THE MARINE RESOURCES OF OUVEA ATOLL (NEW CALEDONIA), A SUMMARY OF THE WORK PERFORMED BY ORSTOM FROM 1991 TO 1994.*

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*: Original in French. Translation by the author. Therefore, please, forgive the English mistakes.

INTRODUCTION

The marine ressources of Ouvéa (Figure 1) had never been studied before 1991. ORSTOM was asked by the "Province des Iles" to undertake an analysis of the marine ressources of that atoll. A simple stock estimate having little interest in the view of long term development, ORSTOM has also investigated the ecological parameters which should allow a global understanding of how this lagoonal ecosystem works.

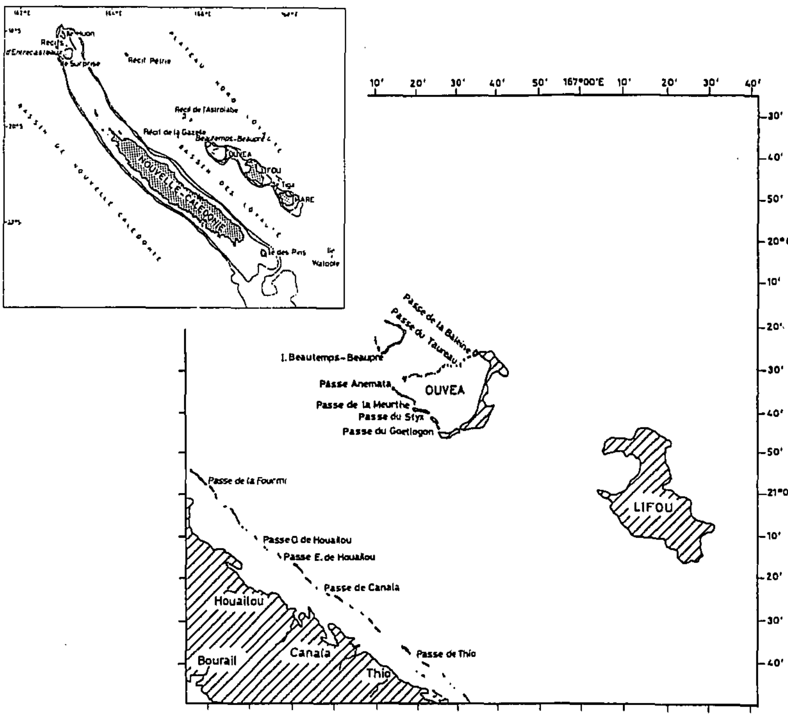

Figure 1: location of the Ouvéa atoll in New Calédonia

The objectives of this study can be divided into two groups,

[1] This summary is an abstract of the work done by : G.Bargibant,C.Chevillon, J.Clavier, S.Dupon, C.Dupouy, C.Garrigue, P.Hamel, M.Kulbicki, R. Leborgne, A.Lebouteiller,J.L. Menou, G.Mou Tham, B.Richer de Forges, M.Rodier,P.Thollot, P.Tirard, L.Wantiez, J.T.Williams

- 1) **development objectives**

- stock assessments
- mapping of the major species
- advice for management and regulations
- prospecting of yet unknown ressources
- mapping of the biotops as a tool for management
- mapping of the sediments for management

- 2) **scientific objectives**

- description of the physical, geomorphological and sedimentological features
- description of the major benthic communities, species composition, biomass, distribution, production, trophic structure
- description of the major fish communities, species composition, density, biomass, trophic structure, life-history strategy structure, distribution
- associations between fish and benthic communities
- correlations between communities and their physical environment
- biomass and production estimates for plankton, correlation with planktivores
- a diagramm of the global functionning of the lagoon.

The development objectives should answer the main questions asked by the users of this lagoon. How much can be caught, how can it be exploited, which are the most interesting species, where are they, what type of management should be followed? The scientific objectives should bring some answers to the origin of the stocks, their production, the functionning of the communities. The following questions could be looked into, is this a productive lagoon, what are the origin of the production, what are the links between the communities, what is the role of the physical environment on the structure of these communities, how stable are these communities compared to other regions, is the diversity of this lagoon peculiar, what are the relationships between this diversity and the functionning of the communities...

After a short account of the methods used, the following points will be studied,
- the physical environment: geomorphology, the water masses, the sediment, the major biotopes
- the plankton: production and biomass
- the benthic communities
- the fish communities

METHODS

The techniques along with the sampling strategies are given in detail in several reports (Chevillon, 1993; Clavier et al., 1993; Kulbicki et al., 1993, 1994a,b; Leborgne et al., 1993). Table 1 summarizes the campaigns performed at Ouvéa and figures 2, 3 show the study sites. The sampling is divided into:

- ground truth: descriptive data on shallow water biotopes in order to map these biotopes from aerial pictures and a satellite image (• figure 3)
- sedimentology: sediment sampling to perform a sediment map and analyse the origin of the sediments and their transport (◉ and ◎ figure 2)
- macrobenthos: quantitative sampling of macrobenthos with a grab, sampling of sediment in order to analyze the photosynthetic pigments (to evaluate the benthic primary production) and ATP (an estimator of living biomass). Qualitative sampling with a dredge. (◉ and ◎ figure 2)

- megabenthos: semiquantitative description of the populations of large size benthic invertebrates (◉ figure 2 and ● figure 3)

- fishing: experimental handline fishing in order to know the spatial distribution of line fishes and to obtain fish samples for biological analysis (reproduction, size distribution, feeding habits) of the major species (◉ ◎ O figure 2)

- visual censuses: to analyse the fish communities (◉ figure 2 and ● figure 3)

- plankton: phyto- and zooplankton biomass and production estimates (✱ figure 3)

- functionning of the benthos: estimation of the benthic metabolism and of sedimentation rates

Table 1: summary of the oceanographic cruises performed by ORSTOM at Ouvéa

Dates of the cruises	Activities	Sampling
April 22nd - May 2nd 1991	Fishing, megabenthos Visual censuses, Ground truth	Longline trials (26 sets) Fish and megabenthos transects (22 stations) Ground truth (42 stations)
July 1st - July 13th 1991	Visual censuses, Megabenthos, Ground truth	Fish and megabenthos transects (25 stations) Ground truth (53 stations)
August 5th - August 14th 1991	Fishing, visual censuses, Megabenthos, sedimentology, Macrobenthos	Fishing (4 stations) Fish and megabenthos (22 stations) Sedimentology and macrobenthos (29 stations)
September 2nd - September 21 1991	Fishing, visual censuses Megabenthos, sedimentology	Fishing (77 stations) Fish and megabenthos (24 stations) Sedimentology and macrobenthos (33 stations)
November 12th - November 22nd 1991	Fishing, visual censuses, Megabenthos, ground truth	Fishing (30 stations) Fish and megabenthos (9 stations) Ground truth (8 transects)
March 16th - March 21 1992	Fishing, visual censuses, Megabenthos, ground truth	Fishing (15 stations) Fish and megabenthos (3 stations) Ground truth (4 transects)
September 4th -September 17th 1992	Plankton, macrobenthos	Plankton (12 stations) Macrobenthos (15 dredge stations)
June 1st -June 16 th 1994	Benthos	Functionning of the benthos (15 stations)

RESULTS

A - THE PHYSICAL ENVIRONMENT

1 - General description of the lagoon

The lagoon of Ouvéa covers 872 km² of which 836 km² are lagoon bottoms and 40 km² are reefs. Among the latter, 4 km² are submerged reefs and therefore are also counted as lagoon bottom. Average depth is approximatively 15m, the lagoon being separated into two zones by a fault line at a depth of 20 m. East of this fault, the bottom has a slope of 0.11% and the reefs bordering the lagoon have many islands. West of the fault, the bottom is nearly twice steeper (0.2% slope) and the islands are rare and of small size, the reef remaining as developped as on the eastern part.

The main island covers 130 km². The west coast is essentially made of a sand beach, cut in places by low coralline cliffs. Several inlets cut the main island, two of these inlets reaching the ocean (Fassi pass in the north, Lekiny bay in the south). There are no streams, the soil being calcareous.

The northern part of the lagoon is limited by a line of reefs and islands, the Northern Pleiades, which run for 37 km. Most of the islands have coralline cliffs 2 to 8 m high. The south part of the reefs, facing the lagoon, are exposed to the trade winds. Conversely, the north part of the reefs is sheltered from the winds and drops to 30 to 80m deep.

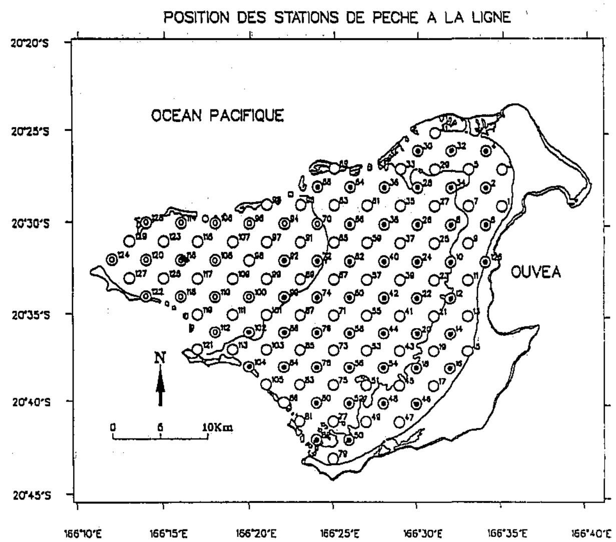

Figure 2: fishing stations (all circles), sediment and benthos (all even numbers), dives (◉)

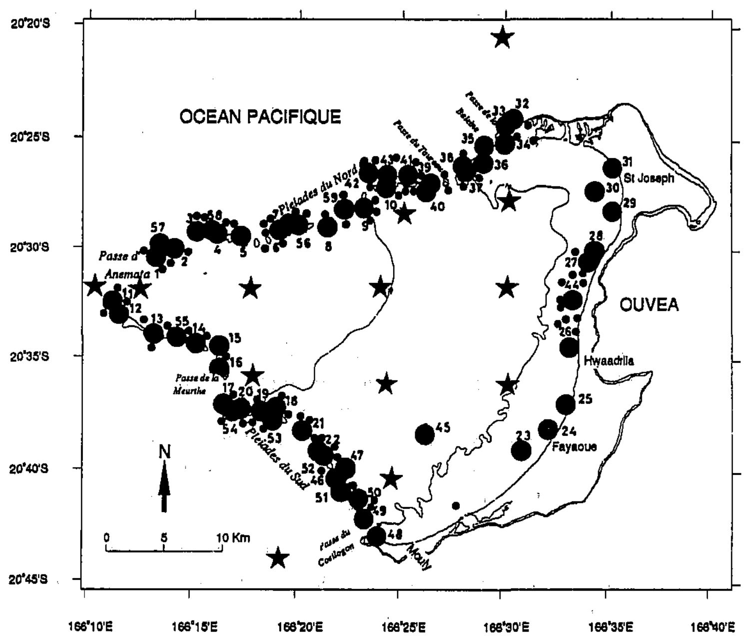

Figure 3 : reef transect stations (●), ground truth stations (•) and plankton stations (✱)

The southern part of the lagoon is also limited by a line of reefs and islands, the Southern Pleiades, which stretch over 35 km. The islands have much lower cliffs than in the Northern Pleiades. The exposure to the trade winds is opposite of what is found in the Northern Pleiades, the inner reefs are sheltered and the outer reefs are exposed.

2 - The water masses

At the moment we have very little information to describe the water masses around Ouvéa and inside its lagoon. Most of the data are provided by 17 CZCS satellite images. The information obtained by the analysis of the surface water colour could not be verified by ground truth. As a consequence, the following paragraph presents only some hypothesis which still need to be tested.

There is an empoverishment of the water in chlorophyll between the island of New Caledonia and the Loyalty islands. The waters are even poorer in chlorophyll between the Loyalty islands and Vanuatu (Figure 4). There is a NW-SE current between the Loyalty islands and the island of New Caledonia, opposite to the trade winds (Figure 4). A water front is at times observed perpendicular to the island of New Caledonia and moves from north to south (Figure 4).

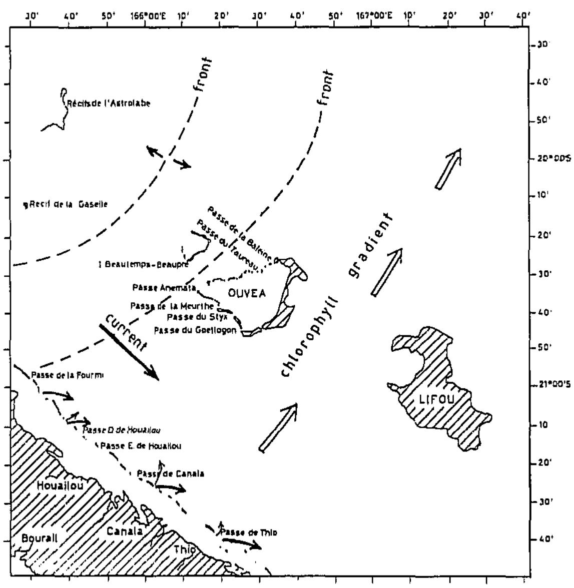

Figure 4: characteristics of the water masses around Ouvéa atoll

Plumes of turbid water, probably coming from inside the lagoon, are observed in the vicinity of Ouvéa. These plumes are mainly located south and east of the Coetlogon pass, at the level of Meurthe pass and north of the Northern Pleiades (Figure 5). The barrier reef in that area would play the role of a screen for the sediments, which would explain the accumulation of sediments near the Northern Pleiades. There is also an income of oceanic waters through the passes. This phenomenon is mainly found at the level of Anemata pass, the incoming current dividing into two branches, one north, the other south (Figure 5). Between the Meurthe pass and Coetlogon pass there seems to exist an inside channel with a water circulation between the two passes (Figure 5). This current is in part confirmed by the absence of fine sediment and the little thickness of the sediments.

The satellite images show also two special zones, likely slow eddies, one located 2 km NE of Su island and the other one off Fayaoué (Figure 5).

ORSTOM is thinking of conducting a more detailled analysis of the water circulation inside the lagoon during the 1995-1996 period.

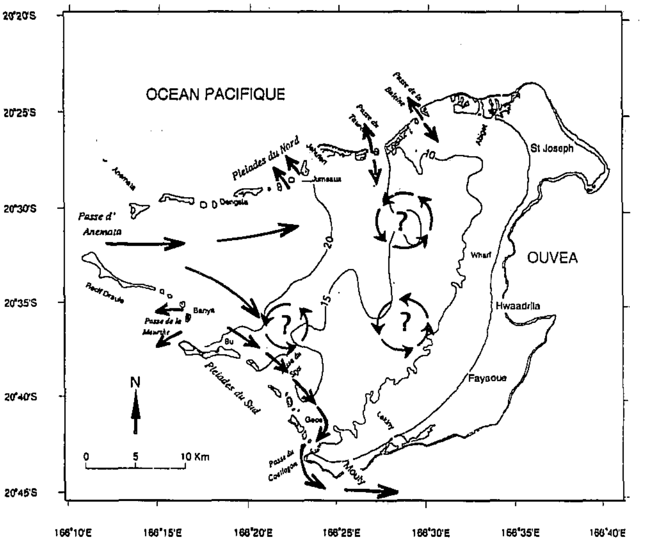

Figure 5: presumed currents near and inside the Ouvéa atoll

3 - The sediments and the main bottom lagoon units

The lagoon of Ouvéa has little sediment despite the presence of more than 50 km of sandy beaches along the main island. The zones where the sediments are the thickest, are found, on one hand along the Northern Pleiades, on the other hand in the bay of St Joseph and off Mouly. The mud content of the sediment is low, the highest concentrations being found in the coastal zone, in areas sheltered from the wind. Beyond 5m, the mud content is lower than 5%. One notices also the very low levels of mud between the Meurthe and Coetlogon passes, along the Northern Pleiades and in the Anemata pass, three zones where currents could be detected on CZCS images. This spatial distribution of mud and sediment thickness is unusual for an atoll lagoon. Usually, these parameters are maximum in the middle of the lagoon. This phenomenon can be explained by the exposure to the tradewinds, the slope of the lagoon and the large opening towards the ocean by deep passes which allow fine sediments to be exported.

The analysis of the sedimentological indices (average grain size, sorting, skewness, normality) shows that sediment production is generally weak and that most of the lagoon is under moderate and homogeneous hydrodynamic conditions. In particular, there are no major transportation of sediment within the lagoon. There is no active sedimentation zone either. These parameters also confirm the data obtain on water masses, there is an active water circulation between Meurthe and Coetlogon passes, at the Baleine and Taureau passes and in the southern part of Anemata pass.

The non muddy sediments are almost entirely of organic origin. Molluscs are the major (51%) constituent of these sediments, bivalves (20.8%) and gasteropods (10.8%) having the major contribution. The other constituents of the sediment are much less important (foraminifers 6%, scleractinarians 4%, Halimeda articles 2%, crustaceans, echinoderms, bryozoans making less than 1% each). Corals are a minor constituent of the lagoonal sediment in Ouvéa. This confirms observations made in the Chesterfield islands and in the SW lagoon of New Caledonia.

Five major biofacies (association of sediment types) were identified in Ouvéa. The association mollusc-foraminifer is the most frequent (61% of the samples), the other biofacies are mollusc-calcareous algae (18%), mollusc-scleractinarians (15%), scleractinarians-molluscs (3%) and foraminifer-molluscs (1%). The spatial distribution of these biofacies is given on figure 6. The molluscs are the major constituent in most samples (95%), bivalves being the most frequent (83% of the samples). Molluscs are found mainly in the central part of the lagoon (figure 7), their importance decreasing little by little outwards. There are also a few concentrations of molluscs along the coast of the main island.

Foraminifers, the second most abundant constituent in the biofacies, display a strong east-west gradient. Their abundance is the highest in the deepest zones of the lagoon. These organisms progressively replace the molluscs beyond 20 m. This zone overlaps the maximum of fish abundance, despite that to our knowledge, there is no relation between fish and foraminifers.

Among the other constituents, scleractinarians hold a special place. They are found in zones with strong currents and near reef formations. Elsewhere, they are only a minor constituent of the substrate, because their transportation is very limited.

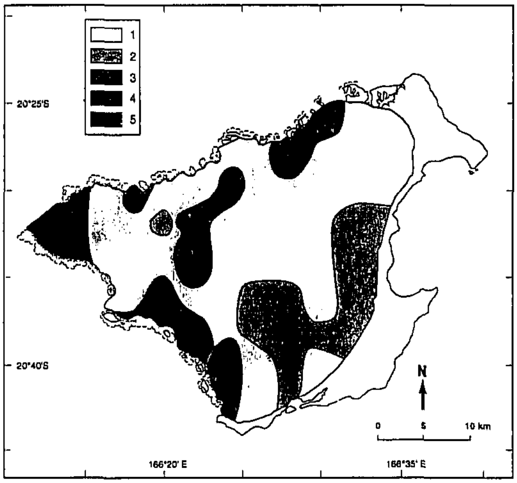

Figure 6: spatial distribution of biofacies: 1: molluscs - foraminiderans; 2: molluscs - algae; 3: molluscs - coral; 4: coral - molluscs ; 5 : foraminifers - molluscs

The coarsest element of the substrate (gravels, debris, boulders, beach rock...) could not be analysed beyond 20m. Reef formations are found either close to shore, either beyond 10m. Their importance increases with depth. Scattered coralline formations, usually of small size, are found over the entire lagoon. The size and the frequency of these coralline formations tend to increase with depth. The coarse elements of the sediment seldom make more than 20% of the substrate and are found mainly near passes.

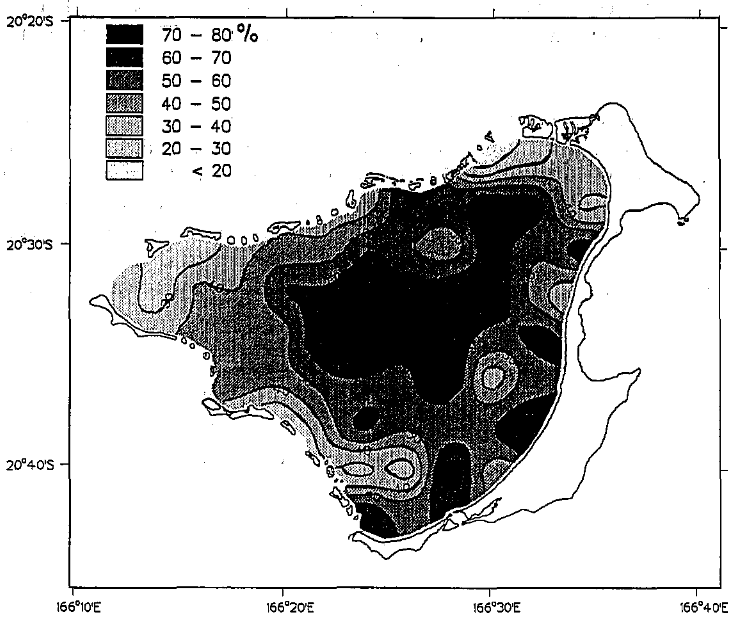

Figure 7: spatial distribution of mollusc shells

The proportion of hard substrate increases with depth (figure 8) down to approximatively 20m. At that depth these substrate represent on average 50% of the bottom. There is however a high variability, in particular the percentage of hard substrate increases near passes.

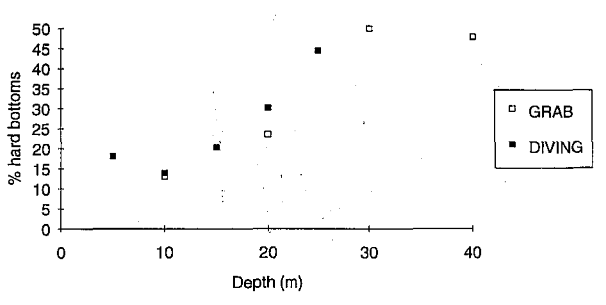

Figure 8: proportion of hard substrates (average values) by depth class

The variability is one of the major trait of substrates on Ouvéa bottoms. In an area of a few hundred m², it is often possible to observe several very different substrate types. This variability is maximum near passes but also in the slow eddy zones spotted off Fayaoué and Su island with the CZCS image analysis. This strong spatial heterogeneity is not unique to Ouvéa, similar conditions are also common in the SW lagoon of New Caledonia. In Ouvéa this variability is yet often noteworthy and is probably at the origin of some of the characterisitics of the benthic and fish communities.

Despite this spatial heterogeneity several substrate types can be differentiated (Figure 9). A coastal zone (zone 1 on figure 9), characterised by fine sediments, is found between 0 and 15m. An heterogeneous coastal zone stretches between Hwadrilla and St Joseph (zone 2 on figure 9), its main features being a low coastal cliff (2 to 5m high), a patchwork of coarse sediments and rock among fine sediments. This prevalence of coarse sediments, the little thickness of the sediments, the presence of beach rock is also found in the passes, however, usually with a lower heterogeneity. The bottom, between 12 and 20m and parallel to the shoreline is characterised by middle to coarse sands, scattered coral patches and beachrock covered by a 1 to 3 cm layer of sediment (zone 3 on figure 9).

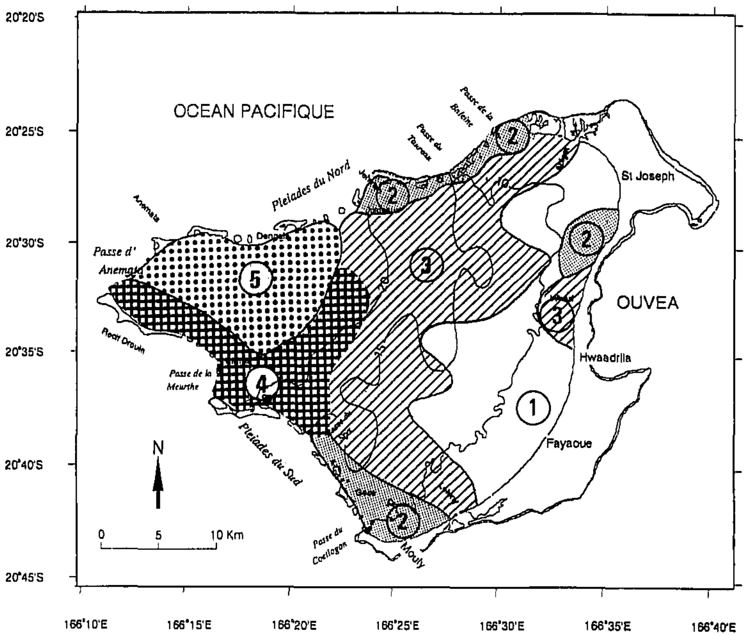

Figure 9: spatial distribution of the major bottom types.

Table 2: area and spatial distribution of the various benthic themes along the shoreline of the main island. The first number is the area in hectares, the second number is the percentage covered in each zone. Since the zones overlap, the total may be greater than the summ of the parts.

Zone1: from Baleine pass to south of St Joseph
Zone 2: from south of St Joseph to north of Hwaadrila
Zone 3: from Hwaadrila to south of Fayaoué
Zone 4: from Fayaoué to Mouly point

Theme	Zone 1	Zone 2	Zone3	Zone 4	Total
Beach rock and hard bottom	85 - 2.7	83 - 5.4	66 - 2.7	38 - 2.2	237 - 2.9
Naked sand	292 - 9.2	25.4 - 1.7	197 - 8.0	250 - *14.1*	752 - 9.3
Rough bottom	93 - 2.9	0 - 0	6.2 - 0.25	62 - 3.5	164 - 2.0
Seagrass beds on hard bottom	148 - 4.7	86 - *5.6*	74 - 3.0	45 - 2.5	305 - 3.8
Seagrass beds alone	33.7 - 1.1	0 - 0	0 - 0	3.6 - 0.2	38 - 0.47
Seagrass beds on sand -high density	770 - 24.4	333 - 21.8	622 - 25.3	251 - 14.2	1744 - 21.5
Seagrass beds on sand - average density	768 - 24.3	911 - *59.5*	1174 - 47.9	814 - 46.0	3195 - 39.4
Seagrass beds on sand - low density	781 - *24.7*	93 - 6.1	315 - 12.8	305 - 17.2	1471 -18.2
Halophylous vegetation	190 - *6.0*	0 - 0	0 - 0	2.5 - 0.14	196 - 2.4.
Total	3160 - 100	1530 - 100	2450 - 100	1770 - 100	8100 - 100

The SW part of the lagoon (between Styx and Anemata passes) has little sediment, the bottom being mainly covered by beachrock and coarse sediments (zone 4 on figure 9). A sedimentation zone is found in the NW part and is characterised by relatively fine sediments. The thickness of these sediments decreases with distance to the Northern Pleiades (zone 5 on figure 9). Coral heads are of large size and comparetively numerous in zones 4 and 5. They are used as refuges by an abundant fauna.

The shoreline has been studied in more details. Nine themes were defined and the shoreline was devided into 4 zones from north to south of the main island (Table 2). Seagrass and algae beds represent a very important area in the coastal zone. Their abundance decreases offshore. According to aerial pictures and satellite images these beds are set very irregularly on the substrate. Reef formations and beachrock are often encountered near the beach, but they never make a large percentage of the area. This is essentially observed between Banutr and the wharf. Some mangroves and halophylous plants are present in the inlets, but the area covered is low.

4 - The major reef biotopes

Fifteen reef biotopes were determined from the analysis of ground truth data along with the examination of aerial pictures and satellite images (Table 3). Reefs were divided into 7 zones, each zone being subdivided into2, 3 or 4 sub-zones (Figure 10). A classification of these zones and sub-zones according to biotopes indicates that there are an east-west and a north-south gradients. This gradation is in great part linked to the effect of the tradewinds and to the east-west slope of the lagoon bottom.

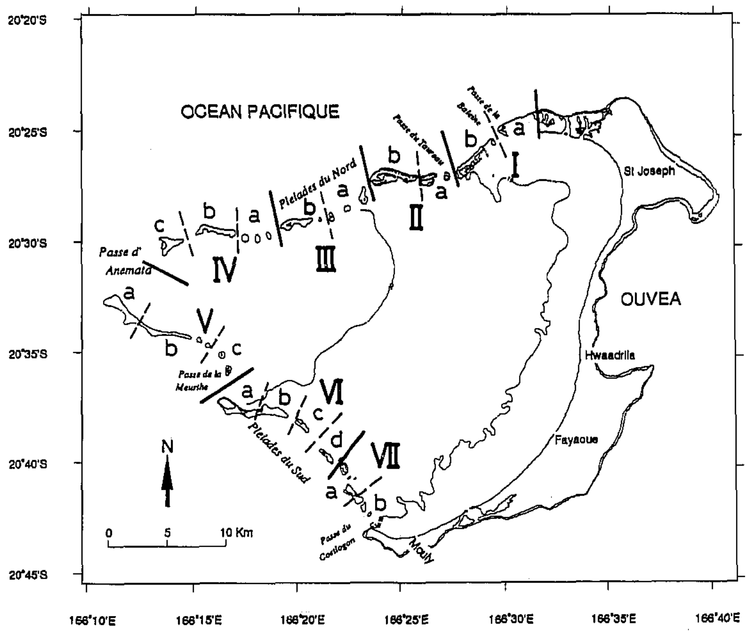

Figure 10: limits of the reef geomorphological zones in Ouvéa

Reefs fall into three groups. In the NE of the lagoon, zones 1 and 2 are characterised by the absence of soft bottoms near reefs, the low level of reef conglomerate but important fringeing reefs. The second group (zones 3, 4, 5) covers all the reefs west of the fault, from Jumeaux island westward to Meurthe pass in the south. These reefs are usually wide with many pools and much reef conglomerates. In this group the islands are scarce and consequently the fringeing reefs are little developped. The third group (zones 6, 7) is found east of the southern Pleiades, between Meurthe pass and Mouly. This part of the lagoon is quite different from the other reefs for several reasons. It has bare beachrock near the passes, large inner reefs, large areas of soft bottoms with scattered coral heads. There are also a few important coral formations which are somewhat similar to the pinnacles of Polynesian atolls. There are few reef pools, likely because of the exposure of the barrier reefs to the trade winds.

The importance of outer reefs increases from east to west. These reefs display deeply marked spurs and grooves in the northern Pleiades, essentially in the west part, whereas in the southern Pleiades the spurs and grooves are often lacking and replaced by a 8 to 20 m dropoff on the top of which branched coral developp. The exposed reefs have a poor fixed fauna, in particular corals. The spatial distribution of fringeing reefs in naturally linked to the distribution of the islands, the latter being found mainly east of the fault line. There are also differences between sheltered and exposed reefs, and between reefs from the northern and southern Pleiades. Leeward fringeing reefs are less indented and usually have a poorer fauna than windward ones. The southern Pleiade fringeing reefs have a wider shelf than those of the northern Pleiades where this shelf is often lacking.

Pools and hollows are much larger in the northern Pleiades than in the southern ones. The size of these pools and hollows tends to increase from east to west. In the northern Pleiades these formations are essentially behind the barrier reef, whereas in the southern Pleiades they are near the inner reef. These pools and hollows accumulate sands and debris and usually they lack fixed fauna. They are zones where predatory and some large size herbivores fishes concentrate during defined tide periods, likely in correlation with the currents.

Channels are more developped in the southern part where the bottom between islands is usually shallower than in the northern part. The bottom in these channels is rocky most of the time with organisms adapted to currents such as some gorgonians and alcyonarians. Most of the water exchanges between the lagoon and the ocean are done through the channels and the passes. Tide channels are usually located at the rear of the barrier reef and they drain the water from the reef flats towards the lagoon. These tide channels are almost absent from the southern Pleiades. In the northern Pleiades these channels are usually on the leeward side of the islands and allow currents to flow along the fringeing reefs. These tide channels are usually between a few tens of meters to 200-300m wide and do not exceed 1 km in length.

In the northern Pleiades rubble bottoms are found in the rear of pools or on the windward side of reefs. In the southern Pleiades these formations are mainly observed in the middle of reefs or near the reef front. These formations tend to increase in size from east to west. In other words rubble bottoms are more patchy near the main island than near Anemata pass. Sand zones are not frequent. In the northern Pleiades they are found mainly winwards of islands, whereas in the southern Pleiades they are dispersed near rubble bottoms and are of smaller size than in the northern part of the lagoon.

In the northern Pleiades the reef conglomerate is located mainly behind the barrier reef along which it makes an almost continuous strip, cut in places by channels and tide channels. There are also a few reef conglomerate zones on the windward side of islands, but these formations have no links with the reef conglomerate from the rear of the barrier reef. In the southern Pleiades the reef conglomerate has a very different spatial distribution. It can either form a strip on both sides of the reef, the two strips joining together on narrow reefs, or it can be scattered in the leeward side of the reefs. The size of "reef conglomerates" tends to increase from east to west.

The reef front is more developped in the southern Pleiades than in the northern ones where these formations decrease from west to east. Beachrock make a narrow zone immediatly behind the reef front on most of the southern Pleiades and the western part of the northern Pleiades. East of the Jumeaux island (northern Pleiades) the beachrock covers large areas which are not connected to the reef front. There are also some beachrock formations between reefs in this zone and near the Styx pass (southern Pleiades).

Lagoon inner reefs are almost absent from the eastern part of the northern Pleiades. These formations are found on the winward side of reef conglomerates in the west of the northern Pleiades. They are usually built of a serie of small reefs with a dropoff inside the lagoon which does not exceed 10m. Conversely, in the southern Pleiades, inner reefs form a nearly continuous strip on the inside part of reef formations. In the western part inner reefs have dropoffs which can reach 30 m and are little indented. Going towards the main island, the dropoff decreases in hight, reaching only 5m at Gece island. These reefs become also much more indented eastwards. On the leeward side of islands, the fixed fauna, mainly corals, is much less abundant on the inner reefs than in the zones between the islands and exposed to water circulation coming over the barrier reef.

The soft bottoms covering beachrock are found essentially near the main island and are more developped in the northern part of the lagoon than in the southern part. These formations are just behind the reefs in the northern Pleiades whereas in the southern Pleiades they are separated from the reefs by soft bottoms with coral isolated coral heads. This is maybe linked to the exposure to trade winds, the inner lagoon being exposed in the north and protected in the south. Consequently, in the south, fine particules drop to the bottom, but in the north they flow over the reef, as demonstrated by the sediment analysis and suggested by the study of the currents. In the northern Pleiades soft bottoms with isolated coral reefs cover large areas, mainly west of the fault at depths over 15m. These formations are also likely to be present inside Draule reef, but could not be noted because of the great depth. These formations are also found on the outer part of Draule reef, sheltered by a bay in this reef. This type of bottom is found from there to the main island.

Table 3: spatial distribution of the hard bottom biotopes in Ouvéa atoll. The first number represents the area in hectares, the second the percentages by zone.

Themes	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Total
Sheltered outer barrier reef	19.9-3.9	32.3-8.4	17.7-4.2	25.0-4.1	35.9-6.7	3.8-0.50	0.9-0.28	136-3.9
Exposed outer barrier reef	10.5-2.6	18.7-4.9	30.0-7.0	53.2-8.8	32.6-6.1	40.2-5.3	14.8-4.7	200-5.8
Fringeing reef of sheltered island	22.8-5.6	20.6-5.4	3.0-0.71	3.6-0.60	3.4-0.64	13.2-1.8	9.9-3.1	76.5-2.2
Fringeing reef of exposed island	13.5-3.3	14.8-3.9	0.7-0.17	2.6-0.42	2.6-0.49	12.4-1.6	4.8-1.5	51.4-1.5
Reef conglomerate	50.9-12.5	47.8-12.5	80.8-18.9	143-23.8	136-25.4	83.3-11.0	51.3-16.1	593-17.2
Reef front	1.5-0.36	14.0-3.7	11.7-2.7	12.6-2.1	33.0-6.1	35.6-4.7	0.4-0.11	111-3.2
Beachrock	45.8-11.3	37.6-9.8	29.5-6.9	45.6-7.6	74.6-13.9	139-18.4	53.2-16.7	425-12.5
Lagoon inner reef	4.8-1.2	1.7-0.44	30.0-7.0	32.9-5.5	38.2-7.1	45.0-6.0	31.4-9.9	184-5.4
Pools	24.9-6.1	27.7-7.2	39.5-9.3	61.6-10.2	34.0-6.3	26.4-3.5	9.0-2.8	223-6.6
Channels and tide channels	30.8-7.6	54.8-14.3	48.1-11.3	47.0-7.8	9.7-1.8	57.4-7.6	53.0-16.7	300-8.8
Rubble	100-24.6	56.2-14.7	73.0-17.1	91.6-15.2	84.6-15.7	148-19.6	23.8-7.5	577-16.8
Sand	7.8-1.9	11.5-3.0	5.3-1.25	4.3-0.72	5.6-1.0	21.7-2.9	2.8-0.88	59.0-1.7
Soft bottom with isolated coral heads	17.4-4.3	17.8-4.6	53.1-12.4	80.0-13.3	35.4-6.6	139-18.4	42.3-13.3	385-9.1
Beach rock with soft bottom	54.8-13.5	28.6-7.4	29.5-6.9	0-0	74.6-13.9	51.1-6.8	53.2-16.7	292-8.3
Pinnacles	1.4-0.33	0-0	0-0	0-0	12.0-2.2	9.8-1.3	8.2-2.6	31.4-0.91
Total	407-100	384-100	451-100	603-100	612-100	826-100	359-100	3643-100

Pinnacles are scarce and dispersed. Actually, several types of reef formations are grouped under this name, from large coral heads (over 10 m in diameter) to coral formations which morphology is close to the one of the pinnacles found in the Polynesian atolls. Pinnacles are almost absent from the northern part of the lagoon. In the southern part, they are dispersed in the deepest zones and are also present in small groups east of the southern Pleiades. Pinnacles are rather small compared to some Polynesian atolls, and they play only a minor role in the geomorphology of Ouvéa atoll.

B - PLANKTON

1 - Oceanic waters

Oceanic waters around Ouvéa are not well known. ORSTOM has sampled 3 stations near Ouvéa during the September 1992 cruise. Conversely, waters around Marée and Lifou (two of the other Loyalty islands) were sampled during several cruises between 1982 and 1984 (PREFIL cruises conducted by ORSTOM). The analysis of CZCS images show that water masses around Marée and Lifou have the same origine than the water around Ouvéa. It is therefore likely that results of the PREFIL cruises apply also to Ouvéa waters.

These studies have indicated that there is no particular enrichment of the water linked to the presence of the islands. These oceanic waters are poor, in phyto- as well as zooplankton. Minerals are almost entirely absent between 0 and 100m, being constantly recycled by the plankton. The planktonic primary production is one of the lowest ever recorded by ORSTOM in the tropical Pacific. Secundary production has not yet been estimated, but the available data suggest that it should be comparable to the very low production observed in the Fijian Bassin (PROLIGO cruises).

The production parameters of these oceanic waters vary much with time, yet they always stay low. These variations seem to be more linked to large scale oceanic phenomenons, such as El Nino, than to seasonal variations. Spatial variations show also a wide amplitude, but the causes are not yet determined.

2 - Inner-lagoon waters

The data from only one cruise (September 1992) is available at the moment. Taking into account the temporal variability which is usually observed for the characteristics of plankton inside atolls, these results are likely to reflect an average situation. This picture does not integrate the frequency of plankton blooms, a phenomenon which is quite often observed in atolls.

Data analysis of temperature, salinity and minerals suggest on one hand an important homogeneity in these waters and on the other hand a recycling, probably fast, of the lagoonal waters by the oceanic waters. The data on minerals leads to think that benthic metabolism dominates over the metabolism in the water columm. The first available data on the functionning of the benthos tend to confirm this hypothesis (see part on benthos). The inner lagoon waters are very poor in minerals, which is comparable to observations made in the SW lagoon of New Caledonia, but is ooposite to data from some atolls in the Center Pacific. The data are summarised in table 4.

Chlorophyll *a* is more abundant nearshore than in the deeper zones. In the latter, chlorophyll *a* is more concentrated near the bottom than to the surface. This spatial distribution is to be linked, on one hand to the increasing influence of the bottom compared to the surface, on the other hand to the probably faster recycling of the water in the deeper stations. The average value (0.233 $mg.m^{-3}$) is very low and comparable to the values found in the surrounding oceanic waters. Similar values have been observed on the GBR (Great Barrier Reef).

Pheopigments, which are degradation products from chlorophyll, show lower values in the shallow stations than in the deeper ones. There is also an increase of pheopigments near the bottom (sampled during dives).

Table 4: average values of the physical and chemical parameters inside and outside of the lagoon of Ouvéa. Numbers between brackets are the number of measures.

Parametre	Lagoon - water columm	Lagoon - bottom	Ocean
Temperature (°C)	23.50 ± 0.23 (217)		23.63 ± 0.19 (18)
Salinity	35.56 ± 0.05 (217)		35.55 ± 0.012 (18)
NO2 (µmole/ l)	0.003 ± 0.003 (126)	0.026 ± 0.006 (9)	0.002 ± 0.001 (11)
NO3 (µmole/ l)	0.016 ± 0.015 (120)	0.236 ± 0.094 (9)	0.003 ± 0.002 (11)
NH4 (µmole/ l)	0.04 ± 0.06 (126)	0.14 ± 0.08 (9)	0.07 ± 0.08 (11)
PO4 (µmole/ l)	0.05 ± 0.03 (126)	0.07 ± 0.01 (9)	0.05 ± 0.01 (11)
Si(OH)4 (µmole/ l)	0.57 ± 0.19 (33)	0.43 ± 0.06 (9)	0.72 ± 0.10 (11)
Oxygen (ml/l)	4.922 ± 0.130 (70)		

Phytoplankton size does not show any particular distribution according to time of day, depth or distance to the main island. Phytoplankton density (number of cells / unit of volume) is low, comparable to values observed on the GBR, but nearly 10 times lower than on Tikehau atoll (French Polynesia), whereas chlorophyll *a* concentrations at Tikehau and Ouvéa are comparable.

Primary production was estimated by three methods with nearly identical results (from 1.9 to 2.3 mg $C.m^{-3}.h^{-1}$). This production comes mainly from small size phytoplankton. These values are comparable to findings on the GBR at the same latitude.

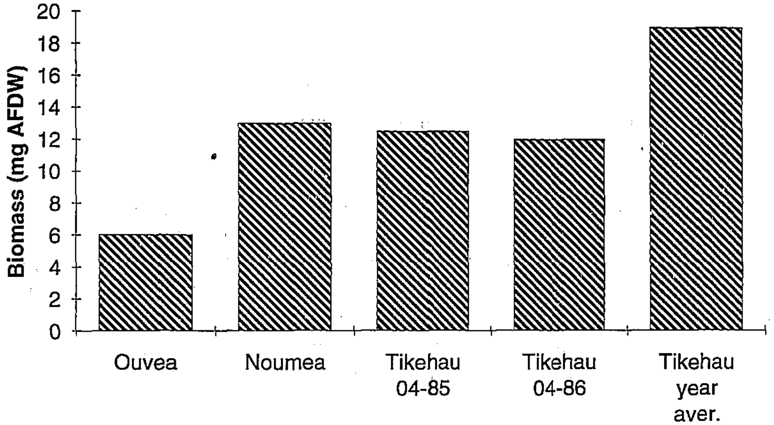

Figure 11: comparison of the biomass (AFDW) of the 200-2000µ between Ouvéa and other lagoons in the Pacific

Zooplankton biomass decreases with depth from the coast - offshore (Figure 11). Conversely, it is not possible to show north-south variations inside the lagoon. Ouvéa lagoon is poor, a first index of this oligotrophy being a zooplankton biomass 2 to 4 times lower than other lagoonal systems (Figure 12). This zooplankton biomass is at best twice larger inside the lagoon than outside in the oceanic waters, which are themselves poor. There is no significant zooplankton enrichment in the lagoon. On the other hand, second index of oligotrophy of this lagoon, zooplankton is dominated by small organisms.

An estimate of the quantity of zooplankton in the lagoon yields 113 kg / km² for the 200-2000 µm fraction and 79 kg /km² for the 35-200µm fraction, that is a total of 161 tonns for the entire lagoon. Daily carbon production by the zooplankton is estimated to reach 4.11 $mg.m^{-3}.d^{-1}$ for the first fraction and 6.32 $mg.m^{-3}.d^{-1}$ for the second one. The calculated turnover is particularly low (the biomass is renewed every 21 h). Since almost all the zooplankton is microphageous, most of its food source is phytoplankton. The ingestion of phytoplankton by zooplankton is estimated at 29.5 $mgC.m^{-3}.d^{-1}$ whereas phytoplankton production is estimated to 30 $mgC.m^{-3}.d^{-1}$. Therefore, there would be an equilibrium between phytoplankton production and zooplankton consumption. It is then possible to estimate the transfert coefficient from phyto- to zooplankton at 35%, a rather high value.

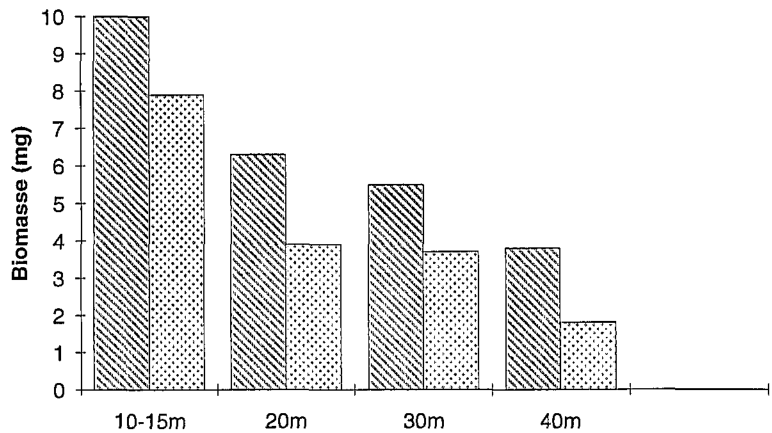

Figure 15: variation of the biomass (AFDW) of the zooplankton with depth. Bars on the left (stripes) : 200-2000µ fraction; bars on the right (dots): 35-200µ fraction

C - THE BENTHOS

Benthos encompasses fixed organisms and mobile organisms linked to the bottom. The study of benthos at Ouvéa was performed into two sequences, a descriptive one and a sequence analysing the functionning of the benthos. Most of the present results are in the descriptive phase, the data on functionning not being yet fully analysed.

1 - Description of the benthic communities

1.1 - Lagoon bottoms

Benthic organisms of the lagoon bottoms are classified into 3 categories, meiobenthos (organisms with a size less than 2 mm), macrobenthos (organisms with sizes between 2 mm and 2 cm), megabenthos (organisms with sizes above 2 cm). The methods needed to study each category are very different. Macrobenthos yielded quantitative measures, but megabenthos could only be estimated according to semi-quantitative criteria.

Meiobenthos was studied with indirect measures. Its biomass is estimated by ATP analysis. The ATP values (297 ng/ cm²) are similar to those found in the SW lagoon of New Caledonia, but are significantly lower than those from Tikehau atoll in French Polynesia (360 ng/cm²). The spatial distribution of ATP in Ouvéa follows a decreasing gradient on a NE-SW axis, the ATP values being higher in zones where the sediment is thin.

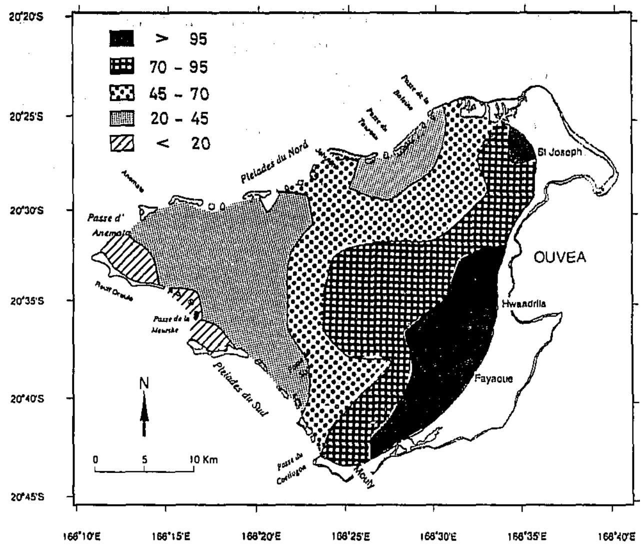

Figure 13: spatial distribution of the macrobenthos abundance (organisms/transect).

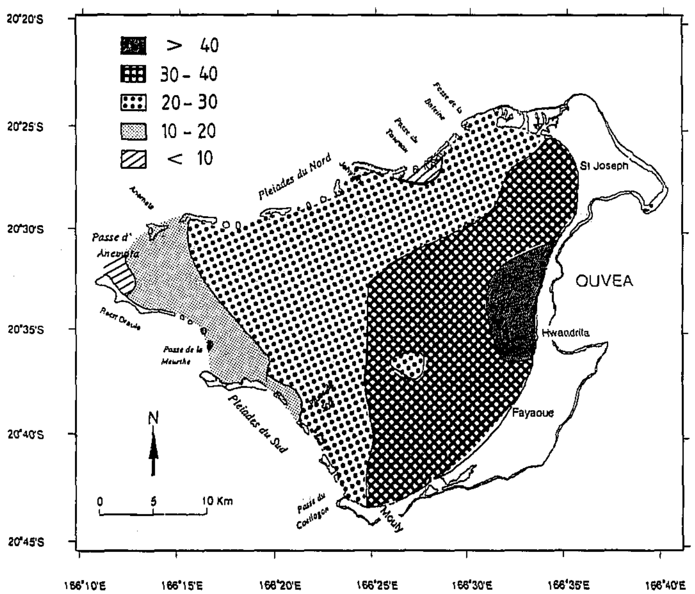

Figure 14: spatial distribution of species richness of macrobenthos (number of species /station)

Microalgae, laying on top of the sediment, are estimated from the measure of chlorophyll *a*. The values are rather high (77 mg/m²), and similar to results from Madagascar or Tokapoto atoll (French Polynesia). They are higher to the findings in the SW lagoon of New Caledonia or Tikehau atoll (French Polynesia). The degradation of chlorophyll produces pheopigments, the amount of which are an indicator of the microalgae production. In Ouvéa, the data suggest a strong production. The spatial distribution of chlorophyll *a* follows a decreasing gradient from the coast to offshore. Pheopigments have a very similar pattern. As ATP, chlorophyll *a* and pheopigments are correlated to the percentage of hard bottoms. The spatial distribution of ATP and of photosynthetic pigments lead to think that the highest production is found in areas where the sediment is the thinest (and consequently the deepest parts of the lagoon, figure 8).

A total of 341 taxa were collected during the study of the macrobenthos, the average number of taxa per station being 27.6 and the number of organisms per station being 60. These numbers are lower than those found in the SW lagoon of New Caledonia using similar methods. The abundance and species richness of the macrobenthos show a clear gradient between the coast of the main island and Anemata pass (Figures 13, 14). These parameters are negatively correlated to depth and the percentage of hard bottom.

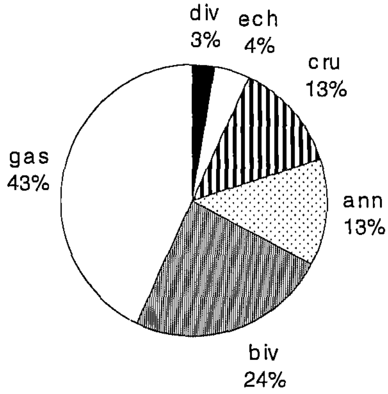

Figure 15: distribution of the major zoological groups of the macrobenthos. ann: annelids; biv:bivalves; cru: crustacean; div.: miscelaneous; ech.: echinoderms; gas. : gasteropods

A total of 250 taxa were identified during the study of the megabenthos, the average number of taxa per station being 16. Sofar, we know of no comparable data set in the Indo-Pacific. There is no particular gradient for the spatial distribution of the species richness of the megabenthos. Conversely, abundance , as for macrobenthos, decreases from east to west.

Macrobenthos is dominated in abundance by molluscs (67% of individuals), worms (annelids) and crustaceans being the following groups (Figure 15). The proportion of the various groups varies depending on which size class is considered, however, molluscs always prevail (Figure 16). For megabenthos it is more difficult to compare the abundance of the various organisms, some being fixed or living in colonies (algae, corals). Among the free living organisms, molluscs are the most abundant, followed by echinoderms. Corals and algae are the most abundant fixed organisms, algae occupying larger areas than corals. The lagoon bottoms in Ouvéa are noticeable for the low numbers of echinoderms and the abundance of molluscs, in particular bivalves. Macroalgae are much less abundant than in the SW lagoon of New Caledonia. The available data suggest that macroalgae are more abundant in Ouvéa than on Polynesian atolls, but confirmation is needed. Corals are more frequent on the lagoon bottoms of Ouvéa than on those of the SW lagoon of New Caledonia. This is likely to be due to the little thickness of the sediment in Ouvéa which allows coral to attach themselves more easily than they can in the SW lagoon where sediments are usually much thicker.

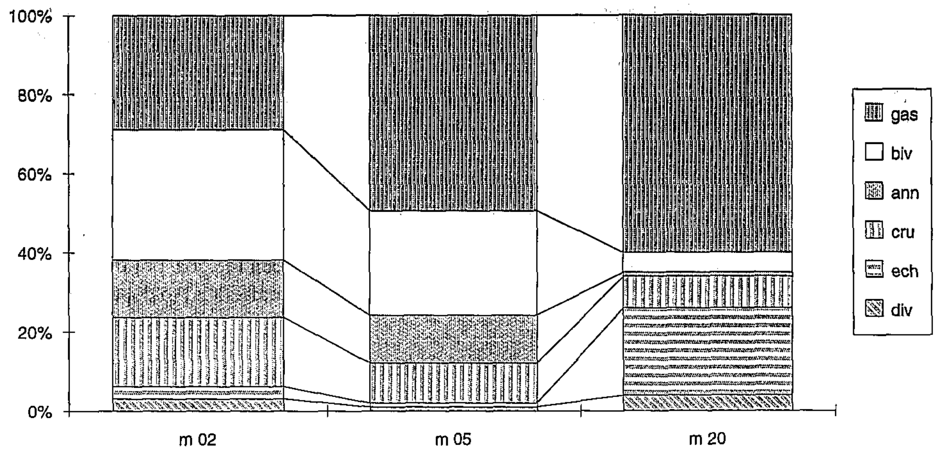

Figure 16: distribution of the major zoological groups collected in the 2mm (m02: 1179 organisms), 5mm (m05: 2256 organisms), 20 mm (m20: 264 organisms)seeves. Abreviations are the same than on figure 15.

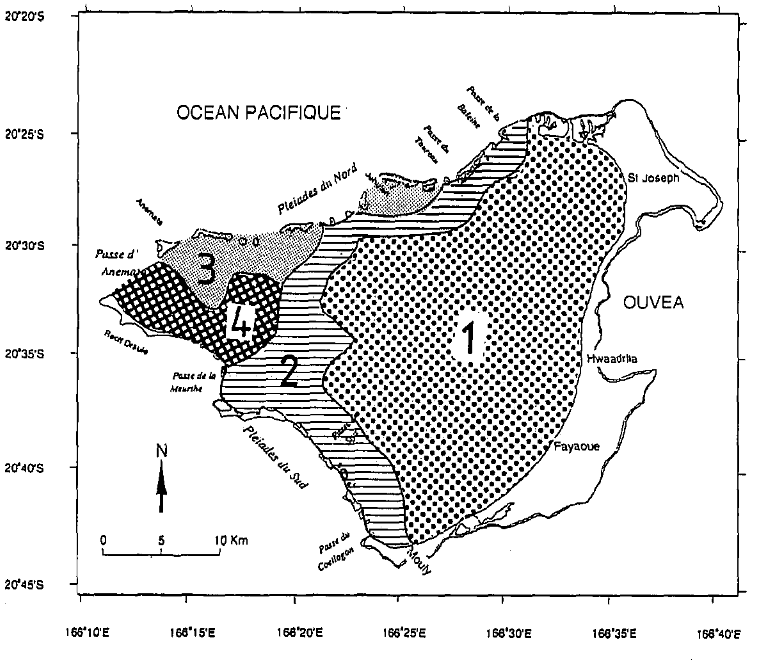

Figure 17: boundaries of the major macrobenthic communities

The comparison of the proportions of the various groups in the benthos (living organisms) with those in the bioclasts (dead organisms) shows some similarities. In particular, molluscs are the main group in both cases. There are however major differences. Gasteropods are the main molluscs in the benthos whereas bivalves are the dominant molluscs in the bioclasts. The spatial distributions of the living molluscs and of their shells show also some important differences. The former are mainly found in shallow zones, the latter are closer to the center of the lagoon. The distribution of mollusc eating fish is closer to the distribution of the shells than of the living animals. Foraminifers are not a major group in the benthos, whereas they are the second group in the bioclasts. One should however notice that many species of foraminifers are less than 2 mm in size and therefore are not taken into account in the study of the macro- or megabenthos. Some differences between benthos and bioclasts may come from the way organisms and their skeletons decay. In particular, there may be difference in spatial distribution of organisms with time. Fish can eat molluscs in one place and defecate the shells in another, the amplitude of this type of phenomenon being not necessarely negligeable.

The spatial distribution of the abundance of most macrobenthic organism follows a decreasing gradient from the coast towards the ocean. It is not the same with the megabenthos. Some organisms (algae, holothurians) follow this gradient. Conversely, most of the other (corals, alcyonarians, sponges, ascidians, crinoids) are linked to hard bottoms and are abundant in places where the sediment is not very thick or where substrate is dominated by hard bottoms (rock or beachrock) (Figure 9).

It is possible to define communities (species associations) from data on organisms abundance. Unfortunately, the use of non homogeneous abundance criteria for macro- and megabenthos did not allow to group the two types of organisms in the same analysis. The study of the macrobenthos gives the zonation on figure 17, the megabenthos gives the zonation on figure 18. These two zonations are closely related and present many similarities with the bottom type zonation (Figure 9).

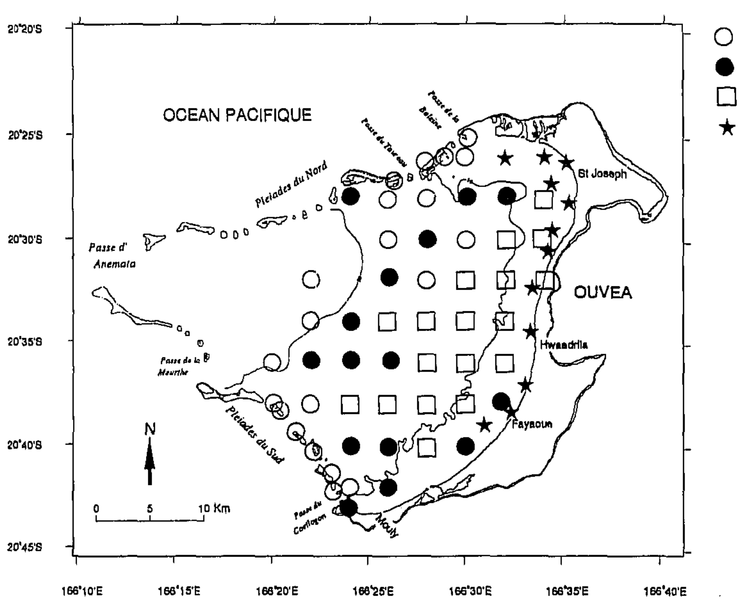

Figure 18: classification of the lagoon bottom stations according to the megabenthos

1.2 - Reefs

Only the megabenthos was studied. The diversity and abundance of the megabenthos are higher on the reefs than on the lagoon bottoms. The available data suggest that the diversity would be lower in Ouvéa than in the SW lagoon of New Caledonia. Abundances for corals are of the same order of magnitude in both areas, but the macroalgae and the echinoderms are less abundant in Ouvéa.

The 7 geomorphological zones defined previously (Figure 10) shelter megabenthos communities which characteristics are presented in table 5. The classification of these geomorphological zones according to their megabenthos yields a similar result than their classification according to their biotope. Megabenthos diversity and to a lesser extent megabenthos abundance are lower on the NE reefs. Elsewhere, the values are almost constant. The spatial distribution of diversity varies with each group of organisms. The NE lagoon (zones 1 and 2) is essentially poor in corals (2 to 4 times less species / station than the other zones). The NW lagoon (zones 3 and 4) has average diversities excepted for gorgonians which are more diversified and more abundant there (this could be linked to currents, gorgonians being usually very good current indicators). The SW lagoon (zone 5) has the highest diversity of holothurians, urchins and alcyonarians. The abundance of corals and alcyonarians increases from east to west and from north to south. The exposure to the trade winds probably influences this distribution. Algae are particularly abundant in the NW lagoon, despite their low diversity.

Table 5: diversity and abundance of the major benthic organisms in the 7 geomorphological zones of the Pleiade reefs. Diversity is in number of species / station. Abundance is either an estimate of the number of individuals per m² for individual organisms, either a cover estimate (algae, alcyonarians, corals, sponges). These abundance estimates have only a relative value, being derived from semiquantitative indices.

	ZONES						
Diversity of the organisms	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Algae	1.71	1.67	1.83	1.14	1.71	3.86	2.25
Urchins	1.14	1.50	2.17	2.00	1.57	1.57	3.12
Holothurians	1.14	0.83	2.50	1.86	3.14	1.14	2.88
Sea stars-ophiurians-crinoides	0.43	-	0.17	0.14	0.43	0.29	0.12
Corals	3.86	7.17	12.83	12.71	11.00	13.71	13.25
Gorgonians	0.43	0.50	1.83	2.71	1.43	0.71	1.38
Alcyonarians	1.43	0.83	1.83	2.00	2.57	1.86	2.88
Sponges	1.29	0.50	1.33	1.29	1.29	0.86	1.75
Ascidians	1.57	0.83	1.17	1.29	1.00	1.14	1.25
Total	13	13.8	25.7	25.1	24.1	25.1	28.9
Abondance of organisms	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Algae	0.102	0.025	0.024	0.108	0.059	0.081	0.033
Urchins	0.018	0.052	0.075	0.078	0.070	0.051	0.083
Holothurians	0.010	0.050	0.022	0.023	0.099	0.020	0.021
Sea stars-ophiurians-crinoids	0.0047	-	0.00055	0.0048	0.0047	0.0019	0.0004
Corals	0.073	0.147	0.301	0.363	0.348	0.386	0.453
Gorgonians	0.0033	0.047	0.025	0.140	0.089	0.0033	0.0125
Alcyonarians	0.034	0.058	0.035	0.080	0.164	0.141	0.229
Sponges	0.035	0.53	0.018	0.025	0.017	0.011	0.055
Ascidians	0.015	0.010	0.017	0.054	0.017	0.016	0.043
Total	0.30	0.92	0.52	0.87	0.87	0.71	0.93

2 - *Benthic communities structures on the lagoon bottoms*

The data collected to understand the structure and the functionning of benthic communities are not yet fully analysed and therefore the following chapter is an intermediate report.

The benthos biomass (scleractinarians excepted) is on average of 4.14 g/m² (all biomass measures are expressed as Ash Free Dry Weight). The plant biomass represents 40% of the total (1.63 g/m²), green algae (Chlorophycae) making 85% and blue algae (Cyanophycae) 14%. The animal biomass (2.51 g/m²) is dominated by gasteropods and bivalves (Figure 19). These values are six times less than in the SW lagoon of New Caledonia, conversely, the ratio of flora to fauna is the same in both regions. The spatial distribution of the biomasses follows approximatively the one of abundance, with a decreasing gradient from east to west. A concentration of animal and plant biomass is noticeable off Hwaadrila and also halfway between Meurthe and Jumeaux passes (northern Pleiades). This latter concentrention zone corresponds to hard bottoms.

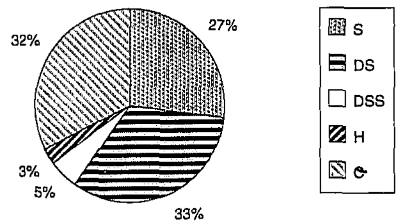

Figure 19: distribution of the biomasses by trophic categories for the whole lagoon. S: suspension feeders; DS: surface deposit feeders; DSS: sub-surface deposit feeders; H: herbivores; C: carnivores

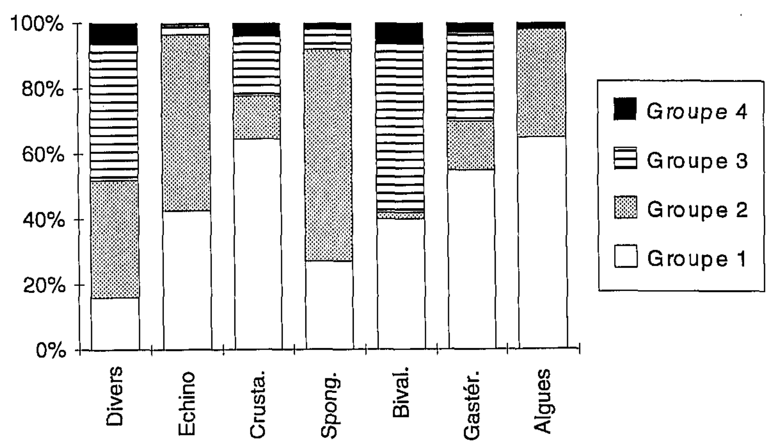

Figure 20: biomass percentages for the major taxonomic group of each macrobenthic community defined on figure 17.

The distribution of the biomass (Figure 20) varies with the communities defined on figure 17. Thus, in the coastal community (group 1), which is the richest (5.72 g /m²), algae dominate followed by molluscs. It is also in this community that crustaceans are the best represented. In the community of group 2 (1.87 g/m²) the presence of hard bottoms explains an important biomass of fixed organisms (Sarcophyton and sponges). Plants are dominated by cyanophycae which are also linked to hard bottoms. Plants represent only 25% of the biomass in this group. In the community of group 3 (2.05 g/m²) algae are even scarcer, most of the biomass being formed by molluscs. The community of group 4 (0.75 g/m²), characterised by deep hard bottoms, is also dominated by molluscs, sessile organisms playing an important role as well.

The distribution of this biomass into trophic groups (Figure 19) gives a first insight in the functionning of these communities. The deposit feeders are the main trophic group (38%). These organisms feed essentially on debris found at the surface or just below the surface of the sediment. The origin of these debris can be extremely varied and in particular it can include living organisms such as microphytobenthos. The first results on benthic primary production indicate that it is high compared to observations made in the SW lagoon of New Caledonia. Most deposit feeders are Cerithidae (gasteropods) or Holothuridae (echinoderms), both are not easy preys for benthic carnivores. In the SW lagoon deposit feeders have a relatively lesser importance (they make only 20% of the biomass), but their absolute importance (3.1 g/m²) is higher than in Ouvéa. One should also notice that in Ouvéa deposit feeders stay almost all on the surface, maybe because the sediment is not thick, whereas in the SW lagoon the partition between surface and sub-surface deposit feeders is 40%-60%.

The trophic structure of the macrobenthos varies according to the benthic community (Figure 21). Primary producers are important in group 1 and 2, which are found in shallow waters. These primary producers have only a minor role in the other groups. The suspension feeders are inversially proportional to the primary producers. The deposit feeders make a relatively stable part from one community to the next. Carnivores are important nearshore (group 1) and in the middle lagoon (group 3). Grazers never make a major group. This variability of the trophic structure between communities is similar to observations made in the SW lagoon of New Caledonia, and is by far more important than the variability observed for fish communities.

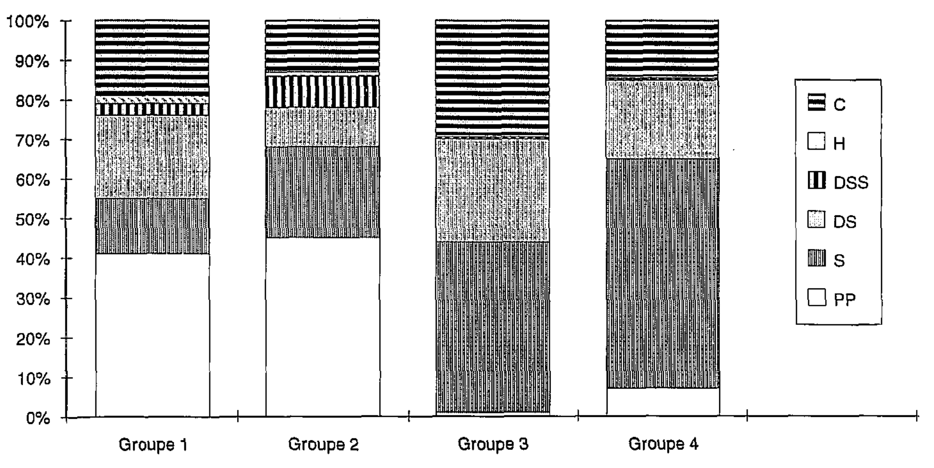

Figure 21: distribution of biomass by trophic groups in each of the communities defined on figure 17.S: suspension feeders; DS: surface deposit feeders; DSS: sub-surface deposit feeders; H: herbivores; C: carnivores; PP: primary producers

The analysis of the energetic budget of lagoon sediments indicates an annual production (P) of 0.88 g C m^{-2} d^{-1} and a respiration (R) of 0.84 g C m^{-2} d^{-1} . These values are greater than those measured in the SW lagoon of New Caledonia. These numbers (P>R) show that these sediments are autotrophic (they produce more than they consume) and are therefore in great part independent from the reef and pelagic productions. The excess of production (approximatively 8 000 tonnes of carbonne / year) is exported to the reefs and to the ocean, however we do not know how much is allocated to each. These results are opposite to the observations made in the SW lagoon of New Caledonia where terrigenous imputs of 40 000 t of carbone per year are needed to balance the benthic catabolism.

D - FISH COMMUNITIES

1 - Species composition

A total of 626 species of fish, distributed among 72 families, were censused during our surveys. 48 species had never been described before from New Caledonia, and two species are new to science. The major families are indicated in table 6. There is nothing particular in the species composition of this atoll excepted for the low diversity of the Siganidae, *Abudefduf, Neopomacentrus* and Clupeidae. Similar findings were made in the Chesterfield islands, which suggests that these exceptions are linked to the isolation of the atoll.

Table 6: species diversity of the families with more than 10 species

Family	**Number of species**	**Family**	**Number of species**
Muraenidae	17	Chaetodontidae	31
Holocentridae	18	Pomacanthidae	13
Scorpaenidae	20	Pomacentridae	55
Serranidae	37	Labridae	69
Apogonidae	27	Scaridae	20
Carangidae	13	Blenniidae	19
Lutjanidae	14	Gobiidae	46
Lethrinidae	17	Acanthuridae	25
Caesionidae	10	Balistidae+Monacanthidae	10 + 6
Mullidae	15		

2 - Description of the communities

For convenience, two types of communities will be distinguished, lagoon bottom communities and reef communities. In fact, these communities are not independent because of the many exchanges occuring between them.

2.1 - diversity

A total of 220 species were censused on the lagoon bottom and 414 on reefs. The spatial distribution of diversity is relatively homogeneous on reefs whereas there is an increase in species richness from east to west on the lagoon bottoms (Figure 22). This change in species number is linked to the increase of the cover by hard bottom (rock, beachrock, coral heads).

The diversity at the family level is also different between reefs and lagoon bottoms (table 7). Apogonidae excepted, lagoon bottom have less species than reefs. Most families display a positive gradient in their diversity from east to west on lagoon bottoms, whereas this gradient is not observed on reefs. Despite this absence of gradient, many families of reef fish show a particular spatial distribution, some prefering the oceanic zones (west of the lagoon), others sheltered zones (east of the lagoon), the surroundings of passes ...

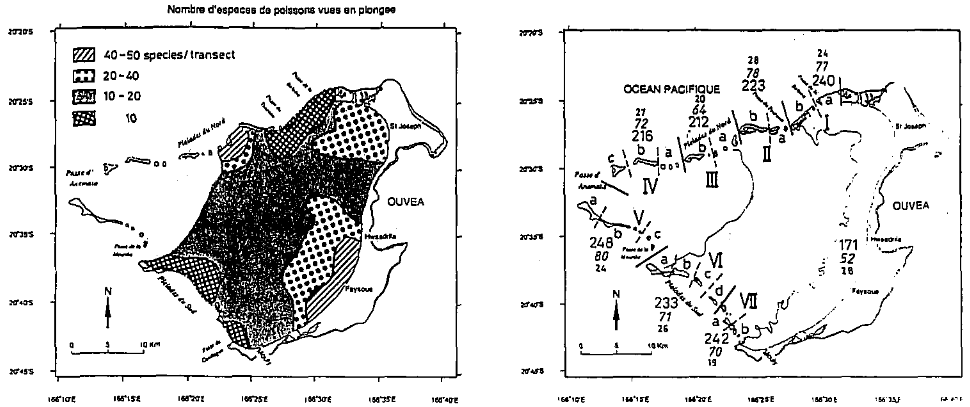

Figure 22: spatial distribution of fish diversity. a) lagoon bottoms (species/transect) b) on reefs (species/zone) (large numbers: all species; medium numbers: commercial species; small numbers: line species)

2.2 - Density

Density is higher on reefs (3.7 fish /m²) than on lagoon bottoms (2.0 fish /m²). These values are relatively high compared to reefs in the Indo-Pacific. The spatial distribution of this density follows an east-west gradient on the lagoon bottom, but displays no particular gradient on reefs (Figure 23). This gradient in the density of lagoon bottom fishes is linked to the abundance of hard substrates. It should be noted that this abundance is opposite to what is observed for benthic invertebrates and planktonic production. If there is a chance that fish influence the abundance of benthic invertebrates, it is very unlikely that they have a direct effect on planktonic production.

The various fish families do not have the same contribution to density on lagoon bottoms and on reefs. Caesionidae, Apogonidae and Pomacentridae dominate lagoon bottoms, whereas Pomacentridae, Chaetodontidae, Acanthuridae are the major families on reefs. On lagoon bottoms the density of most species is not homogeneously distributed. Some species have affinites for passes and reef proximity (for instance *Lutjanus gibbus, Lethrinus atkinsoni, L.rubrioperculatus*, Scaridae and Acanthurus spp.), other species prefer the middle of the lagoon (for instance Lethrinus nebulosus, *Diagramma pictum, Epinephelus cyanopodus*), shallow waters (i.e. *Lutjanus quinquelineatus*) or on the opposite the deepest parts of the lagoon (i.e. *Lutjanus bohar, Aphareus furca, Gymnocranius* spp.). On reefs many species do also have special spatial distributions, however, reef species are much more linked to a biotope than to a particular zone on the reef. For instance, one can segregate species (*Scarus microrhinos, Acanthurus lineatus, A.triostegus...*) which prefer habitats with a strong hydrodynamic action (barrier reef, reef front), but these species have approximatively the same density from one zone (the 7 zones defined in chapter A-4) to the next.

Table 7: diversity, density and biomass of the major fish families on the lagoon bottoms and reefs of Ouvéa. Densities are in fish/m² and biomasses in g/m².

	Lagoon bottoms			Reefs		
Family	Diversity	Density	Biomass	Diversity	Density	Biomass
Sharks	2	0.0001	1.45	7	0.0010	18.68
Holocentridae	3	0.0005	0.11	14	0.0116	1.87
Epinepheliinae	12	0.0142	6.17	19	0.0344	14.18
Anthiinae	4	0.3933	0.92	4	0.181	1.48
Apogonidae	13	0.6535	0.38	10	0.0151	0.14
Carangidae	3	0.0026	10.0	13	0.0055	6.37
Lutjanidae	7	0.0087	4.71	13	0.0950	24.86
Caesionidae	5	0.7906	11.58	7	0.2389	12.13
Haemulidae	5	0.0034	2.88	4	0.0011	2.04
Lethrinidae	9	0.0118	4.90	16	0.0992	14.86
Mullidae	11	0.0506	1.00	15	0.0350	4.67
Chaetodontidae	12	0.0114	0.25	31	0.623	1.92
Pomacanthidae	4	0.0036	0.08	10	0.0384	1.29
Pomacentridae (Total)	25	0.3812	1.00	50	2.0855	10.65
Chromis	9	0.0554	0.15	14	1.5781	6.30
Dascyllus	4	0.1663	0.40	4	0.0151	0.10
Pomacentrus	7	0.1532	0.43	11	0.2654	1.45
Labridae	23	0.0040	1.39	60	0.1810	12.55
Scaridae	13	0.0135	2.56	20	0.1295	55.90
Acanthuridae	15	0.0144	4.74	27	0.2680	56.07
Siganidae	1	0.0001	0.04	4	0.0188	3.19
Balistidae	7	0.0091	1.10	17	0.0113	2.11
TOTAL	220	2.012	56.17	414	3.72	259.5

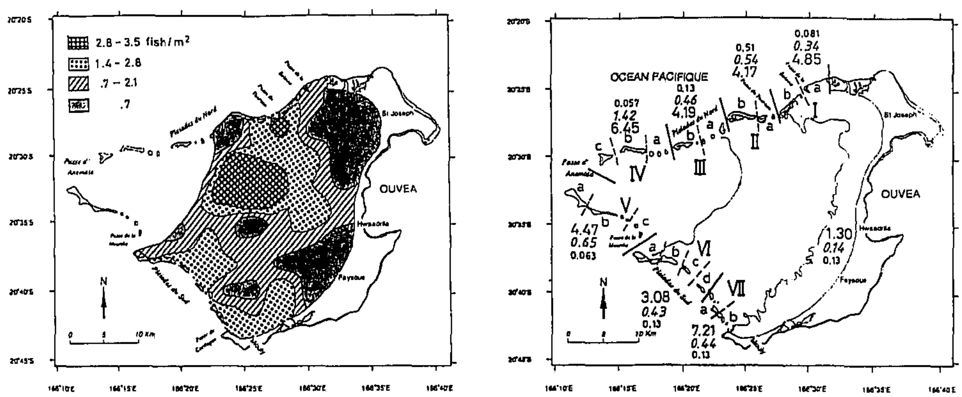

Figure 23: spatial distribution of fish density (fish/m²). a) lagoon bottom b) reefs (large numbers: all species; medium numbers: commercial species; small numbers: line species)

2.3 - Biomass

Fish biomass on reefs is greater (259 g/m²) than on lagoon bottoms (56 g/m²). The value found for reefs is high compared to similar reefs in the Indo-Pacific. Similar values were however observed on barrier reefs in the SW lagoon of New Caledonia. The values found for lagoon bottoms is similar to those found in the SW lagoon and slightly superior to those from the Chesterfield islands. In the SW lagoon terrigeneous inputs are however much greater than in Ouvéa. It is likely that in Ouvéa these values are due to the abundance of hard substrate which allow the fixation of juveniles and are used as shelter by the adults. Up to now, the figures given by the analysis of the planktonic and benthic production do not justify such biomasses on the lagoon bottom.

Biomass is not evenly distributed on the lagoon bottoms. The gradients found for the diversity and density are even stronger (Figure 24). This increase in the gradient is linked to the depth distribution of the average weight of fishes. Indeed, the larger fish tend, for most species, to migrate in the deeper zones of their habitat. Such an increase in biomass with depth is an unusual phenomenon, the largest biomasses being usually found in the shallow waters because they support a higher primary and benthic production. In Ouvéa, the data on benthos suggest that production is the highest in the shallow zones. Therefore, there is a paradox in the distribution of fish on the lagoon bottoms.

On reefs, fish biomass does not significantly vary from one zone to another (Figure 24). Conversely, fish biomass varies between reef biotopes, those with the highest biomass presenting numerous shelters and calm waters (inner reef, pinnacles, soft bottoms with coral heads). The lowest biomasses are found in habitats with little shelter or turbulent waters (beachrock, channels and tide channels, reef front).

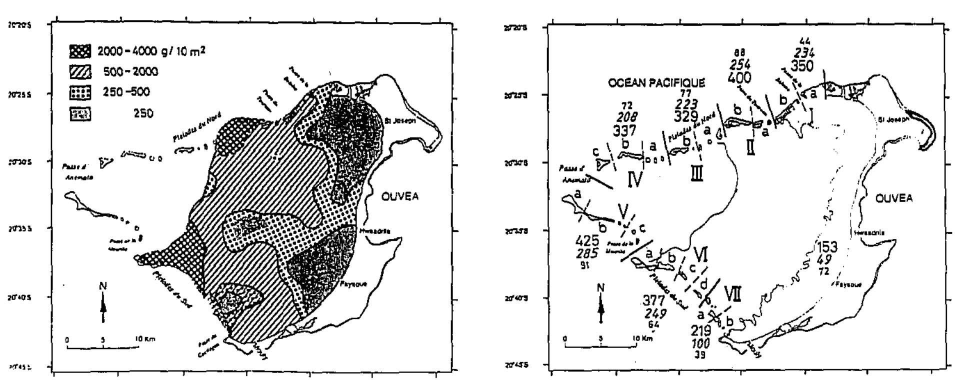

Figure 24: spatial distribution of fish biomass (g/m²). a) lagoon bottoms b) reefs (large numbers: all species; medium numbers: commercial species; small numbers: line species)

The most important families in biomass are not the same on lagoon bottoms and reefs. Caesionidae, Carangidae, Lethrinidae, Serranidae and Acanthuridae dominate soft bottoms, whereas on reefs Acanthuridae, Scaridae, Lutjanidae, Lethrinidae and sharks are the major components of the biomass (table 7).

The commercially important fish make most of the biomass (72% on reefs, 66% on soft bottoms).

2.4 - Size distribution

Many species of fish have sizes which vary from one biotope to another and especially between lagoon bottoms and reefs. Most of these species are not territorial and it is likely that the observed differences in size are mainly linked to migrations with age and not to a difference in growth between biotopes (despite the fact that such differences between biotopes do probably exist).

On lagoon bottoms juveniles of non sedentary species are unusual. Lethrinidae, however, recrute on seagrass and algae beds where they stay several months before moving to deeper waters. Mullidae have also many juveniles on lagoon bottoms, however these species are also observed as juveniles on reefs. The other families which are at times found as juveniles on the lagoon bottoms are Scaridae, Serranidae and Acanthuridae.

On reefs, juveniles are at times abundant and all families are represented. In particular, most commercial species have juveniles on reefs or near reefs. The reefs the closest to the main island have higher densities of non sedentary juveniles than reefs away from the main island. By contrast, the juveniles of many species (Haemulidae, Caesionidae, Kyphosidae...) were not observed. The juveniles of sedentary species are found in the same areas than the adults, however it is frequent that juveniles and adults form separate schools.

3 -Structures

3.1 - Trophic structures

Trophic structures in species numbers (table 8)(Figure 24) are almost identical on lagoon bottoms and on reefs. This type of result is usual, the trophic structure in species varying only little from one reef type to another within a region. This structure is dominated by carnivores, piscivores and zooplanktivores. The structure found in Ouvéa is very close to the one observed in the SW lagoon of New Caledonia, with however slightly more planktivorous and microherbivorous species in Ouvéa. An analysis on a regional scale suggest that the proportions of planktivores and microherbivores are inversely correlated to the abundance of terrigeneous inputs.

Table 8: trophic categories on lagoon bottom and reefs. Diversities are in species numbers, densities are in fish /m² and biomasses in g/m².

Trophic category	Diversity		Density		Biomass	
	Lagoon	Reef	Lagoon	Reef	Lagoon	Reef
Piscivores	32	54	0.045	0.101	16.5	56.2
Macrocarnivores (C1)	67	115	0.126	0.317	17.2	68.9
Microcarnivores (C2)	30	48	0.097	0.219	0.88	6.8
Zooplanktivores	42	67	1.615	2.688	14.0	31.5
Macroherbivores	3	10	0.002	0.054	1.05	19.8
Microherbivores	35	68	0.111	0.692	5.84	115.2
Coral feeders	7	27	0.006	0.046	0.11	1.5
Detritius feeders	3	7	0.011	0.097	0.62	9.3

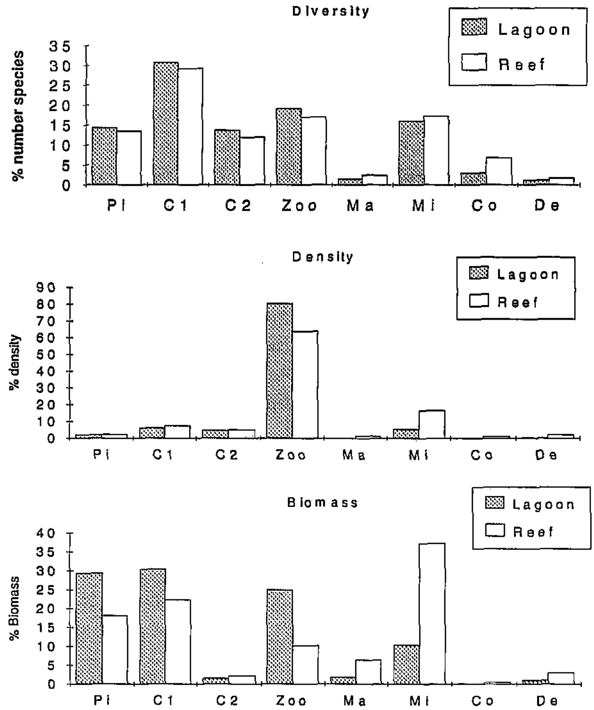

Figure 25: proportion of the various trophic groups in the diversity, density and biomass of the fish communities. Pi: piscivores; C1: macrocarnivores; C2: microcarnivores; Zoo: zooplanktivores; Ma: macroherbivores; Mi: microherbivores; Co:coral feeders; De: detritus feeders

The trophic structure in density is dominated by planktivores (figure 25). Carnivores and microherbivores are the two other important trophic categories (table 8). There are slight differences between lagoon bottoms and reefs. On lagoon bottoms zooplanktivores are proportionaly more numerous and conversely microherbivores, coral feeders and detritus feeders less numerous. Zooplanktivores are of different types on reefs and lagoon bottom. On the latter, most zooplanktivores feed high in the water colum, whereas on reefs this category feeds mainly near the bottom. The proportion of zooplanktivores on lagoon bottoms in Ouvéa is very high compared to the SW lagoon of New Caledonia, but of the same order of magnitude than in the Chesterfield islands. The proportion of zooplanktivores in the central Pacific is much lower (2 to 22%). It is therefore likely that planktivores play a special role in the functionning of the fish communities in Ouvéa.

There are important differences in the trophic structure in biomass between reefs and lagoon bottoms (table 8, figure 25). Herbivores are the major group on reefs followed by carnivores and piscivores. On lagoon bottoms carnivores are the main group, zooplanktivores and piscivores being also important. The structure observed in Ouvéa is close to the one found in the SW lagoon of New Caledonia, either for reefs or lagoon bottoms.

On lagoon bottoms, there are relationships between the spatial distribution of fish trophic groups and their preys. Thus, zooplankton decreases with depth on lagoon bottoms and zooplanktivores are found near passes and in the Hwaadrilla bassin which is not very deep. Piscivores have their highest relative abundance in the shallow zones, where juveniles of many mobile species can be found. Microcarnivores are found in the coastal fringe which is also the zone where the density of macrobenthos is the highest. Microherbivorous fish and herbivorous benthos have roughly the same distribution in the lagoon, the largest abundances being found along the coast. Conversely, macrocarnivores do not present a spatial distribution which corresponds to the observations done on their preys (mainly molluscs). It is likely for the latter that sampling problems could be involved.

We have only limited information allowing to correlate fish with their preys on reefs. The relationships with the megabenthos are often significant, in particular most trophic groups are correlated to corals and negatively correlated to algae. However, these relationships indicate habitat affinities and not trophic relationships.

3.2 - life-history strategy structures

Each fish species has vital traits (average size, longevity, reproductive rate, behaviour...). These traits define a life-history strategy for the species. It is possible to classify species in broad categories according to their life-history strategies. We have defined 6 classes of strategies for reef and lagoon fishes, the first class grouping all fish with a short life, a strong reproductive effort... and at the other end of the scale fish of class 6 have long longevity, a reproductive effort spread over a long period of time, size is usually large... It is then possible to characterise a fish community by the distribution of the species among these life-history strategy classes. We have noted this structure, life history structure.

Table 9 : fish life histories on lagoon bottoms and reefs. Diversity are in species numbers, densities in fish/m², biomass in g/m².

Strategy class	Diversity		Density		Biomass	
	Lagoon	Reef	Lagoon	Reef	Lagoon	Reef
1	21	36	0.237	1.916	0.5	7.4
2	94	140	1.688	1.777	14.9	51
3	31	63	0.026	0.245	11.7	65
4	27	77	0.026	0.160	1.33	11
5	34	63	0.030	0.101	19.4	98
6	12	18	0.005	0.021	8.4	76
Total	219	397	2.016	4.22	56.15	309

There are only minor differences in the life history structure in species between lagoon bottoms and reefs (figure 26), reefs having a lesser proportion of short lived species (classes 1 and 2). This structure is very close to the observations made in the SW lagoon of New Caledonia and in the Chesterfield islands, but is markedly different from the Central Pacific where short lived species are proportionally much less important, in favor of species with an average life span and a larger size (class 4 mainly).

Fish from classes 1 and 2 (short life, high reproductive effort, small size...) make most of the density (Figure 26, table 9) on either reefs or lagoon bottoms, with however a higher proportion of class 1 species on reefs. Fish of classes 3 to 6 (average to very long life span, spread out reproductive effort, medium to large size) represent only 4.3% of the density on lagoon bottoms and 12.5% on reefs. These numbers are very close to those found on the other lagoon bottoms in the region (3.4 to 7.2%), but these fish usually represent higher percentages on reefs within the region (24.2 to 29.3%). Therefore, the reef fish population in Ouvéa is likely to have a higher turnover rate than the other reef fish communities in the region. An analysis of the trophic composition of classes 1 and 2 fish indicates that they are mostly species feeding on small preys (plankton, microalgae and microbenthos), resources which abundance probably fluctuates and is difficult to predict. Conversely, this type of prey (microalgae excepted) make only a minor contribution to the diet of classes 3 to 6 species, which preys are mainly macrobenthos and fish.

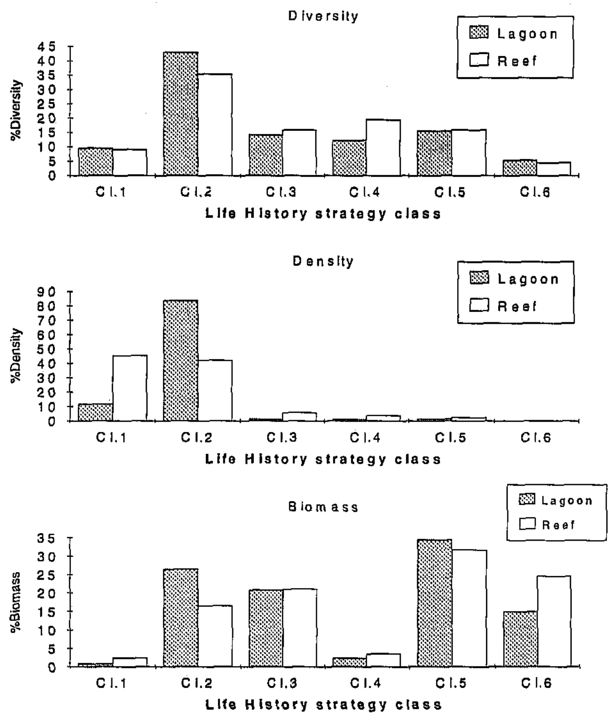

Figure 26: proportion of the various life history classes in diversity, density and biomass in fish communities.

The biomass of the various life history groups is distributed in a way very different from what was observed for density (Figure 26, table 9). Indeed, fish of classes 3 to 6 have large individual weights which compensate for their scarcety. In particular, the largest fish (classes 5 and 6) account for more than 50% of the biomass (49.5% on lagoon bottoms, 56.3% on reefs), whereas they accounted only for 1.8 and 2.9% of the density. The magnitude of this phenomenon is not the same everywhere in the region. In particular, on reefs, these fish have usually a much lower contribution to biomass (34 to 37%). It is likely that in Ouvéa the low fishing pressure, a factor to which these fish are highly sensitive, could be responsible for this matter of fact.

Species of classes 1 and 2 are mainly found in the shallowest parts of the lagoon bottoms and classes 5 and 6 species prefer average depth zones (10-15m). On reefs, there is no clearcut gradient in the spatial distribution of life history classes with the geomorphological zones. Conversely, classes 1 and 2 species prefer biotopes with numerous shelters and exposed to currents.

4 - Fish - habitat relationships

Only a few relationships could be established between fish and their environment on lagoon bottoms, whereas on reefs theses relationships are very strong. It is likely that a sampling problem is at the origin of this. Indeed, most samples performed for the study of the lagoon bottom substrate were limited to soft bottoms, whereas most fish are linked to the hard substrates found on the lagoon bottoms.

On lagoon bottoms, species richness, biomass and average weight are correlated to the presence of rocky formations (beachrock, rock, coral heads). Species richness decreases very significantly with sand coverage. The density of most fish community elements are not correlated to benthos, with the exception of herbivores and coral feeders which are linked to the abundance of coral heads.

On reefs, species richness, density and biomass increase significantly with reef formations and coral cover. The presence of sand or macroalgae has, on the opposite, a negative effect on these communitiy parameters. The other elements of the reef substrate (beachrock, rubble, debris and gravel) have no direct influence on these parameters.

It is very difficult to establish homogeneous zones on the lagoon bottom to which could be linked distinct fish communities. The zonations found by analysing the benthos or the sediment (Figures 9, 17, 18) have different types of fish communities (table 10). The fish communities become more complex (increase of the species richness, density, biomass) from zone 1 to 4 (zone 5 was not sampled by visual censuses for fish). This corresponds to coarser sediments, to an increase in the heterogeneity of the substrate, to the increase of coral heads and rocky formations (rock, beachrock, large boulders).

Table 10: species richness (fish/transect, density (fish/m²) and biomass (g/m²) of the fish communities defined by the zonation of figure 9.

Zones	Species richness	Density	Biomass
1	14	0.67	17.2
2	25	0.63	37.7
3	27	1.33	49.9
4	39	1.37	177

Table 11: characteristics of the fish communities from different biotopes. Diversity is the total number of species found in each biotope (sampling effort was not taken into account). Density is in fish /m², biomass in g/m² and average weights in g. Areas are in ha (10 000m²).

Biotopes	Total surface	Diversity	Density	Biomass	Average weight
Barrier reefs	336	229	5.43	291	54
Fringeing reefs	128	152	2.41	343	142
Reef conglomerates	593	273	3.62	365	101
Reef front	111	182	5.16	229	44
Beachrock	425	214	2.60	296	114
Inner reefs	184	225	7.48	404	54
Pools	223	166	2.56	217	85
Channels and tide channels	301	221	8.23	226	27
Rubble	577	200	2.48	159	64
Soft bottom with coral heads	385	168	4.73	494	104
Soft bottom with beachrock	292	219	2.74	357	130
Pinnacles	32	64	4.95	542	109

On reefs, it looks like there is no fish community zonation which corresponds to the geomorphological zones defined on figure 10, whereas the megabenthos presented strong affinites with this zonation. Conversely, fish are distributed according to reef biotopes, each biotope carrying a different community. These reef biotopes are very patchy and there is an important circulation of fish from one biotope to the next, however each biotope has distinct species. Despite it is not possible to give precise figures with the available data, it looks like the most complex communities (highest species richness, density and biomass) are found where the substrate offers the most shelters. The sheltering role played by rocky formations on sandy bottoms or on rubbles is often spectacular, densities changeing within meters between 01 -0.3 to at times 20 fish / m². This role is mainly important for small fish, in particular the planktivores which tend to gather in schools around coral heads, specially in zones with current (in particular near passes).

5 - exchanges between lagoon bottoms and reefs

Fish communities in Ouvéa support two major types of species, sedentary species and wandering species (or mobile species). The distinction between these two groups is not always easy, a number of mobile species staying for long periods in the same place. The degre of mobility (or range) of most reef fishes is not well known. Our data indicate beyond doubt that exchanges exist between lagoon bottom and reef fish communities.

A number of species (Lethrinidae, Lutjanidae) migrate daily form the reefs to the lagoon bottoms and back. Reefs are used as shelters, these fish feeding mainly on lagoon bottoms. These daily migrations could reach several km (case of the large Lethrinidae), but in most cases they probably do not exceed a km. Other fish come and go between the lagoon bottoms and the reefs without apparent pattern. It is the case of *Aprion virescens* (green job fish) or *Lethrinus olivaceus* (longnose emperor). A limited number of species feed on the reef and take refuge in the isolated coral heads nearby (some Acanthuridae and Scaridae). A large number of grazers (Scaridae, Acanthuridae, Siganidae) move with the tide, grazing at high tide on the top of reefs and at low tide on rocky formations either on the reef or on the lagoon bottoms, in particular on beachrock.

There are longer term migrations. As already mentioned, many juveniles of Lethrinidae, Siganidae and to a much lesser extent Lutjanidae, Scaridae and Acanthuridae recrute on seagrass and algae beds and migrate little by little to the reefs. These biotopes play therefore a role of collector, despite the fact that juveniles of these species are also seen on reefs. It is possible, as it has already been found in the Carabbeans, that lagoon bottoms shelter the juveniles which were in excess on the reef at the time of recruitment. This role is specially well filled in Ouvéa, where refuges abound on the lagoon bottoms.

There are probably also reproductive migrations. In Ouvéa, the only observation which corresponds to this type of migration is a concentration of *Aprion virescens* around the "Ile de la Tortue". It is likely that many other species, in particular the Serranidae (*Plectropomus* spp., *Epinephelus cyanopodus*) and Lethrinidae (*Gymnocranius* spp.) or Lutjanidae (*L.gibbus*) migrate to passes for spawning as it is observed in the SW lagoon of New Caledonia. Some Lethrinidae are also known to come in shallow waters to spawn near seagrass beds (*L.nebulosus, L.atkinsoni*).

E - THE RESOURCES

1 - Mineral resources

The present study never had the purpose of evaluating such resources, however, the presence of a 50 km beach may lead to think that there are important stocks of sand underwater in this lagoon. Most stations had only a thin layer of sediment, usually less than 5 cm, which suggests that it is very unlikely that there are great quantities of easily exploitable sand.

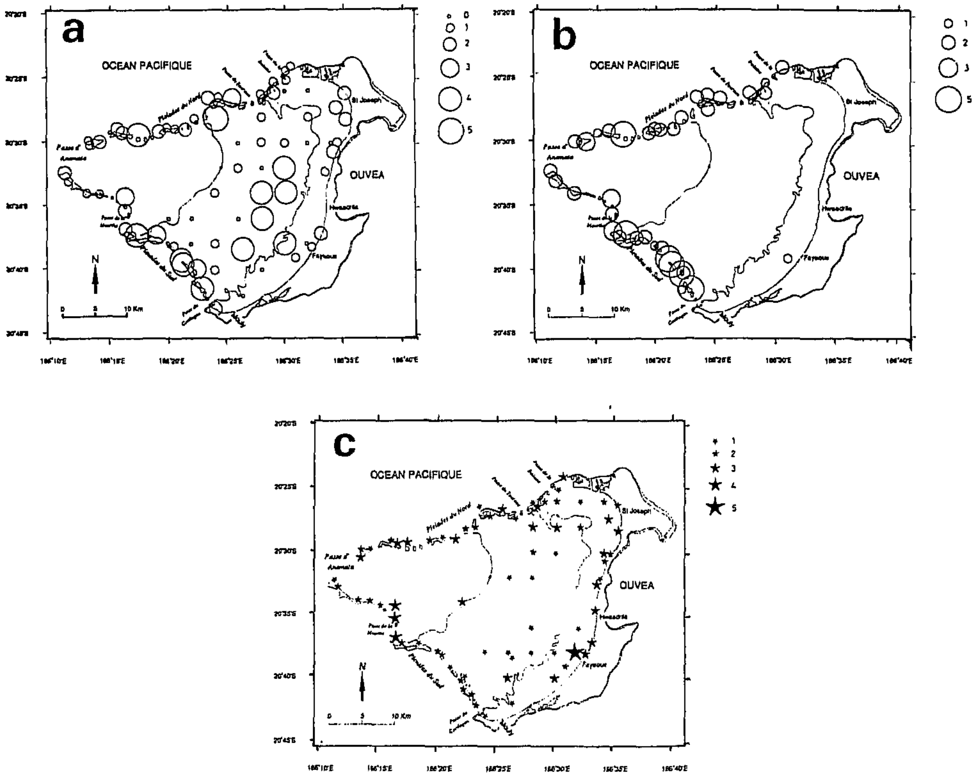

Figure 27: benthic invertebrate resources (relative abundances: 1: rare; 5: very abundant)
a) shells for handycraft b) giant clams c) holothurians

2 - Invertebrates

Our study did not find any exploitable invertebrate resource. Semiquantitative estimates show however that there are some small concentrations of holothurians and giant clams (figure 27) and that decorative seashells could be collected for a small scale handycraft. It should be noticed that two of the major invertebrates exploited on the mainland of New Caledonia, trochus (*Trochus niloticus*) and Pectinidae (scallops), are very rare in Ouvéa.

In shallow water, there are many sites well protected from the trade winds along the beach of the main island. These sites could be favorable to sea weed farms if such an activity developped in New Caledonia (at the moment it would not be economically viable).

3 - Fish

Two methods were coupled to evaluate the fish stock in Ouvéa. On reefs, only the visual censuses were used. Conversely, part of the lagoon bottoms could not be accessed by diving, and it was necessary to use both experimental fishing and visual censuses.

3.1 - Stock estimates

3.1.1 - Reefs

Reefs cover approximatively 40 km^2 in Ouvéa. It is possible to estimate the total stock either by geomorphological zone (Figure 28) or by biotope (table 12), the two methods giving very close results. The detail for the major commercial species is given in table 13. Reefs in Ouvéa carry on average 190 tons of fish /km^2. There are few studies giving values for reef fish stocks, but Ouvéa seems to have important ones. In the SW lagoon of New Caledonia the numbers are twice lower (80 tonnes /km^2). On the GBR values are intermediate. Five families dominate the commercial species, Serranidae, Lutjanidae, Lethrinidae, Scaridae and Acanthuridae. The same families usually dominate on most reefs of the Indo-Pacific. Scaridae and Acanthuridae, two families of herbivores, have biomass which are much higher than in all the other studies we know of. Unfortunately, we do not have the values of the primary production on the reefs of Ouvéa in order to know if these biomasses originate from a high primary production or just translate a very low fishing pressure.

Table 12: stock estimates by biotope. Surfaces are in ha, stocks in tons. The intervals given are 95% confidence intervals.
* : we had no observed value for the sandy areas in reef zones. The values given are extrapolated from the average biomass observed on lagoon bottom stations where sand made more than 80% of the substrate
** : we do not have enough coastal stations to partition between the various coastal biotopes

Biotopes	Surface (ha)	Total stock	Stock of commercial species	Stock of line fish
Sand *	60	12*	7.8*	2.4*
Barrier reefs	336	978±128	667±195	284±181
Fringeing reefs	128	439±125	363±126	64±47
Reef conglomerates	593	2164±231	1622±326	436±166
Reef front	111	254±45	162±61	61±62
Beachrock	425	1258±165	826±298	286±259
Inner reefs	184	743±63	498±184	130±94
Pools	223	484±76	274±154	139±111
Channels and tide channels	301	680±120	440±126	57±42
Rubble	577	917±156	718±208	176±98
Soft bottom with coral heads	385	1902±393	1018±454	636±604
Soft bottom with beachrock	292	1042±225	932±537	200±120
Pinnacles	32	173±32	65±54	55±68
Coastal zone **	401	593±104	198±20	291±23
Total	4048	11639±529	7654±721	2520±459

3.1.2 - Lagoon bottoms

Among the 128 experimental fishing stations, 46 were also sampled by visual census. The correlations between the catch (CPUE) and the biomass observed along the transect is not very good. A similar study in the SW lagoon of New Caledonia had correlated visual censuses with bottom longline catches. In this latter case, correlations were very good, certainly because the visual surveys were performed at the same time as the fishing, whereas in Ouvéa fishing and observations took place on different dates and not necessarily at the precise same place. It is however possible to relate CPUE and the biomass of fish observed (figure 29a)

$$\ln(\text{Biomass}) = 7.39\ (\pm 0.41) + 1.579\ (\pm 0.131)\ \ln(\text{CPUE in weight}) \qquad r = 0.489 \qquad N=43 \qquad (1)$$

It is possible with this equation to estimate fish stocks for all the lagoon bottoms even in areas where visual censuses were not performed. However, the high variance of the data can be strongly decreased by stratifying the data by depth zones (equation 2 - figure 29b)

$$\ln(\text{Biomass}) = 0.455\ (\pm 0.132)\ln(\text{CPUE in weight}) + 0.857\ (\pm 0.158) \quad r = 0.86 \quad N=7 \qquad (2)$$

Table 13: estimation of reef stocks for the major commercial species. Stocks are in tons. The upper and lower limits are the 95% confidence interval, * all other commercial species in the same genus or family

Species	Stock lower limit	Stock upper limit	Stock average value
SERRANIDAE			
Epinephelus cyanopodus	30.2	31.5	30.8
Epinephelus maculatus	18.1	19.7	18.9
*Epinephelus spp.**	42.8	48.4	45.6
Plectropomus laevis	168	189.8	178.9
Plectropomus leopardus	92	100.2	96.1
Variola louti	43.4	49.6	46.5
LUTJANIDAE			
Aprion virescens	82.9	92.3	87.6
Lutjanus gibbus	21.0	23.9	22.4
LETHRINIDAE			
Lethrinus atkinsoni	109.3	133.7	121.5
Lethrinus nebulosus	9.8	10.8	10.3
Lethrinus olivaceus	30.6	33.0	31.8
Lethrinus obsoletus	6.2	6.8	6.5
Gymnocranius spp.	90.0	101.2	95.6
*Lethrinidae spp.**	26.9	34.9	30.9
LARBIDAE			
Cheilinus undulatus	286.2	311.2	298.7
SCARIDAE			
Scarus microrhinos	275.5	346.3	310.9
Scarus ghobban	75.1	85.3	80.2
Scarus altipinnis	266.5	326.5	296.5
Scarus rubroviolaceus	53.5	59.5	56.5
Hipposcarus longiceps	696	934	815
Cetoscarus bicolor	89.9	99.7	94.8
ACANTHURIDAE			
Acanthurus blochii	455	733	594
Acanthurus mata	89.0	124.2	106.6
Acanthurus dussumieri	143.9	177.9	160.9
Acanthurus xanthopterus	303.6	464.0	383.8
Naso brevirostris	36.8	42.4	39.6
Naso tuberosus	147.4	175.6	161.5
Naso unicornis	83.9	102.3	93.1
SIGANIDAE			
Siganus argenteus	32.6	46.0	39.3
Siganus punctatus	75.3	90.1	82.7
TOTAL	3881	4994	4438

Figure 28 indicates that most of the stock is found in the deeper parts of the lagoon. A detailed account of the stocks for the major species is given in table 14. Commercial species represent 17 tons/km^2 of which 10.3 tons/km^2 are line fish.

These values should be considered as order of magnitude for the stocks. There are numerous sources of error and of variation which can not be possibly taken into account. Thus, it is very likely that there are seasonal and annual variations of the standing stocks. The magnitude of these variations are sofar unknown, but preliminary data from the SW lagoon of New Caledonia suggest that they could be very important (up to 50% over a 4 year period). There are also biases due to the methods, all species are not detected the same way on the transects. In particular, many Lethrinidae were captured but few were seen during the censuses. Conversely, some species are attracted by divers (Serranidae in particular). Depending on the time of day and the tide, fish are more or less active and therefore more or less detectable, and consequently their biomass estimates may vary.

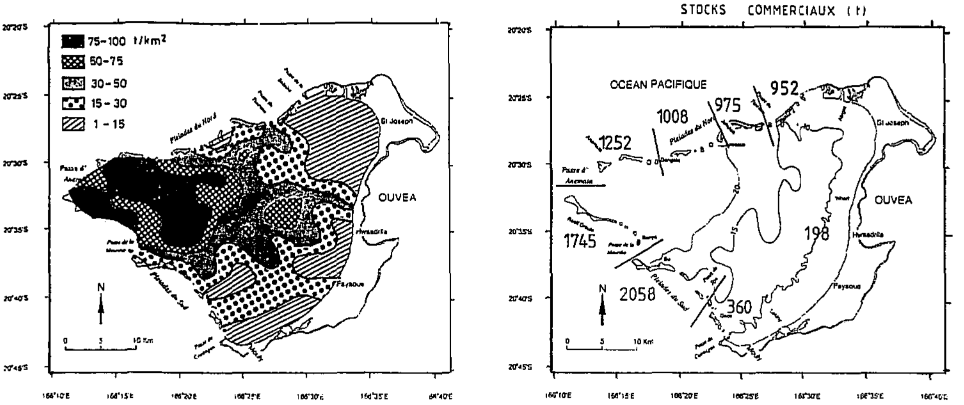

Figure 28: spatial distribution of the standing stock (commercial species).
a) lagoon bottoms b) reefs

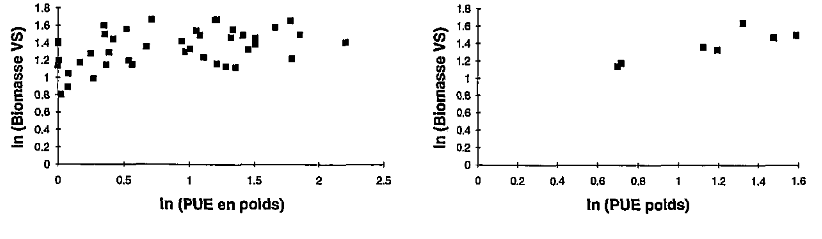

Figure 29: a)biomass-CPUE in weight VS: visual census b) biomass-CPUE in weight relationship stratified by depth zones

The standing stocks found for the lagoon bottoms of Ouvéa are higher than in most studies performed in similar habitats. In the SW lagoon of New Caledonia a study correlating diving and bottom longlining indicates 3.7 tons/km². On the atoll of Tikehau (French Polynesia) the analysis of the available data suggests 7.5 tons /km² of commercial fish. In the Maldives, a study based on bottom longlining yields estimates of 8.9 tons /km². It is difficult to give a reason for the high values found in Ouvéa. The lagoon has a very low fishing pressure and stock can be considered as in an virgin state, conversely to the other lagoons. The first results from the benthic production survey suggest a rather high production. On the opposite, planktonic production is low, the lagoon and oceanic waters being poor in minerals. The special structure of the lagoon bottoms (abundant rocky formations) is certainly a major factor for the size of the standing stock. Indeed, most lagoons have few shelters, the central parts of lagoons being frequently sedimentation zones with very fine sediments. Studies on artificial reefs on sandy bottoms indicate that reefs play not only a role of shelter but also favor the retention of juveniles. In Ouvéa, the lagoon rocky formations could therefore increase the recrutment capacity and allow a better use of the primary resources as indicated by the high percentage of plankton feeders in the communities of the lagoon bottoms.

Table 14: Standing stock estimates for the major commercial species. All values are in tons. L95: lower limit of the 95% confidence interval. H95 upper limit of the 95% confidence interval.(VS: visual census)

a) line fish

Species	VS - average	VS L95	VS H95	Fishing - average	Fishing L95	Fishing H95
Epinephelus cyanopodus	564	312	1030	341	189	623
Epinephelus maculatus	422	234	772	525	290	959
Other Serranidae	679	376	1241	80	44	146
Carangidae	1034	572	1888	19	10.5	35
Aprion virescens	1187	657	2169	229	127	420
Lutjanus bohar	997	541	1786	476	263	871
Lutjanus gibbus	74	41	135	292	161	533
Other Lutjanidae	759	420	1387	173	96	316
Diagramma pictum	596	330	1088	246	136	450
Gymnocranius spp.	117	65	214	140	77	256
Lethrinus atkinsoni	392	217	715	773	427	1413
Lethinus nebulosus	548	303	1000	2896	1602	5290
Lethrinus olivaceus	166	92	303	337	186	615
Lethrinus rubriopercuiatus	7.7	4.3	14	279	154	510
Other Lethrinidae	417	230	761	82	45	149
Sphyraenidae	13	7.2	24	66	37	121
Bodianus perditio	125	69	229	6	3.3	11

b) other species (from visual censuses only)

Species	Stock -average	Lower limit	Upper limit
*Epinephelus spp.**	280	135	625
Plectropomus laevis	343	150	755
Plectropomus leopardus	280	130	620
*Carangidae spp.**	6000	2700	12620
Lutjanus vittus	78	35	165
*Lethrinus spp.**	970	460	2040
Cheilinus undulatus	455	205	955
Bodianus perditio	250	110	525
Scarus ghobban	770	350	1615
Scarus altipinnis	90	40	185
*Scarus spp.**	350	150	740
Acanthurus blochii	362	160	765
Acanthurus dussumieri	1085	490	230
Acanthurus xanthopterus	335	150	705
Naso annulatus	120	55	255
Naso tuberosus	600	270	1270
Naso spp.	155	65	325
TOTAL	12523	5655	24395

3.2 - the fishing potential

Only part of the stock can be taken by fishing. It is desirable for this appropriation to be optimal, i.e. the catch should be maximum yet without jeopardizing the perennity of the stock. Such a value is called maximum sustainable yield (MSY). This value is only theoritical and its main purpose should be to give an order of magnitude of the fishing potential. It is difficult to estimate this MSY for a multispecific stock, presently no method is really satisfactory. On the other hand we have only very limited data on the biology of the fish making the stock in Ouvéa. For these reasons, we used an approximation, the Gulland formula:

$MSY = 0.5\, M \times B$ where M is the natural mortality rate and B the stock in tons.

We have no good measure of M for reef species, however most of these species should have mortality rates between 0.3 and 0.5. The estimated MSY's for the major species are given in table 15. These numbers are certainly well above the real potential of the atoll. Our days, the Gulland formula is usually minored by a factor of 2.5. On the other hand, despite the lack of formal studies on the mortality rates of commercially important reef fishes, it is likely that natural mortality rates are lower than the numbers usually given. If these biases are taken into account, the MSY for the whole lagoon becomes close to 1000tons/year.

table 15: estimated MSY (in tons/year) of the major commercial species in Ouvéa

Species	MSY	Species	MSY
Epinephelus cyanopodus	225	*Bodianus perditio*	15
Epinephelus maculatus	182	*Scarus microrhinos*	55
Plectropomus laevis	60	*Scarus ghobban*	65
Plectropomus leopardus	40	*Scarus altipinnis*	50
Variola louti	34	*Scarus rubroviolaceus*	15
Carangidae	740	*Hipposcarus longiceps*	125
Aprion virescens	610	*Cetoscarus bicolor*	50
Lutjanus gibbus	55	*Acanthurus blochii*	75
Lutjanus vittus	14	*Acanthurus mata*	40
Diagramma pictum	255	*Acanthurus dussumieri*	100
Lethrinus atkinsoni	190	*Acanthurus xanthopterus*	80
Lethrinus nebulosus	200	*Naso brevirostris*	20
Lethrinus olivaceus	65	*Naso tuberosus*	110
Lethrinus obsoletus	2.5	*Naso unicornis*	25
Gymnocranius spp.	85	*Siganus argenteus*	25
Lethrinidae spp. *	140	*Siganus punctatus*	40
Cheilinus undulatus	25	TOTAL (all commercial species)	4290

Fisheries operating on reef systems or on atolls have very variable yields, from 2kg to 370 kg/ha/year. If an MSY of 1000 tons/year was applied to Ouvéa, it would correspond to yields of 12 kg /ha/year, which is in the lower range. At the moment the yields in Ouvéa are only of 0.8 kg/ha/year, thus showing that the fishing potential of this atoll is underexploited.

It is very important to note that this fishing potential of 1000 tons/year is not evenly distributed on the lagoon (Figure 28). The deeper parts of the lagoon and the reefs have the highest potentials and the fishing effort should be directed primarily to these zones. Conversely, the coastal zone of the main island, the most fished zone at the moment, has only a low fishing potentail and will not be able to withstand a large increase in fishing effort.

CONCLUSION

There are several paradoxes in the atoll of Ouvéa. On one hand, planktonic production is low but planktivorous fish are abundant. On the other hand, macrobenthos is poor (low abundance and biomass) but benthic carnivores are one of the major fish trophic groups. At last, the spatial distribution of species richness, the increase of diversity and fish biomass with depth, are opposite to the observations made for benthos and to the usual distribution found in atolls.

The atoll of Ouvéa has a special geomorphology, conversely to most atolls, it is not formed around a bassin, but displays a regular slope from east to west, in the axis of the tradewinds. This structure could be at the origin of the very thin sediment layer found in Ouvéa. It is possible to define 5 groups of sediments in this atoll. The benthic and fish communities have characteristics which are linked to this sediment structure.

There is an east-west and north-south gradient in the geomorphology of the reefs bordering the atoll. The samė gradients are found in the organisation of the benthic communities, but not for the fish communities.

The plankton production of the atoll is low. The production maxima are found in the shallow parts of the lagoon. It is there also that benthos is the richest. Conversely, fish have the opposite distribution, biomass, and very likely production, increasing with depth. It is possible that sampling problems are at the origin of these observations. Indeed, benthos was sampled on soft bottoms, the hard parts of the bottom (rock, beachrock,coral heads, boulders) were not taken into account. It is precisely on these hard parts that most of the lagoon bottoms fish communities are found. The available data do not allow to say whether fish choose these hard structures for shelter or because food is more abundant there than on soft bottoms. It has been hypothesised that, according to the distribution of ATP and of the photosynthetic pigments, the zones with the thinest sediment layer were among the most productive in the lagoon.

Fish communities are different on lagoon bottoms and on reefs. Species richness, density, biomass are larger on reefs where the spatial organisation of the communities is linked to habitat distribution and not to geomorphological zones. On lagoon bottoms, fish communities are linked to sedimentological zonations and to depth, the major element in the spatial distribution of fishes being the abundance of hard bottoms. The trophic structure of the fish communities are dominated by zooplanktivores and microherbivores. On lagoon bottoms, zooplanktivores are essentially species feeding high in the water columm, whereas on reefs they are made of species feeding near the bottom. The abundance of zooplanktivores may explain in part the high values of the fish biomass in this atoll, plankton being much better used than in Polynesian atolls where plankton production is much higher and fish biomass lower. Ouvéa fish communities have a high percentage of species with a short life span. This suggests that there could be important variations of communities on a short term basis (2 - 5 years).

Besides fish, no important marine resource was found during this survey. The total fish standing stock is high, approximatively 17 000 tons, of which 13 000 tons are on lagoon bottoms and 4 000 tons on reefs. It should be possible to exploit approximatively 1 000 tons /year, the present tonnage being around 70 tons/year. One should yet pay a very special attention to the spatial distribution of the fishing effort which should directed to the deepest parts of the lagoon, which are also the furthest from the villages. The species which have the highest fishing potential are *Aprion virescens, Lethrinus nebulosus, Epinephelus cyanopodus, E.maculatus* and *Diagramma pictum.*

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