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PHOSPHORUS BUDGET IN AN ATOLL LAGOON

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ABSTRACT

The different states of Phosphorus (mineral, organic, dissolved and particulate) were studied between 1982 and 1987 in the oceanic and lagoon waters and sediment pore waters of the atoll of Tikehau. Fluxes associated with the different forms of phosphorus were measured or estimated.

In the lagoon, the mean of total phosphorus integrated to 25m (average depth) is equal to 534 $mgP \cdot m^{-2}$, i.e. 1.4 time higher than in oceanic surrounding waters (for the same integrated depth).
The percentages of phosphorus forms in the lagoon are 58% for the dissolved organic (DOP), 23% for the phosphates (PO_4) and 18% for the particulate organic (POP).
Living POP is composed by 28% of phytoplankton, 20% of heterotrophs <5µm, 26% of heterotrophs 5µm - 35µm and 26% of zooplankton (35µm - 2000µm).
86% of POP belongs to particles of a size of less than 35µm of which 49% are less than 5µm.
Heterotrophic excretion supply 75% of Phosphorus requirement of phytoplanktonic production (12 $mgP \cdot m^{-2} \cdot d^{-1}$).
Phosphate flux from sediment give all the Phosphorus required by phytobenthic production (6.8 $mgP \cdot m^{-2} \cdot d^{-1}$).
Detritus probably come from reef production.
POP exportation from the lagoon represents only 2.5% of phytoplankton production.

INTRODUCTION

Atolls represent a special model of coral reef ecosystem. The main part of atolls is mainly formed by the lagoon in which planktonic and sand primary production can play a preponderant role (CHARPY-ROUBAUD *et al.*, in press).
The cycle of matter in atoll is one of the main objectif of the ORSTOM program (ATOLL) in French Polynesia. We studied Tikehau Atoll because of the maritime and air links and its economic importance (40% of fresh fishes consumed in Tahiti are taken from this atoll). Because of its geomorphology, we have considered it as being representative of open atolls (i.e., those having one or several open accesses to the sea).
From 1982 onwards, our research had focused on : physical and chemical characteristics of the lagoon and neighboring oceanic waters, quantization of exchanges between ocean and lagoon, quality and quantity of organic matter in the lagoon under the particulate form, estimation of the production, excretion and ingestion of zooplankton, remineralisation within the sediments and exchanges between interstitial and lagoon waters.
Phosphorus is an important element of organic matter and generaly a limiting factor for primary production. In this paper we study the different forms of Phosphorus and fluxes related to the compartments (phytoplankton, phytobenthos, heterotrophs and detritus) in order to modelise the cycle of the Phosphorus in atoll lagoon ecosystems

MATERIAL AND METHODS

The stations covered the whole lagoon and surface oceanic waters were studied as reference.
A representation of the methodology employed is provided in Figure 1.
We use the mean Phosphorus concentration integrated over 25 metres (average depth of the lagoon): $mgP \cdot m^{-2}$.
Phytoplanktonic Phosphorus was estimated from the mean chlorophyll concentration, the C/Chlorophyll=50 ratio and the C/P=37 assimilation ratio for the phytoplankton, measured by CHARPY and LEMASSON (in preparation), i.e. a P/Chlorophyll = 1.35 . The separation of phytoplanktonic P by category of size corresponds to the mean of the percentage of chlorophyll passing through a filter of 5µm.
Phytobenthic Phosphorus was estimated from the mean content in functional chlorophyll of a 0-0.5cm thick layer of sediment and the P/Chlorophyll relation used for phytoplankton.
Living P was estimated from the mean concentration of ATP and the relation:

$$P/ATP = (C/ATP) / (C/P)$$

with C/ATP = 250 and C/P = 37; i.e. a ratio P/ATP = 6.76.
Living P <5µm was estimated from the percentage of ATP passing through a filter of 5µm pore size.
The P of heterotrophs of a size <5µm was estimated from the difference between living P <5µm and phytoplanctonic P <5µm.
The P of heterotrophs of a size of between 5µm and 35µm was estimated from the difference between living P >5µm and phytoplanktonic P >5µm.
The P of heteroptrophs of a size of between 35µm and 200µm corresponds with that of microzooplankton; the percentage of P in the dry weight of particles captured by a net with a 35µm mesh (a flter sifting over 200µm) was determined on subsamples. Microzooplanktonic P was then equal to this percentage multiplied by the dry weight of particles from which the weight of debris had been substracted.
The living P >200µm corresponds to the mesoplanktonic P; it was obtained as previously from the edges of net with a 200µm mesh (LE BORGNE *et al.*, in press).

Flux unit is $mgP \cdot m^{-2} \cdot d^{-1}$.
P assimilation by phytoplankton was measured directly by *in situ* incubations in the presence of ^{32}P.
Phytobenthos P uptake was estimated using gross average O_2 production transformed into Carbon production by the equation by McCLOSKEY *et al.* (1978) (which for a photosynthetic coefficient = respiratory coefficient = 1, becomes:

$$C \text{ production} = (12/32) \cdot O_2 \text{ production})$$

and dividing C production by the C/P uptake ratio measured for phytoplankton (we have no data on C/P uptake ratio for phytobenthos).
The excretion of P by zooplankton was measured in vials incubated in darkness by observing in-

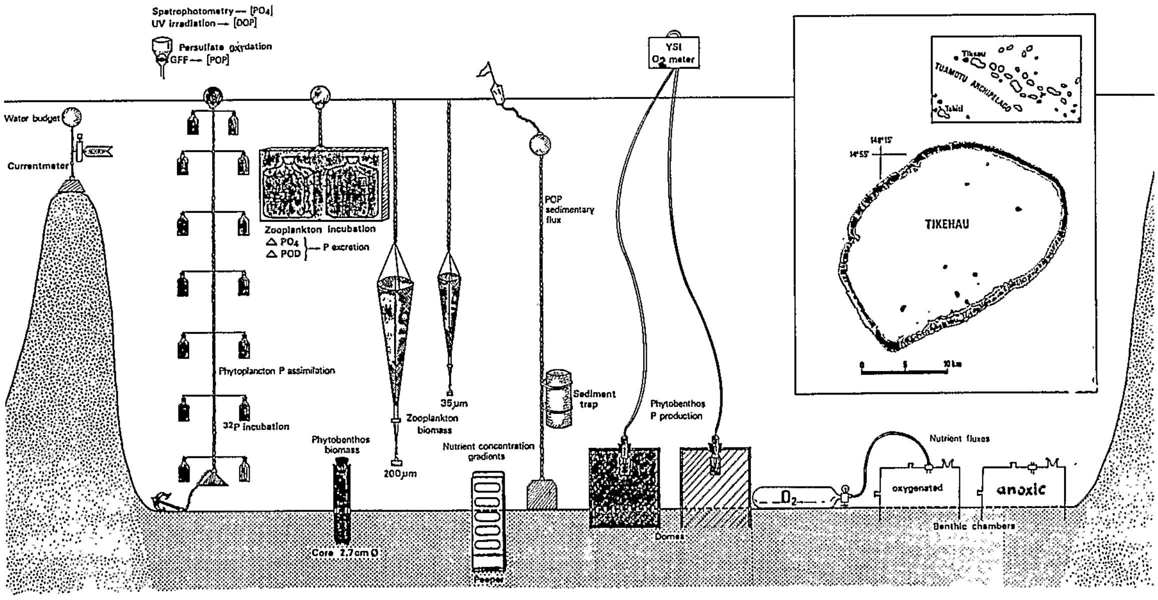

Figure 1: Methods used for measurements of Phosphorus standing stock and fluxes.

creases in concentrations of PO_4 and DOP. Production can be estimated from the excretion and net yeld in growth, calculated from the N/P relation of preys, the excretion and constitution of zooplankton. Ingestion is the sum of quantity produced and excreted , subject to the assimilation coefficient which is the assimilation/ingestion ratio.

The flux of PO_4 to the water sediment interface was measured in anoxic benthic chambers (CHARPY-ROUBAUD *et al.*, in prep.).

Sedimentation rate of POP was estimated using sediment trap, placed at 5 metres above the bottom.

The exportation of P was estimated from measurement of currents in the main channels of comunication between lagoon and ocean and the differences of concentrations between the lagoon and surface oceanic waters.

RESULTS AND DISCUSSION

Table 1 summarizes the result of P, chlorophyll and ATP concentrations used in this paper.

Table 1: Average Phosphorus, Chlorophyll and ATP concentration ($mg \cdot m^{-3}$) in lagoon (L) and surface oceanic waters (O). Confidence intervalls are given with 95% security; waters were prefiltered on 35µm.

	PO4 (1)	DOP (1)	POP (2)	Chl. (2)	ATP (2)
L	5.0±0.6	12.4±3.1	3.6±0.2	0.2±0.01	0.1±0.01
O	5.0±0.4	9.3±3.0	1.4±0.3	0.06±0.01	0.02±0.01

(1) CHARPY-ROUBAUD *et al.* (submitted)
(2) CHARPY and CHARPY-ROUBAUD (submitted)

Total Phosphorus (integrated on 25m) is equal to **533.5 $mgP \cdot m^{-2}$** in the lagoon (525 $mgP \cdot m^{-2}$ of POP <35µm and 8.5 $mgP \cdot m^{-2}$ of Phosphorus from particles of a size >35µm (BLANCHOT *et al.*, in press)), against **393 $mgP \cdot m^{-2}$** in the ocean.

The most important form of Phosphorus in the lagoon is the dissolved organic Phosphorus (**58%** of total Phosphorus); phosphates represents **23%** and particulate organic Phosphorus (POP) **18%**.

Using data of ATP and Chlorophyll from Table 1, the percentages of ATP and Chlorophyll passing 5µm (45±11% and 50±11% ,CHARPY and CHARPY-ROUBAUD, submitted), results of phosphate uptake by phytoplankton given by CHARPY & LEMASSON (in preparation), results of biomass, ingestion, production and excretion of zooplankton given by LE BORGNE *et al.* (in press), the mean of phytobenthic chlorophyll (9.6±1.4 $mgChlorophyll \cdot m^{-2}$, CHARPY-ROUBAUD, in press) and the average benthic primary production ($0.25 gC \cdot m^{-2} \cdot d^{-1}$, CHARPY-ROUBAUD, in press) transformed in P uptake, we can make the Table 2 and Figure 2.

POP is composed by **77%** of detritus. Phytoplankton represents **28%** of living P (23 $mgP \cdot m^{-2} \cdot d^{-1}$), zooplankton (micro + meso) **26%**, heterotrophs of less than 5µm **20%** and heterotrophs of a size between 5µm and 35µm **26%**.

86% of POP belong to particles less than 35µm and **42%** belong to particles less than 5µm.

Heterotrophic (5µm - 2000µm) excretion give:
0.8 $mgDOP \cdot m^{-2} \cdot d^{-1}$ and 7.2 **$mgPO_4 \cdot m^{-2} \cdot d^{-1}$**
The sum of this two excretion supply for **75%** of phytoplanktonic P requirements.

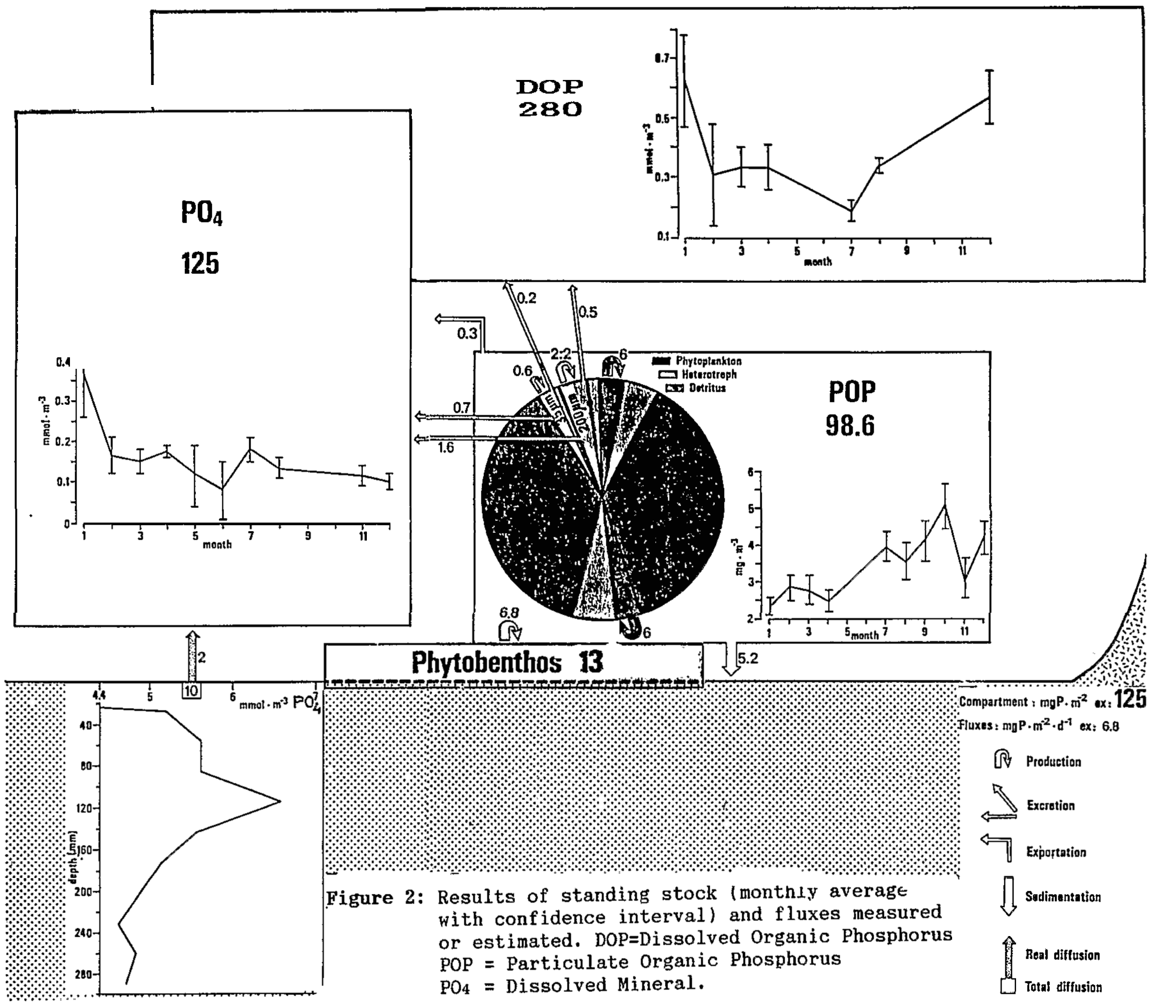

Figure 2: Results of standing stock (monthly average with confidence interval) and fluxes measured or estimated. DOP=Dissolved Organic Phosphorus POP = Particulate Organic Phosphorus PO4 = Dissolved Mineral.

Table 2 : Biomass (B), Assimilation or Ingestion (A), Production (P), Excretion of PO4 (EPi), and DOP (EPo).

	C/P	B ($mgP \cdot m^{-2}$)	A	P	EPi	EPo
			($mgP \cdot m^{-2} \cdot d^{-1}$)			
Phytoplankton						
<5µm	37	3.2	6⁺	6⁺	0	0
>5µm	37	3.2	6⁺	6⁺	0	0
Phytobenthos						
	37	13.0	6.8⁺	6.8⁺	0	0
Heterotrophs						
<5µ	37	4.6	?	?	?	?
5-35µ	45	5.9	12.0*	4.2*	4.9*	0.1*
35-200µ	45	2.1	1.7	0.6	0.7	0.2
>200µ	45	3.9	4.7	2.2	1.6	0.5
Detritus						
<5µ	68	36.5				
5-35µ	68	36.7				
35-200µ	68	0.9				
>200µ	68	1.6				

⁺ For phytoplankton and phytobenthos, we assume that production of organic P = assimilation of mineral P and that Phosphorus excretion is neglectible.

* These values are estimated, assuming: 1) phytoplankton is consumed only by heterotrophs of a size less than 35µm (Ingestion = 12 $mgP \cdot m^{-2} \cdot d^{-1}$) 2) excretion and production of this class of size of heterotrophs can be estimated by the Ingestion/Excretion and Ingestion/Production ratios measured for heterotrophs of a size between 35µm to 200µm.

Flux of PO_4 from the sediments, measured in the anoxic benthic chambers is equal to: **9.5** $mgPO_4 \cdot m^{-2} \cdot d^{-1}$ (CHARPY-ROUBAUD *et al.*, subm.) It can supply the total phosphate requirement of benthic primary production (6.8 $mgPO_4 \cdot m^{-2} \cdot d^{-1}$). Organic matter mineralised in the sediments comes from POP sedimentation (**5.2** $mgP \cdot m^{-2} \cdot d^{-1}$, CHARPY & CHARPY-ROUBAUD, submitted) and POP produced by phytobenthos.

Sedimented organic matter is mainly composed by detritus; the rate of appearance of detritus in the water column can be estimated by its rate of disappearance (if we assume that we are in equilibrum). Process of disappearance of detritus are: sedimentation, net exportation and ingestion by organisms other than zooplankton (e.g. fishes). Exportation can be calculated by difference between POP inside the lagoon and outside the lagoon (2.2 $mgP \cdot m^{-3}$) multiplyed by the water output (700 $m^3 \cdot s^{-1}$) and divided by the lagoon surface ($400 \cdot 10^6$ m^2, LENHARDT, 1987): **0.3 $mgP \cdot m^{-2} \cdot d^{-1}$**. We have no data on detritus fish ingestion; however the minimum rate of detritic P appareance in the lagoon is 5.5 $mgP \cdot m^{-2} \cdot d^{-1}$. Planktonic production can not explain such rate; indeed, phytoplankton production is totally consumed by heterotrophs of a size less than 35µm which production is consumed by zooplankton. Micro and mesoplankton production (2.8 $mgP \cdot m^{-2} \cdot d^{-1}$) can explain a part of detritus by the production of pellets but with a rate which generally can not exeed 40% of production.

POP exportation represents only 2.5% of water column primary production.

CONCLUSION

The lagoon is 1.4 time richer on total Phosphorus than oceanic surface waters. The main difference is due to Particulate Organic form. Organic P represente 76% of total P.

In the plankton, a strong equilibrum exists between production and ingestion; phytoplankton production is totaly consumed by heterotrophs of a size between 5µm and 35µm which production is also consumed by micro and mesoplankton. Plankton excretions (DOP and PO_4) produce 75% of Phytoplankton requirement.

Detritus sedimentation is very high and exeed the possibility of plankton detritus production therefore detritus origin has to be searched in coral reef production.

Mineralisation in sediments supply the PO_4 requirement for phytobenthos thanks to the organic sedimentation.

Net export of organic phosphorus exists but its importance compared with other fluxes (production, ingestion, excretion and sedimentation) is low.

Phosphorus budget point out that lagoon ecosystem can work because it receives an input of detritic Phosphorus which remineralisation permits benthic production.

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