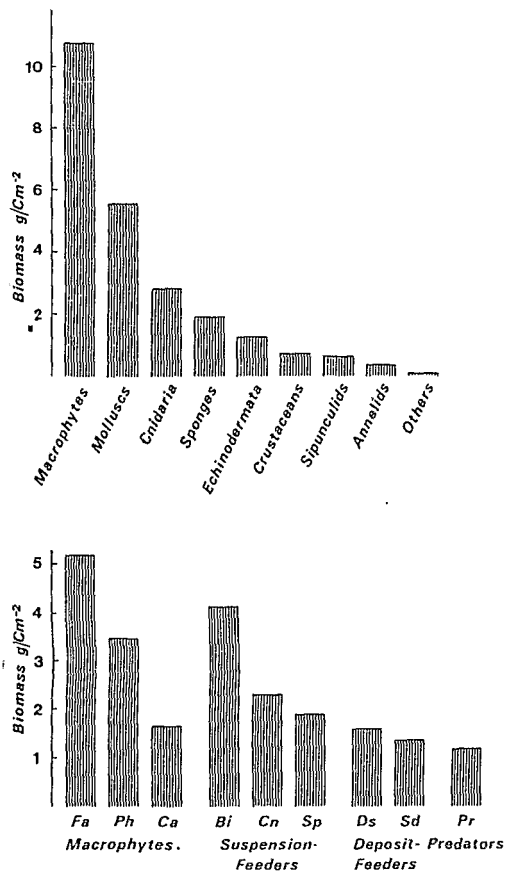
A = Benthic station  
T = Traps experiment stations  
C = Pelagic station "côtiers".

## Available data

**Benthos.** Biomass and trophic structure of the macrobenthos are based on a benthic survey of 35 stations (figure 1) the results of which are



described in detail in Chardy *et al.* (1987). The taxonomic groups dominant by weight are identified in figure 2a. Categorization of species into trophic groups according to their dominant feeding behaviour (figure 2b) is discussed in Chardy and Clavier (1988). Species biomasses for the whole area investigated are calculated according to the stratified sampling of the community study. The major trophic groups are characterized by the following dominant species among the 311 taxa recorded.



**Figure 2. a :** distribution of biomass among the main macrobenthic groups in the lagoon. **b :** distribution of the biomass by trophic groups. Fa = fleshy algae ; Ca = calcified algae ; Ph = phanerogams ; Sp = sponges ; Bi = bivalves ; Cn = cnidarians ; Sd = surface deposit-feeders ; Ds = deposit-swallowers ; Pr = predators.

Macrophytes : Amantia glomerata, Cymodocea serrulata, C. rotundata, Halophila ovalis, Halimeda incrassata.

Deposit-feeders : Strombus gibberulus, S. luhuanus, S. eythrinus, Aspidosiphon corralicola, Maretia planulata.

Suspension-feeders (including free living scleratinians) : Heteropsammia michelini, Anadara scapha, Brachtechlamys vexillum, Ircinia sp..

Carnivores (including necrophages) : Murex ramosus, Pentacaster alveolatus, Paguridae.

Biomasses are expressed in g. AFDW m<sup>2</sup>.

At 5 stations (figure 1), the following parameters were measured on the top first cm layer of the sediment :

- organic matter content determined as weight loss on ignition (550° C) after drying for 48 hours at 80° C,
- ATP biomass analysed by the firely luminescence method (Chardy and Clavier, 1988),

**Pelagos.** General features of chlorophyll *a* and nutrients concentration in the water column are available in Rougerie, 1985, and analysis of planktonic copepod communities is provided by Binet (1985). During a six year survey (1982-88) chlorophyll *a* and zooplankton biomass were sampled every weeks at the pelagic station "côtière" (figure 1). This study is continuing together with a spatial survey of the plankton in the south-west lagoon, the data of which is unpublished but available for the present work.

Suspended organic matter and vertical sedimentation flux are taken from Chardy *et al.* (in preparation). Sinking material was collected every month at 5 stations (symbols "T" in figure 1) using sediment traps. Particulate organic carbon (POC) was measured in the traps and in the water column with Hewlet Packard CHN analyser. Chlorophyll *a* and pheopigments were measured fluorometrically in 90 % acetone extracts.

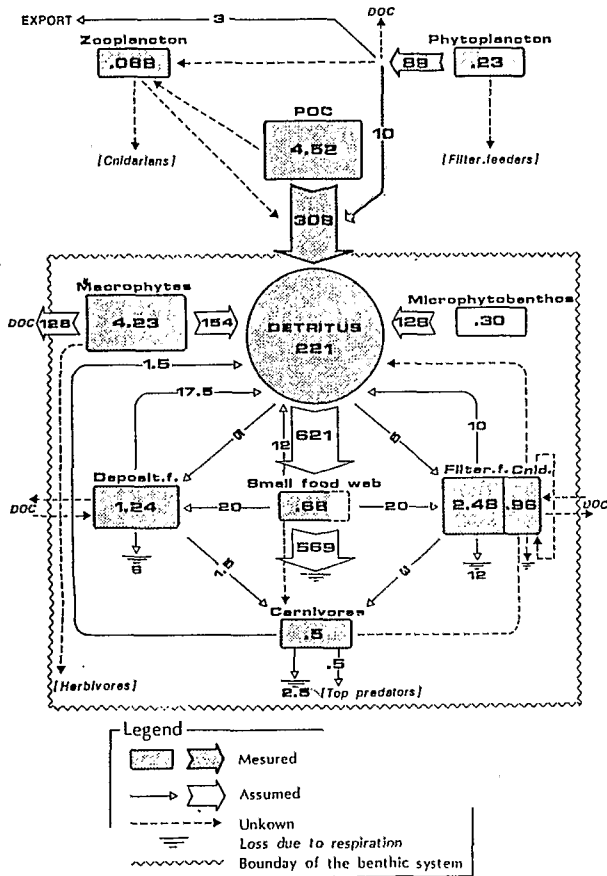
Primary production was determined in five periods of the annual cycle at the pelagic station "côtière" (figure 1), using <sup>14</sup>C method. Incubation was carried out every 5 metres from 0 to 30 metres depth (unpublished data).

#### Conceptualisation of the compartmental flow diagram

Obviously, the energy flow diagram format is used to summarize biomass and production data into a concise framework. Nevertheless, spatial and seasonal variations are ignored, which of course severely limits the realism of the model. Then, the level of complexity of the model depends on the amount of available information. We suggest a highly simplified energy flow diagram (figure 3) which consists of 10 compartments listed as follows : 1) phytoplankton, 2) zooplankton, 3) suspended particulate organic matter, 4) benthic macrofauna (algae and phanerogams), 5) benthic microflora, 6) benthic detritus, 7) small food web (bacteria, microfauna and meiofauna), 8) deposit-feeders, 9) suspension-feeders (including the special case of cnidarians), 10) invertebrate carnivorous including necrophagous. According to Kuipers *et al.* (1981), bacteria, microfauna, meiofauna, and small macrofauna, are regarded as one functional whole, the "small food web".

Only the benthos (compartments 4 to 10) is regarded as a carbon balanced system. Available information on the pelagic component is not sufficiently clear as yet to allow a proper energy budget estimate. Thus, pelagic compartments (1 to 3) are "forced", that is to say they are outside the system of definition. They are only regarded as a source of energy for the benthos. For each benthic compartment, as well as for the benthic

system itself, the sum of inputs equals the sum of outputs. The energy budget of biotic compartments is constructed in the conventional form  $C = P + R + (F + U)$  when  $C =$  consumption,  $P =$  production,  $R =$  respiration,  $(F + U) =$  faeces combined with excretion. Benthic detrital pool is an abiotic compartment and represents a passive storage of energy. Biomass are expressed in  $g. C m^{-2}$  and flows in  $g. C m^{-2}.year^{-1}$ .



**Figure 3.** Highly simplified energy flow diagram of the southwest New-Caledonian lagoon. Biomass in  $g C m^{-2}$  are in boxes and fluxes in  $g C m^{-2} year^{-1}$  are in arrows. POC = particulate organic carbon ; DOC = dissolved organic carbon.

**Assumptions**

Parameter values derived from the literature represent the most controversial part of such an approach. We restrict our discussion to those parameters that are the most essential to an understanding of the energy budget. The following conversion coefficient has been adopted :  $1 g C = 0.40 g AFDW$  (Steele, 1974) ;  $C/Chl$  ratio = 30 (assumed from extensive literature) ;  $C/ATP$  ratio = 200 (Gerlach, 1978). Direct measurements to assess the production of benthic flora and fauna are not available. A tentative estimate of annual production is made by adopting turnover rate from the literature.

It is conventionally considered that a part of the macrophytic production is released as dissolved organic matter ; we assume that 45 % of it is transformed in DOC ; Smith and Forman, 1984). Benthic macroflora production data are derived from Doty (1971), Buesa (1977), Bay (1982) for the species. Microphytobenthic production and biomass are derived from an extensive study carried out by Charpy-Roubaud (1986) in the lagoon of Tikehau (French Polynesia).

The recorded annual P/B ratio at community level for macrofauna usually lies in the range of 1 to 2 (Mills and Fournier, 1979 ; Barnes and Mann, 1980 ; Dewilde et al., 1986) despite the large dispersion at species level (Robertson, 1979). Comparison of northern boreal, mediterranean and indian tropical species by Ansell et al. (1978) shows that P/B ratio increases with low latitude, but there is considerable overlap. Using several indicators, Longhurst (1983) assumes a factor of 2 between european and tropical P/B ratio. After taking all this evidence into consideration, a P/B = 2 is assumed, in this study, for the macrobenthic compartments. From this production, 60 % is assigned to predation and 40 % to non-predatory mortality (Brylinsky, 1972), these return and go back to the detritic compartment.

Annual respiration ( $R_a$ ) of zoobenthos is derived from the relation established by Schwinghammer et al., 1986 :  $\log_{10} R_a = 0.367 + 0.993 \log_{10} P_a$ , where  $P_a =$  annual production.

Assimilation efficiency ( $A_e$ ) for suspension-feeders is assumed to be .70, after an extensive review of the literature, mainly devoted to bivalves (Widdows and Bayne, 1971 ; Tenore and Dunstan, 1973 ; Navarro and Winter, 1982). For deposit-feeders, estimated " $A_e$ " values are usually lower and depend on the trophic source itself. From the compilation of Webb et al. (1977), Dame et al. (1981), Pace et al. (1984), Pandian and Marian (1985), we accept the rate of .60 for ingestion of "small food web" and .10 for ingestion of detritus. In carnivores, " $A_e$ " is assumed to be 80 % (Pace et al., 1984 ; Pandian and Marian, 1985). Consumption ( $C$ ) is determined from the relation  $C = A/A_e$ , where  $A = P + R$ .

According to Newell et al. (1982), carbon conversion efficiency of natural detrital material by heterogeneous assemblage of marine bacteria, fluctuates between 6 and 14 %. This order of magnitude is accepted for the conversion efficiency of the "small food web" in the New-Caledonian lagoon. Non-predatory mortality rate for this compartment is assumed to be .05 day<sup>-1</sup> according to Pace et al., 1984.

**RESULTS AND DISCUSSION**

Figure 3 summarizes the major energy flow pathways for an annual cycle of the lagoonal system, derived from available data and assumptions explained earlier. The importance of the amount of organic matter arriving in the benthic system (46 % of the detritus storage) must be regarded as a dominant feature in the overall system. This value lies in the upper range of the energy inputs expected for coastal shallow waters (Mann, 1982). Relative contribution of the phytoplankton compartment to this flow appears negligible and represents only

15 % of the primary pelagic production. Despite the lack of information about grazing of filter-feeders on phytoplankton and possible predation of cnidarians on zooplankton, the links between planktonic and benthic compartments appear limited. Thus, it seems realistic to divide primary planktonic production into zooplankton grazing and released of dissolved organic matter (both unknown), whilst export of phytoplankton to the open ocean is low (derived from Rougerie, 1985) when expressed as a percentage of primary production.

Benthic macroflora and microflora production represents respectively 25 and 21 % of the input of organic carbon to the detritus pool. Despite the roughness of our calculations, the high macrophytic standing stock suggests the significant role of this compartment as a carbon resource for the zoobenthos. Conversely, the annual microphytobenthic production estimate is purely theoretical, the data being extracted from an other lagoonal site (French Polynesia : Charpy-Roubaud, 1986). We may observe that this order of magnitude is relevant with data summarized by Bunt *et al.*, 1972, in tropical sediment.

The main problem at this stage is to know to what extent the energy available in the detrital pool is consumed directly by deposit and suspension-feeders or via the "small food web". The hypothesis of balance between detritus input and macrobenthic energy demand requires the assumption that the "small food web" consumes the major portion of the detrital fluxes with a low carbon conversion efficiency. Moriaty *et al.* (1985) show that the flux of organic matter through bacterial decomposition processes must be large in lagoonal systems, and the significance of bacteria as the main potential trophic source for a variety of benthic organisms is widely recognized (Sorokin, 1973 ; Reiswig, 1975). In order to match a balanced carbon budget of the benthic system, we must accept that the "small food web" accounts for 80 % of the energy required by deposit and filter-feeders and consumes almost all the available detritus with a carbon conversion efficiency of 8 %. We notice that this conversion efficiency corresponds to values produced by Newell *et al.* (1982) for natural organic detritus decomposition. From our derivations, doubling time for the "small food web" in the New-Caledonian lagoon is approximately 4 days, which falls in the range of bacterial productivity measured by Moriaty *et al.* (1985) on a reef flat sandy sediment.

The ecological efficiency of deposit-feeders, suspension-feeders and carnivores is 6 %, 12 % and 13 % respectively. These values are lower than those assessed by several authors in temperate systems, where 20 % is recognized as a moderate estimate (Steele, 1974).

This attempt highlights several important gaps in our understanding of the carbon budget of the New-Caledonian lagoon. The lack of data, particularly evident for pelagos fluxes, does not bring into question our understanding of the benthic community in as much as the input of POC is estimated. Conversely, studies on microphytobenthos production are highly suitable to confirm the order of magnitude advanced. Dissolved

organic matter is not discussed in this paper, although it is recognized that it may represent a potential trophic resource for benthic invertebrates (Darnell, 1967). The role of the free living scleratinians is also questionable. In situ observations reveal that polyps of *Heteropsammia michelini* are commonly expanded during the day, suggesting photosynthetic activity (Semens and De Riemer, 1977), nevertheless it is reasonable to assume a polytrophic activity of these polyps, not quantified in our budget. The lack of data is particularly critical for small-sized organisms, categorized within the "small food web" compartment which itself represents a complex trophic system and has a fundamental role in the carbon cycle. More generally, the flow diagram presented highlights the paucity of quantitative information on fluxes.

Although it is premature to make a definitive statement on the energy budget of the New-Caledonian lagoon from this oversimplified approach, the following evidences should be outlined.

- 1) Energy flow between the water column and benthos is mainly due to allochthonous energy source. As it is conventional to consider coral reef organic production to be approximately balanced by consumption, the most probable source of energy for the lagoon would be the adjacent land mass, especially shoreline colonized by mangroves.
  - 2) Benthic macro and microflora contributes greatly to the amount of detritus material, other autochthonous sources such as phytoplankton, and faecal material appear much smaller.
  - 3) Pattern of energy distribution into the benthic system suggests a very large flow from the detrital pool to the decomposers which are the basis of the benthic food web.
- Finally, in spite of a large input of energy (POC sedimentation plus benthic primary production), production at the top of the benthic food web is low, suggesting a relatively low efficiency of the benthic community of New-Caledonian lagoon as energy transformer.

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