Proceedings of the Fifth International Coral Reef Congress, Tahiti, 1985, Vol. 6

THE NEW CALEDONIAN SOUTH-WEST LAGOON : CIRCULATION, HYDROLOGICAL SPECIFICITY AND PRODUCTIVITY

LE LAGON SUD-OUEST DE NOUVELLE-CALEDONIE : CIRCULATION, SPECIFICITE HYDROLOGIQUE ET PRODUCTIVITE

F. ROUGERIE
Centre ORSTOM de Tahiti, B.P. 529, Papeete, POLYNESIE FRANCAISE

ABSTRACT

According to its topographic and geomorphologic features the lagoon in the south-western part of New Caledonia can be described as a small inland sea through which transiting oceanic surface water has its physical and chemical properties deeply altered by local climatic factors such as evaporation-rainfall balance, wind systems, possible hurricane events in austral summer etc.

Samples and measurements from 21 cruises by N.O. VAUBAN during the period 1976-1979 in the S.W. lagoon between HAVANNAH pass (south) and St. VINCENT pass (west) have collected some 20000 data for a dozen parameters ranging from hydrology to chlorophyll.

- As to water circulation, the most energetic parts of the system are coastal areas and deep channels, particularly with strong trades and ebb tide: surface layer is blown northwestwards while bottom water is evacuated southeastwards through HAVANNAH pass.
- Dissolved silica importance is particular in the nutrient balance of the lagoon; high content of running rain water on the main land leads to concentrations in the lagoon water up to 4.3 mmole/m^3, more than twice the mean surface oceanic water figure. Unlike the other two nutrients, silica is therefore not a limiting factor for the autotrophic production in the lagoon and its easy disposability favours selectively some taxa (diatoms, silicoflagellates, sponges).
- Phytoplankton chlorophyll-a distribution in space and time reflects the variations of these physical and chemical parameters; concentrations usually increase from the ocean (0.30 mg:m^3) through the coastal lagoon (0.47 mg/m^3) to the estuaries (0.72 mg/m^3). Maxima are found after strong flooding and in urban effluent areas.

All these considerations lead to establish the lagoon as a complex ecosystem which could ultimately enrich the ocean with plankton taxa and nutrients, mainly silica; its functioning can be simply analysed by the interaction of five elementary systems: the orographic system, the estuarine system, the coastal lagoon system, the central lagoon system and the nearby oceanic system.

RESUME

De par ses caractéristiques topographiques et géomorphologiques, le lagon Ouest de Nouvelle Calédonie (166°30E, 22°30S) constitue une petite mer intérieure où l'eau océanique superficielle en transit lagonaire subit des modifications physico-chimiques importantes. Les prélèvements et mesures effectuées de 1976 à 1979 au cours de 21 campagnes du NO Vauban, dans la partie Sud-Ouest du lagon calédonien, entre les passes Sud (Havannah) et Ouest (St Vincent), ont permis de recueillir quelques 20 000 données portant sur une douzaine de paramètres, de l'hydrologie des masses d'eau jusqu'à leur concentration en chlorophylle. Au plan de la circulation des eaux, c'est dans le lagon côtier et les chenaux profonds que le système est le plus dynamique, en particulier par fort alizé en marée descendante : la couche de surface dérive vers le Nord-Ouest alors que l'eau de fond s'évacue vers le Sud-Est en direction de la passe de Havannah. La silice dissoute joue un rôle particulier dans le bilan nutritif lagonaire : très abondante dans les eaux de ruissellement, sa concentration moyenne atteint 4,3 mole/m3 dans le lagon, soit plus de deux fois la moyenne océanique de surface. Contrairement aux deux autres nutriants phosphatés et azotés, la silice n'est donc pas un facteur limitant la production autotrophe. La distribution spatio-temporelle de la charge chlorophyllienne phytoplanctonique intègre les fluctuations de ces différents paramètres physico-chimiques : un gradient croissant des teneurs en chlorophylle a est généralement observé depuis l'océan (0,30 mg/m3) en direction du lagon côtier (0,47 mg/m3) et des estuaires (0,72 mg/m3). Les pics de plus grande abondance apparaissent après les fortes crues et dans les zones d'émission des effluents urbains. Toutes ces considérations permettent d'établir la fiche signalétique du lagon qui se comporte ainsi comme un "incubateur biologique" pouvant ponctuellement enrichir l'océan en taxas planctoniques et en silice lors des décharges d'eau lagonaire. Le fonctionnement global du lagon peut finalement être schématisé par un découpage en 5 écosystèmes interactifs : le système hydrographique orographique, l'écosystème d'estuaire, l'écosystème lagonaire côtier, l'écosystème lagonaire central et l'écosystème océanique proche.

GENERAL CHARACTERISTICS OF NEW CALEDONIA'S SOUTHWEST LAGOON

PHYSICAL ENVIRONMENT

Topography and bathymetry of the lagoon

The island of New Caledonia is in fact the emerged land mass of an underwater structure known as the Norfolk Ridge. Over the various geological eras, periods of erosion chiselled out the central mountain chain, composed for the most part of highly basaltic rock and, at the end of the Tertiary, created a large coastal plain on the Western part of the island. Between 18,000 and 5,000 B.C. the melting polar ice caps caused the oceans to rise over 50 meters, thus submerging the West coastal plain which then became a lagoon, while the old fringing reef turned into the great barrier reef.

Climatic features of South Caledonia

Made up of a narrow mountain chain, lined up along the Northwest-Southeast axis between 20 and 23° South latitudes, New Caledonia lies just North of the Tropic of Capricorn on the edge of the anti-cyclone belt of the Austral winter (July-Sept.) subtropical high pressure systems. During Austral summer (Dec-March) the island is subjected to equatorial low pressure systems, and besides winds from the West, may encounter tropical cyclones and depressions forming in the Coral Sea and North of the Salomon-New Hebrides arc. When the low pressure belt goes back up to the equator, the island finds itself once again in a zone of maximum trade-wind activity.

For the period 1958-1978, average annual climatic conditions on the peninsula of Noumea were the following :

- air temperature : 23.29°C ; rainfall : 1,020 mm ; wind : 5.1m/sec ; sunshine : 2,475 hours ; evaporation : 1,350 mm ; relative humidity : 74.5 % ; atmospheric pressure : 1,013.1 mbar.

Hydrology of the Southwest lagoon (166°30'E, 22°20'S)

The area studied here, from Prony Bay 40 km SE of Noumea to St.Vincent's Bay 50 km NW, gives a good overall picture of the Caledonian lagoonal system, having a classic sequence on a coast to sea transect : mangrove swamp at the end of the bay, coastal channel, islet in the middle and fringing reefs, a secondary channel and great barrier reef with passes. Six shore-lagoon-ocean radii were travelled along on each mission, giving 26 stations and 90 samplings. Between 1977 and 1979 22 missions were made, providing a total of around 20,000 readings dealing with some 15 parameters (Rougerie, 1985).

Thermohaline characteristics and temporal evolution

The water found in the lagoon consists mainly of surface ocean water whose thermohaline properties can be changed to a greater or lesser degree depending on the amount of fresh water brought by rivers and on local variations of the evaporation-precipitation balance. In the Southwest lagoon, annual thermal evolution is accompanied by appreciable spatial variations. For example, the water closest to the shore is the warmest in summer and the coolest in winter due to orographic and bathymetric effects. The overall mean temperature of the Southwest lagoon for February is 26.5°C, for August 21.5°C. The coastal lagoon water, even outside of the estuary zone, has a lower salinity

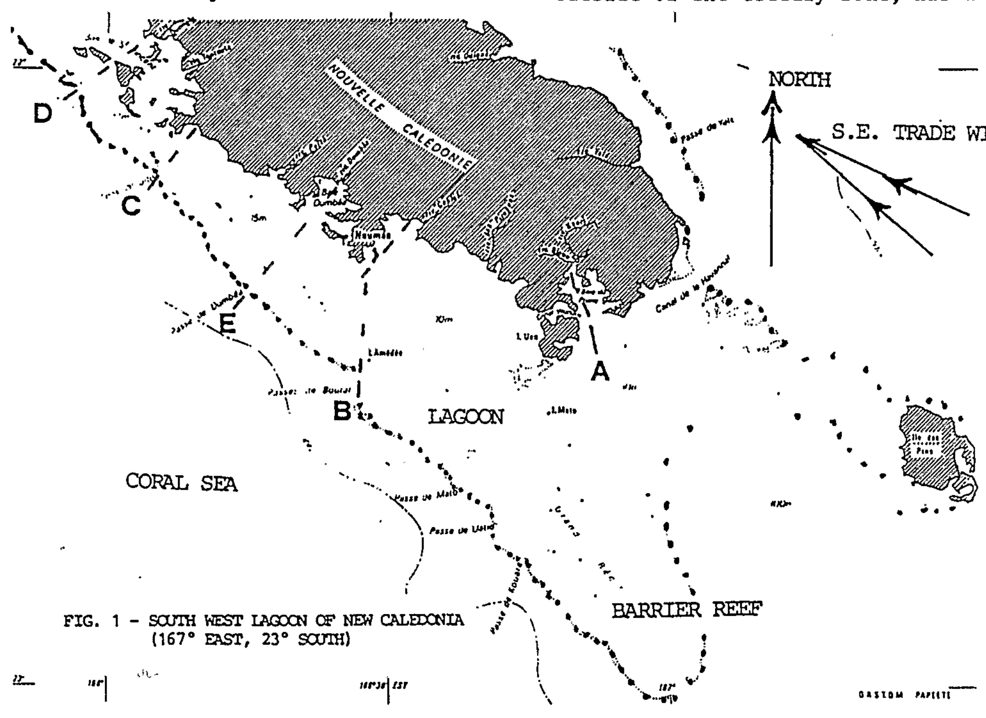


FIG. 1 - SOUTH WEST LAGOON OF NEW CALEDONIA (167° EAST, 23° SOUTH)

than that near the barrier reef, sometimes dropping below 35 ‰. Average salinity for years "'77-'79" was 35.28 ‰, or 0.4 ‰ less than around the Amédée lighthouse. Fluctuations in salt content are only indirectly attributable to seasonal changes, but lagoon waters are the least salty during the hot season because of the cyclonic rains. Average salinity for the overall lagoon waters is stabilized at 35.45 ‰, or 0.13 ‰ less than the 0-50 m layer of ocean waters just beyond the reef. For the Southwest lagoon this indicates that the amount of fresh water contributed by rainfall and rivers is greater than the water lost by evaporation.

Density and formation of lagoon waters

The temporal evolution of the surface layer along radial D (St.Vincent's) indicates that maximum variations in water density at the end of the bay (Station D1) are found within the range σt = 24.6 (Sept 1977, August 1978) and σt = 21.7 (Sept 77) to σt = 22.2 (Feb 78), while Station D3 in the St.Vincent Pass (reef-lagoon water) registered winter-summer fluctuations between σt = 24.6 and σt = 23. However, reef-lagoon waters generally have a slightly higher density than surface ocean water or estuary water. This unusual situation, caused by the large amount of surface water evaporated during dry windy periodes, creates a maximum water density in the middle of the lagoon above σt = 24. In the vicinity of the pass the general tendency of isopycnes suggest an influx of ocean waters at pass floors, counterbalancing the escaping of superficial lagoon layers (radials B & D) towards the ocean.

Dynamics of the Southwest lagoon

One of the most baffling aspects in the understanding of lagoon water movement is the existence of sharp reversals in the direction of currents near passes and in coastal channels. The alternating of water flow entering the lagoon and leaving it is obviously modulated in a first approximation by the state of tide level, but many observations have noted highly unusual discrepancies, even the exact opposite in the real system as compared to the expected system.

In a period of stable trade winds (12-20 knots) the overall circulation is largely Southward along the island's coast line (57 % against 31 % for vectors going NW). Near the great reef the situation is reversed - over 55 % of the current vectors head NW and less than 30 % SE. In the Dumbea Pass, surface flow moves in an ocean to lagoon direction in 26 % of the cases, and in the contrary direction in 46 %. We can assume that circulation in a particular lagoon area is ruled firstly by barometric pressure, secondly by tides and thirdly by swells (Renon, 1978). This general scheme can be elaborated by operating a triple discrimination using tide factor, wind strength, and wind direction (Jarrige, 1978). In the Dumbea Pass the alternating outflow axis varies little between surface and bottom ($\bar{V}$ = 30 cm/sec). In the middle of the lagoon, on the contrary, surface waters move along a NW-SE axis ($\bar{V}$ = 20 cm/sec), while on the lagoon bottom water flow direction is more vague, basically due to the fact that flow speed averages four times less than on the surface ($\bar{V}$ = 5 cm/sec).

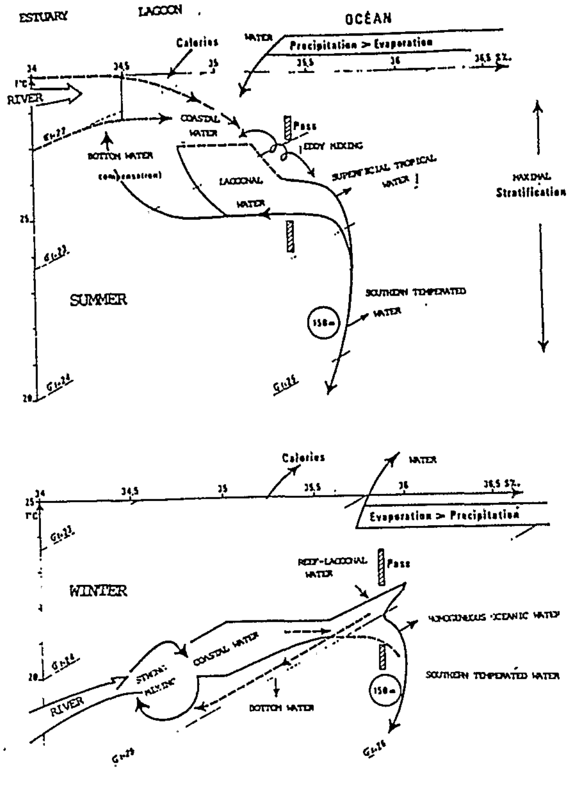


Fig. 2 - Readjustment of various kinds of water according the density field

Residence time of lagoon waters

Taking the fraction of lagoon water considered as having definitively left the lagoon at the end of each tide cycle and thus replaced by an equivalent volume of ocean water, we can calculate a minimal residence time of waters in the St.Vincent-Boulari basin - 11 days. Another way of calculating would be to take the case of reef-lagoon waters whose increase in salinity and density during the winter period would indicate a definite confinement. Residence time can be expressed in this case by the following equation (Smith & Jokiel, 1975), where Z = depth in meters

$$T = \frac{Z}{(E-P)} \cdot \frac{\overline{Sl}-\overline{So}}{So}$$

E-P = daily evaluation of evaporation-precipitation (in meters) ; $\overline{So}$ = salinity of ocean ; $\overline{Sl}$ = salinity of lagoon.

In september 1977, a month without rain, $\bar{P}$ = 0 and $\bar{E}$ = 1.5 mm/day, So = 35.5 ‰ and Sl = 35.6 ‰, which gives T = 28 days. This winter residence time of reef-lagoon waters is thus almost three times higher than the minimal overall time calculated from flow evaluation.

NUTRIENTS AND RELATED PARAMETERS

Phosphate Molecules

Dissolved mineral phosphate content is generally somewhere between 0.2 and 0.4 mmol/m³ of P-PO_4 (mean for all data : 0.35 mmol/m³). Occasional high values appear in estuary zones (notably Prony and Dumbea) because of bacterial decomposition of land vegetation, but the demand for phosphorus is such that as soon as they are oxydized the phosphate molecules are immediately fixed by sea plants. Over the period being considered, our measurements of disolved organic phosphate (DOP) suggest that the average content is 0.41 mmol/m³, a figure scarcely higher than the average value of mineral phosphate.

	BAY	Central lagoon	Oceanic surface	Lagoon (average)
Depth (m)	0-2	0-20	0-50	20
Température (°C) Salinity (S‰)	24,20 < 35,0	24,08 35,68	23,47 35,58	23,97 35,45
Dissolved mineral Phosphate (PO_4-P)	0,40±0,08	0,33±0,03	0,30±0,03	0,35±0,05
Dissolved organic Phosphate (D.O.P.)	0,70	0,38	0,35	0,41
Particulate organic Phosphate (P.O.P.)	0,12	0,05	0,03	0,07
Ammoniaque NH_4 - N	0,15	0,09	0,04	0,10
Nitrite NO_2-N	0,14±0,08	0,10±0,05	0,05±0,02	0,11±0,02
Nitrate NO_3-N	> 0,58±0,12	0,36±0,08	0,28±0,04	0,38±0,06
Dissolved organic nitrogen (D.O.N.)	18,0	16,0	14,0	16,6
Particulate organic nitrogen (P.O.N.)	> 3,0	2,0	1,4	2,2
Dissolved silicate SiO_3 - Si	≥ 20±7,6	3±1,1	1,8±0,2	4,3±2,1
Dissolved oxygen (ml/l)	4,70±0,4	5,0±0,3	4,80±0,2	4,88±0,2
Saturation (%)	92	104	100	102
Apparent oxygen utilisation (A.O.U.) (ml/l)	0,22	0,0	0,0	≃ 0,0
pH unit	8,33	8,39	8,40	8,37
Total alcalinity (méq/l)	1,7	2,52	2,50	2,45
Chlorophyll a (mg/m³)	0,72±0,18	0,39±0,04	0,31±0,02	0,57±0,05
Pheophytine (%)	60,0±4	59,0±2	60,0±2	58,8±2

Means values of physico-chemical parameters - Nutrients unit are in mmole/m³ - 95 % confidence band is indicated.

The last type of phosphate recorded in the lagoon is particulate organic phosphorus (POP) which represents the phosphorus element included in particles with a diameter greater than 0.45 µm, without being able to distinguish between living plancton and tripton (detritus). POP content is expressed as follows - overall lagoon average (1977) : 0.07 mmol/m³, ocean average (0-50 m) : 0.03. The highest values recorded (POP > 0.15 mmol/m³) were in the coastal lagoon channel where hydrodynamism and turbidity are known to be high.

- Nitrogen molecules

Measurements of ammonia have only shown relatively low concentrations, on rare occasions above 0.3 mmol/m³ of N-NH_4, while the overall average is set at 0.10. This result is no surprise, this molecule is very unstable and is quickly oxydized to the nitrite (N-NO_2) stage (Oudot & Wauthy, 1976) characterized by an average content of 0.08 mmol/m³ and a maximum concentration of 0.3. Several areas rich in nitrites appear in the estuary zones and close to the shore, developping after strong rises in the rivers. In a state of maximum oxydation, nitrogen molecules attain higher values - nitrate concentration often exceeds 0.8 mmol/m³, with average overall value being 0.38 mmol/m³ of N-NO_3. Here again peak quantity concerns the bays, with 0.6 mmol/m³ inside the Bay of Prony and 0.55 in the Bay of St.Vincent, and appreciable local variations between these two sites. Dissolved organic nitrogen (DON) whose average content is 15.6 mmol/m³, represents 30 times the total of dissolved mineral forms. In the constant replenishment of the mineral pool from dissolved organic matter the latter 'weighs' so heavily that even a slight variation in value may turn into a strong fluctuation in the mineral nitrogen concentration, with a certain lag due to the time needed for remineralization. This situation is strengthened elsewhere by the presence of large quantities of particulate organic nitrogen (PON). This element attains an average value of 2 mmol/m³ with extremes of 1.2 and 4.5.

- Dissolved silicate

Average overall silicate content in the Southwest lagoon is 4.3 mmol/m³ of Si-SiO_3 with extremes of 25 at the end of St.Vincent's Bay and 1.8 off-reef between Boulari and St.Vincent's. These figures suggest at first glance a major contribution by the streaming waters along the shores and by the river flow. The SiO_3-salinity regression gives an excellent correlation of r = - 0.87 along the shore line and - 0.69 for the overall value.

- Dissolved oxygen and pH

The fact that lagoon waters are on the average a bit more oxygenated than ocean water may seem surprising. However the role played by the crashing of swells over the barrier reef should not be overlooked - this phenomenon increases oxygenation which may exceed 125 % saturation at moments.

Values registered (overall average : 4.88 ml/l) do not demonstrate any significant difference between oxygenation of water at the surface or at the bottom, further evidence of the thoroughness of vertical mixing within the lagoonal system. The low values of the AOU parameter, rarely above 0, suggest that the oxydation process of organic matter to the mineral stage is carried out in a gentle and continuous fashion. pH values of the Caledonian lagoon are about the same as those of the surface Coral Sea (Rotschi, 1961) and indicate a slight positive gradient between the end of the bays (pH = 8.33) and the open sea (pH = 8.4). At lagoon station type B1, the pH varies between 8.33 and 8.48, with strongest values at the end of Austral winter (August-October).

PHYTOPLANCTON PRIMARY PRODUCTION

Chlorophyll-a : statistical evaluation of the chlorophyll-a content is as follows : overall average - Chla = .57 mg/m³ minimum value on a weekly basis - Chla = .26 mg/m³ (Feb 1977), maximum value Chla = 1.01 mg/m³ (March 1978). Spatial distribution map shows a primary production maximum near the shore (Chla = 0.47 mg/m³) - the isopleths of chlorophyll-a follow the geometry of the shore line, the richness in pigments reaching as far as mid-lagoon. Beyond this point, whether it be in the South lagoon towards the barrier reef or in the superficial layers of the ocean, content is both lower and more homogenous, around 0.3 mg/m³. The pheophytine corresponds with the primary stage of chlorophyll oxydation and thus is an indication of tissue or cell degeneration of plants material. The mean percentage of degenerated pigment or pheopigment in the South west lagoon is 58.8 %. It appears also that this percentage remains relatively constant whatever the distance from the shore - all averages fall within the estuary maximum (60 %) and the relative shore water minimum (56.8 %).

GENERAL FUNCTIONING

We know that during each tidal cycle a fraction of lagoon water escapes through the passes, carrying with it phyto- and zoo- plancton biomass that we must consider as being definitively lost by the lagoon. Taking just the chlorophyll pigment content we can evaluate daily loss in a specific lagoon area, for example between the shore to pass tansects of Boulari and St.Vincent's. The volume exiting daily is somewhere around 10^9 m³/day, corresponding to a loss of chlorophyll of 0.55 10^9 mg/day. Ocean influx containing 0.25 mg/m³ of chlorophyll brings in 0.3 10^9 mg of chlorophyll-a, which compared with total volume indicates an overall loss of 0.012 mg/m³/day. The greater part of the phytoplancton mass being stationary, this loss in ocean waters is compensated by renewed production, assimilation of carbon and new nutrients. Thus using a mean relationship of NO_3-N/chlorophyll-a = 14 (Antia, 1963) the loss of mineral nitrogen comes to 0.018 mmol/m³/day. For phosphorus, an identical calculation gives a flow of 0.006 mmol/m³/day of phosphorus lost by the lagoon, and thus supplied in the form of mineral phosphate dissolved by outside contributions. These contributions are indispensible to maintaining primary production at its stationary level and come from two sources. The first originates in the ocean and is related to the uplift and intrusion of richer oceanic water breaking over the barrier reef ; the other comes from precipitation and water rushing down the mountain sides : this is especially great during heavy rains, specially in summer, whereas the arrival of subsurface uplifted water in the lagoon would be an essentially winter phenomenon related to the existence of a quasi-isothermal mixed oceanic layer 0-150 m deep. It is not possible to make a distinction between these two sources but we can consider their roles as being equivalent, which amounts to saying that 0.006 mmol/m³/day of nitrates are injected into this lagoon area from the two sources mentioned. The flow of dissolved silica is easily counted - average lagoon content ; 4.3 mmol/m³ minus ocean content (0-50 m) : 1.8 mmol/m³, the difference (2.5 mmol/m³) representing excess silica present in the lagoon, despite autotrophic fixation and direct loss to the ocean. Silica lost to the ocean can be calculated at 0.1 mmol/m³ using the same parameters as before. As for the mass of Silica fixed daily and lost through phytoplancton leaving the lagoon, evaluation can be made by using the figure 0.012 mg/m³/day of chlorophyll leaving and the ratio Si/Chl-a = 42, and we get an additional loss of 0.018 mmol/m³/day of Silica. Rivers in the area studied bring in an average of 0.86 mmol/m³/day assuming an overall arrival of fresh water of 50 m³/sec with a silica content of 0.4 mol/m³. Looking at these figures we notice the silica flowing into the lagoon is greater than that flowing out, which would give a positive balance sheet and indicate that the lagoon acts as a silica trap. In fact a part of the silica can be stored in the sediment (accumulation of diatom clay) and can not be totally put back into suspension during upturning by cyclonic storms.

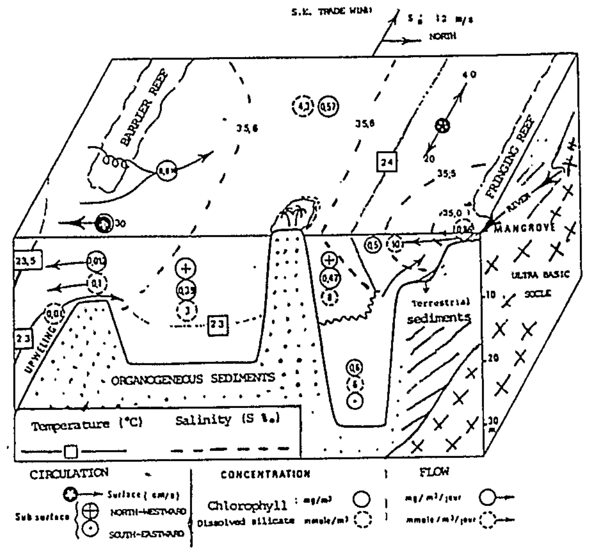


Fig. 3 - Circulation, mean thermohaline field, silicate and chlorophyll-a budget.

Modelling elements

However the imbalance basically derives from the fact that the plume from the lagoon is also filled with zooplancton having proliferated by feeding on phytoplancton and thus carrying a large amount of ingested silica. Any attempt to balance the scales of nutritional salts must therefore suppose that the average density in Zooplancton, larvae and other organic and waste composition of the seston be known. Much data has been collected in this area by Binet (1983) but still without conclusive evidence, especially concerning phytobenthos and bacterioplancton. Nevertheless, it is possible to separate the whole into 5 sub-ensembles, corresponding to relatively well differentiated ecosystems.

- The orographic hydrologic system

Wheathering along the foothills brings with it, besides large quantities of fresh water, dissolved nutritive elements, organic and terrigenous matter.

- The estuary system

Subject to abrupt surges, it is both unstable and capable of rapid readjustment. For the ensemble of lagoonal biotopes, it constitutes a preferential zone for egg laying and hatching for many species (fish, molluscs, crustaceans). Thermohaline variations here are the most rapid and the widest, and the year to year thermal difference the strongest.

- The coastal lagoon

Downstream from the preceding system, this ecosystem has the highest dynamics, as much on the physical level (speed of currents, degree of turbulence and countercurrents) as on a biological level. Elements brought by the rivers stimulate the growth of phytoplancton cells, which manifest themselves in vegetation "explosions" or blooms, remarkable for the green or brown colorations they vige to the water.

- Central lagoon

The central basin is subjected to smaller hydroclimatic variations and constitutes a stable ecosystem with a high degree of maturity. It can be compared to the coastal bays of West Madagascar studied by Frontier (1978) who noted that the phyto- and zoo- plancton taxa are the most specific of all the lagoon, growing in size proportionally to the time the water remains, and that the juvenile plancton flow coming from the coastal lagoon is exploited by this ecosystem.

- Nearby superficial ocean system

Very stratified and oligotropic in summer or at its maximum chlorophyll production in winter, the nearby superficial ocean layer is always poorer in biomass than the lagoon. The plume of elements leaving the lagoon during ebb-tide thus constitutes an obvious periodic enrichment, easily visible to the naked eye. However, a part of this flow is recovered by madrepores and fauna attached to the outer slopes.

CONCLUSION

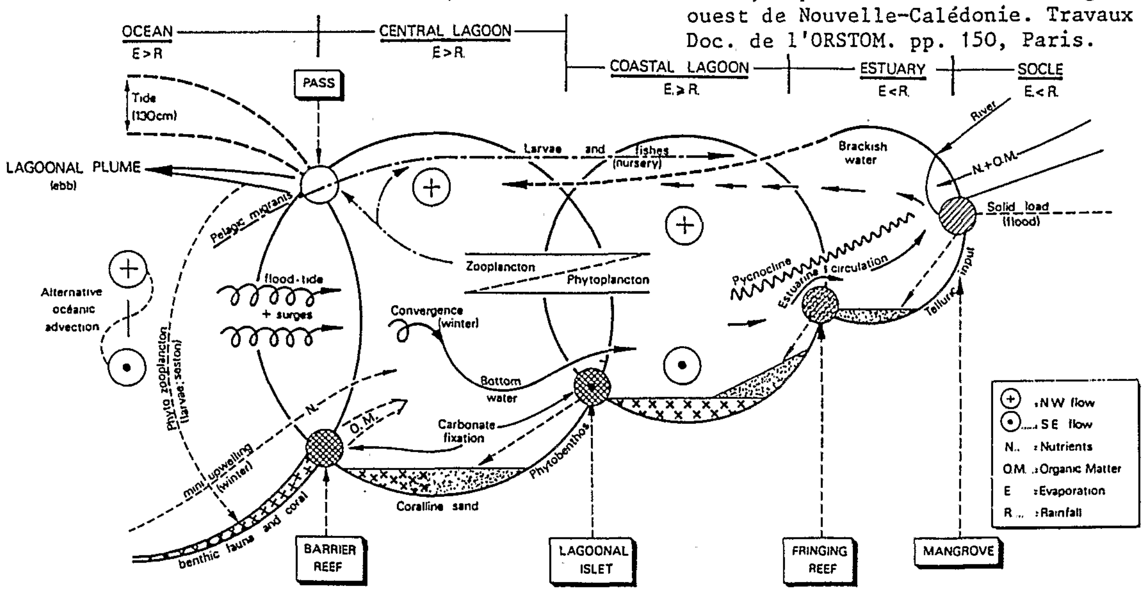
Elements brought from the mountains through water rushing down the slopes constitutes a major source of dissolved silica with for this reason is not a factor limiting primary production, as is the case for phosphate and nitrogen nutrients, at least in their mineral form. In the passes, discharges of lagoon water maintain plumes of greener water more rich in seston than ocean water - this "lagoon effect" permits the ocean to recover a part of the nutritional flux it provided upstream, especially during winter when the rich phytoplancton water of the mixed layer breaks over the reef after ponctual uplift. During periods of heavy rains, strong winds or typhons, vertical exchanges are on the contrary accelerated according to various advective and turbulent processes, among which an internal circulation in deep bays, known as "estuary circulation", plays a major role. These disturbed hydroclimatic episodes thus set off a sort of "forced respiration" of the lagoonal system, accelerating biochemical cycles and nutritive transfers between the effluents, the sediments and the lagoon water. Residence time of waters is thus modulated and according to zone spans from 10 days to more than 30 days.

BIBLIOGRAPHIE

JARRIGE F., RADOK R., KRAUSE G. et RUAL P., 1975. Courants dans le lagon de Nouméa. Publication ORSTOM Nouméa, HLIO (Adelaïde), FUA (Australie), 5 p. + 27 figures.

PICKARD G.L., DONGUY J.L., HENIN C. and ROUGERIE F., 1977. A review of the physical oceanography of the great barrier reef and Western coral sea. Australian Institute of Marine Sciences. Monographies series. Vol. 2 : 134 p.

ROUGERIE F., à paraître en 1985. Le lagon sud-ouest de Nouvelle-Calédonie. Travaux et Doc. de l'ORSTOM. pp. 150, Paris.



I) Surface oligotrophic oceanic ecosystem
stratified in summer it becomes a mixed layer in winter.

II) Mature ecosystem
feeds on ecosystem I and III, strong secondary production large rate of coral colonisation.

III) Juvenile ecosystem
high reactivity, phytoplanktonic bloom in spring and after rainfall.

IV) Estuarine ecosystem
quick flow transit, specially during summer flood.

V) Hydrologie system
discontinued, 5 to 500 m³/s by creek, depending season.

FIG. 4 - INTERACTIONS THROUGH ECOSYSTEMS ALONG A TRANSECT OCEAN-LAGOON-ESTUARY.