

MARINE BIODIVERSITY IN FRENCH GUIANA: ESTUARINE, COASTAL, AND SHELF ECOSYSTEMS UNDER THE INFLUENCE OF AMAZONIAN WATERS

LA BIODIVERSIDAD MARINA EN GUYANA FRANCESA: LOS ECOSISTEMAS DE ESTUARIOS, LAS COSTAS Y PLATAFORMAS BAJO LA INFLUENCIA DE LAS AGUAS AMAZONICAS

Luis Felipe Artigas¹, Philippe Vendeville², Marc Leopold², Daniel Guiral³
& Jean-François Ternon³

¹L.A.B.E.L. (UMR 8013 ELICO) - Université du Littoral Côte d'Opale - M.R.E.N. - 32, av. Foch – 62 930 Wimereux – France. Email: artigas@mren2.univ-littoral.fr

²Institut Français de Recherche pour l'Exploitation de la MER – IFREMER Délégation Guyane – Domaine de Suzini – BP 477 – 97 331 Cayenne - French Guiana

³L.E.L. (UR R053 ELISA) – Institut de Recherche pour le Développement – IRD Centre de Cayenne – route de Montabo – BP 165 – 97 323 Cayenne Cedex – French Guiana

ABSTRACT

Marine biodiversity in French Guiana is strongly influenced by the Amazon River waters of the river Amazon, which constitute a major structuring factor for the estuarine, coastal, and shelf marine ecosystems. Moreover, the marked seasonal and interannual variabilities play important roles in the stability or fluctuations in the environmental parameters that influence biodiversity at the ecological, population, and genetic levels. Previous and ongoing studies of the marine and littoral biota relate mostly to commercial marine species, protected species in danger of extinction and, specially, to the biodiversity and functioning of local coastal and littoral ecosystems such as estuaries, mudflats, sandy beaches and, particularly, littoral mangroves. A more integrated approach involving local, regional, and international scientific collaboration is needed for a better assessment and understanding of marine biodiversity. Such studies would benefit from international cooperation that would allow the gathering of new information and the comparison of previous data, the organization of common oceanographic surveys, the homogenisation of analytical protocols, and also favour the exchange of scientists and postgraduate students for a real transfer of ideas, techniques, and know-how. Moreover, research on the comparative biodiversity of analogous littoral and marine ecosystems in different parts of South America would allow a more accurate estimate of marine biodiversity on a continental scale.

KEYWORDS: French Guiana, marine biodiversity, coastal systems, Amazon river waters, Intertropical Convergence Zone, ecological and conservation studies

RESUMEN

La biodiversidad marina en la Guyana Francesa está fuertemente influenciada por los aportes amazónicos, los cuales constituyen un factor estructurante de los ecosistemas estuarinos, costeros y de plataforma continental. Además, debido a las cambiantes condiciones meteorológicas y oceanográficas, la variabilidad estacional e inter-anual puede jugar un rol importante en la estabilidad o la modificación de los parámetros medio-ambientales que afectarían la biodiversidad ecológica, poblacional y genética de los ecosistemas locales. Los estudios llevados a cabo sobre la biología de las especies marinas y litorales se refieren principalmente a especies de interés comercial, especies protegidas en peligro de extinción, y sobre todo a las características del funcionamiento de ciertos ecosistemas costeros y litorales característicos como los estuarios, bancos de fango, playas de arena, y sobre todo los manglares. La idea de estudios o series de estudios mejor coordinados entre sí a nivel regional e internacional, emerge como una necesidad para una mejor estimación y comprensión de la biodiversidad marina. Estos estudios beneficiarían de una importante cooperación internacional que permitiese comparar e integrar el conjunto de datos obtenidos en el pasado, llevar a cabo misiones oceanográficas conjuntas, mutualizar y homogeneizar los protocolos analíticos, y favorecer el intercambio de técnicas y estrategias por intermedio de intercambios de científicos y estudiantes en formación de postgrado. Finalmente, estudios comparativos sobre la biodiversidad de sistemas costeros análogos sudamericanos permitirían de alcanzar una mejor estimación de la biodiversidad marina de este continente.

PALABRAS CLAVES: Guayana Francesa, biodiversidad marina, sistemas costeros, aportes de aguas Amazónicas, Zona Intertropical de Convergencia, estudios ecológicos y de conservación.

INTRODUCTION

Until recently, most of the marine research programs developed in French Guiana dealt with sedimentology and geomorphology (e.g. Moguedet 1977, Bouysse *et al.* 1977, Prost 1989, Pujos & Froidefond 1995) or fisheries (e.g. Bullis/Thompson 1959 ; Morice Warluzel 1968 , Abbes *et al.* 1972, Bonnet *et al.* 1975, Venaille, 1979, Dintheer *et al.* 1989a, Blanchard *et al.* 2000 ; Rivot *et al.* 2000). In 1997, however, the first integrated program (PNEC: National Program of Coastal Environment) supporting coastal oceanographic research in French Guiana (Fig. 1) was set up with the participation of several French research institutes and universities (Clavier 1996). This program focuses mainly on the characterization and quantification of the influence of the Amazon river on the continental shelf and littoral zone of French Guiana, in terms of coastal oceanography (physical and bioge-ochemical characteristics in relation to living resources), geomorphology (mudflat displacements along the coastline), and mangrove ecosystems (particularly those colonizing the stabilized mudflats). The ultimate objectives of the PNEC program are to establish a better monitoring system of economically exploited living resources (fishes and shrimps) as well as improve economical management and ecosystem preservation of the coast where about 90% of the population of French Guiana live.

At present, in addition to fisheries studies and fish and shrimp stock assessments carried out as parts of the IFREMER programs, ongoing marine research is concerned with 4 different spatial scales: 1) the continental shelf (the "CHICO" and "GREEN" oceanographic projects - PNEC), 2) the littoral the "ELISA" coastal (0-20 m depth) project of the IRD, the PNEC program, and the Cayenne Island "LITEAU" program 3) estuaries (e.g: the Kaw River estuary-PNEC and ELISA-IRD, programs), 4) islands (Grand Connétable Island Natural Reserve). Three complementary strategies are being employed: 1) observations and measurements on various spatial scales (continental shelf, mudflats, estuaries), 2) the development of a hydrodynamic numerical model for the continental shelf and coastal zone, and 3) the analysis of satellite data. The nutritional requirements of certain targeted

marine species have also been investigated as well as the biological colonisation of the mudflats. As well as this large scale institutional approach, local naturalist and ecological associations are involved with more specific studies (e.g. marine turtles). This paper reviews, firstly, our present knowledge of the structure of the marine, coastal, and littoral ecosystems, in order to assess local and regional marine biodiversity in French Guiana, and then discusses possible perspectives on short and medium term bases.

CLIMATIC AND OCEANOGRAPHIC CONDITIONS

French Guiana has a typical wet equatorial climate, driven mainly by the seasonal meridional migration of the Intertropical Convergence Zone (ITCZ). In its southern position, the ITCZ causes northeast trade winds in French Guiana from January to July while, for the rest of the year when it is in its northern situation, the country experiences southeast trade winds. There are 2 periods of high rainfall, May - June (the principal one) and January- February (secondary). The dry season lasts from July to December when stable south-eastern trade winds are dominant. The flow of the rivers of French Guiana is similar to that of the rainfall being maximum in May-June and minimum generally in November, when the flow rate of the Amazon River is considerably lower. The tide in French Guiana is semidiurnal, with an amplitude of up to 2.5 meters (spring tides, mesotidal regime). With its 320 km of coastline from the Oyapock estuary in the east to the Maroni estuary in the west, French Guiana is included in the Amazon-Guianas ecotone that extends from the Amazon River mouth to the Orinoco River mouth and is considered to be part of the "Guianas Coastal Province" (Longhurst 1998). The coastal waters of this province are highly turbid, specially north of the Amazon mouth, and extensive mudflats occur and migrate along the coast (Froidefond *et al.* 1988). Indeed, from January until July, the meso-scale coastal current (North Brazil Current, NBC) and its extension, the Guianas Current (GC), flow north-westwards, carrying the low-salinity and nutrient- and sediment-rich water coming from the Amazon along the sorelines of French Guiana, Suriname, Guyana and Venezuela (Fig. 2). During

the period of NBC retroflection, more saline and less turbid surface waters cover most of the continental shelf. These 2 well differentiated hydroclimatic situations, together with a marked spatial and temporal variability, represent major constraints for the coastal ecosystems and their biota. Moreover, constant upwelling, that is not accompanied by a pronounced

lowering of the sea surface temperature but provides additional nutrient enrichment, would be generated by the direction of the prevailing wind and the geostrophic slope of the isopycnals associated with the Guianas Current, which is enhanced by the outflowing Amazon water (Cadée 1975).

The "SABORD 0" cruise in May 1996 was the first

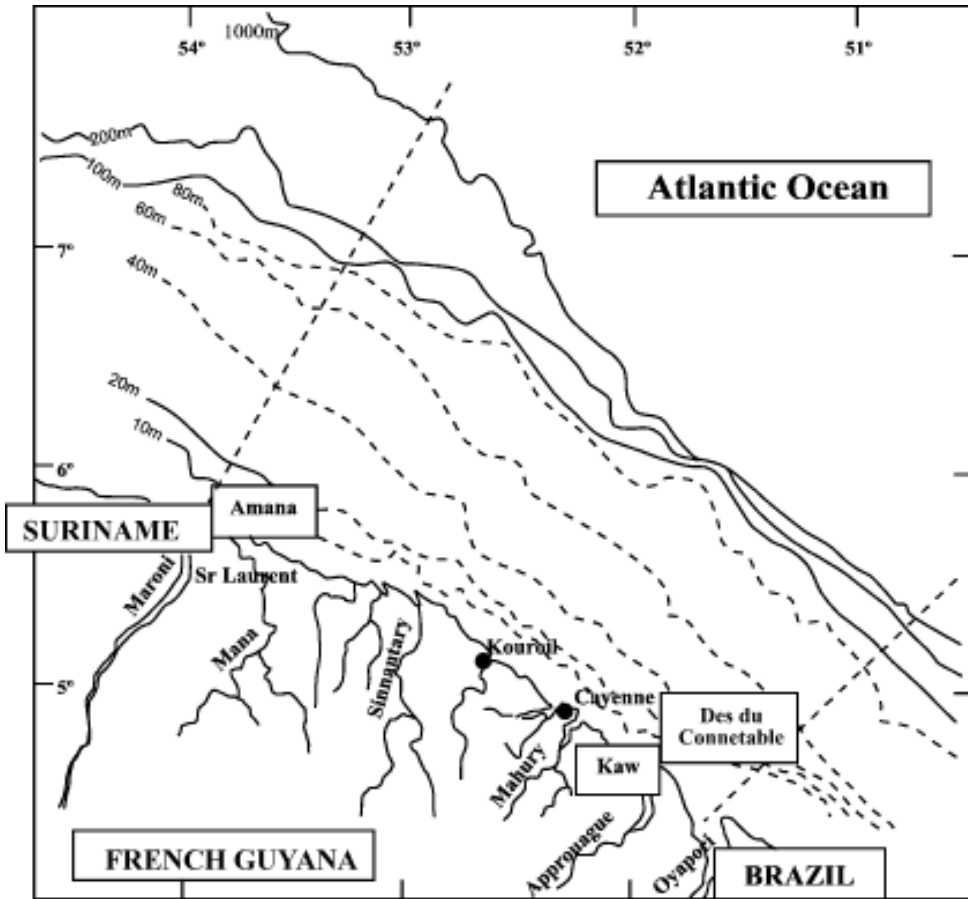


FIGURE 1. French Guiana Coastal and Shelf areas (from Frouin 1997). Protected areas are shown in rectangles.

FIGURA 1. Areas costeras y de plataformas en Guyana Francesa (Frouin 1997). Las áreas en rectángulos son protegidas.

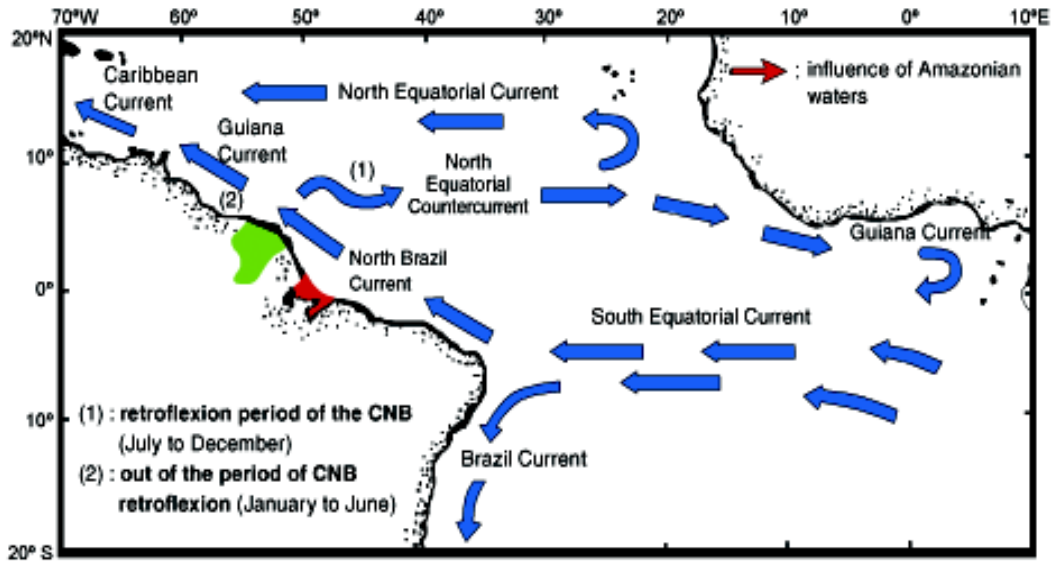


FIGURE 2. Surface circulation in the tropical Atlantic Ocean (from Johns *et al.* 1998, in Ternon *et al.* 2002).

FIGURA 2. La circulación superficial en el Océano Atlántico tropical (Johns *et al.* 1998, en Ternon *et al.* 2002).

devoted to the French Guiana continental shelf. A steep salinity gradient found at about 10 m depth showed the presence of a low salinity surface layer. Geochemical measurements made on the surface water showed that it was of Amazonian origin (low salinity / high silicate / low CO₂). The area acts as a sink for atmospheric CO₂, unlike the equatorial ocean which is generally considered to be a global source of CO₂ (Ternon *et al.* 2000). The “CHICO” project, which started in 1999 within the framework of the “PNEC” program, consists of physical and biogeochemical oceanographic cruises over the whole continental shelf during 3 periods with different characteristics: February (the start of the wet season; no NBC retroflexion; increase in the Amazon flow), May (the wet season; start of NBC retroflexion; maximum Amazon flux), and November (the dry season; NBC retroflexion; minimum Amazon flux). Physical, chemical and biogeochemical parameters are being determined from the coast (20 m depth) out to the shelf break (200 m depth), on an east to west transect across the continental shelf. At the same time, cruises for fish and invertebrate species biology (“GREEN”) are conducted over the same area. A numerical model of the dynamics over the

shelf is currently being developed (C. Chevalier, IRD-Marseille) and will eventually be linked to a biological model (M. Baklouti, IRD-Marseille). The preliminary “CHICO 0” cruise confirmed (Ternon *et al.* 2001, 2002) that the hydrodynamics of the French Guiana continental shelf present remarkable features caused by the presence of a large area of low salinity water at the surface (8 to 10 m depth), mainly from the Amazon, over most of the shelf (out to 120 km from the coast). Four water classes were identified using radiometric measurements at wavelengths corresponding to those of the SeaWiFS sensors and could thus represent water masses of well differentiated biogeochemical characteristics (Froidefond *et al.* 2002).

THE HISTORY OF BIOLOGICAL OCEANOGRAPHY IN FRENCH GUIANA

Knowledge about the marine resources of French Guiana followed the development of fishing activities over the continental shelf and slope (Frouin 1997, Bernadac *et al.* 1999). The first studies occurred after the second world war, at

the end of the 1940s, with the compilation of an inventory of marine fish species from artisanal coastal fishery landings (Puyo 1949). During the 1950s, when the American shrimp fisheries in the Gulf of Mexico extended to Central America and then to north South America, trawling surveys with R.V. Oregon covered both the northern Brazil and Guianas areas and were concerned mainly with shrimp species, but included the associated fish species. Between 1954 and 1958, ORSTOM (IRD) scientists studied the benthic and demersal continental shelf fauna between 15 and 100 m depths (Durand 1955, 1959). Later, during the 1960s and 1970s, ships from the USA, Japan, Korea, Venezuela, and Cuba operated off the Guianas and northern Brazil for shrimp and red snapper fisheries (Venaille 1979) and this led to an improvement in the knowledge of the demersal and benthic fauna. The local ISTPM laboratory, founded in 1971 (IFREMER), carried out trawling surveys between 20 and 1000 m depths with the R.V. Thalassa (Abbes *et al.* 1972), the R.V. Phaeton (1975) and the Deana T (1976-1978). It also participated in scientific cruises organised by other countries (Dragovich *et al.* 1978), Kaiyo Maru in 1973 (Japan) and Oregon II from 1972-1976 (NMFS-USA), and, in 1975, carried out its own trawling in the littoral area between 5 and 15 m depths, focusing on seabob, a coastal penaeid shrimp (Bonnet *et al.* 1975). The first primary productivity measurements (CICAR Dutch cruises) in both the Suriname and French Guiana shelf zones were also made during this period (Cadée 1975).

Surveys during a Japan Marine Fishery Resource Research Center (JAMARC) program conducted off Suriname and French Guiana from 1979 to 1983 resulted in the identification of 452 species of bottom fish, 146 species of crustaceans, and 143 species of molluscs trawled in the area from 10 to 1000 m depth (Aizawa *et al.* 1983, Takeda and Okutani 1983). This survey program also included an analysis of the shrimp species caught incidentally and a resource assessment (Vendeville 1984).

The IFREMER PENJU (1987-88) and ORSTOM JUVECREV (1989-90) trawling surveys both focused on the spatio-temporal distributions of shrimps (Dintheer & Rosé 1989, Vendeville & Lhomme 1997). In the same periods, IFREMER

conducted surveys of red snapper populations (Perodou 1994, Rivot 2000; Rivot *et al.* 2000). Similar surveys (IFREMER RESUBGUY) in 1993-94 updated incidental shrimp catch assessment in the 15 to 60 m depth area in terms of communities and assemblages as well as providing further spatial distribution information (Guéguen 1993a, b, Nérini 1994, Rosé 1994, Rosé & Achoun 1994, Moguedet *et al.* 1995).

In 1994, another trawling survey (the EPAULARD cruise) was carried out in the littoral area from the coast out to 15 m depth and focused on shrimp and juvenile fish population distribution (Vendeville 1995) and, in 1999, a preliminary survey (GREEN 0 cruise, PNEC project) was made.

Research in the infralittoral area began in 1971 with the study of a coastal marsh in the western part of French Guiana and the biology of the young stages of the shrimp *Penaeus subtilis*; this was in relation to the ORSTOM (IRD) project for the development of shrimp aquaculture in the country (Rossignol 1970, 1972a, b, c). After the introduction of rice cultivation in the area in 1984, a short study was conducted by ORSTOM and IFREMER to evaluate its impact on marine resources (Lointier & Prost 1986, Dintheer *et al.* 1985). Between 1988 and mid 1994, numerous data and observations on the young stages of shrimps (postlarvae and juveniles of *Penaeus subtilis*, *Xiphopenaeus kroyeri* and *Macrobrachyum* sp.), in relation to the variability of shrimp recruitment in the fishery, were collected in several estuaries (Vendeville & Lhomme 1997).

FISHERIES IN FRENCH GUIANA

The continental shelf shrimp fishery in French Guiana started to develop with the arrival of US trawlers at the end of the 1950s and Japanese fishing boats a few years later. The fishing fleet was largest in 1983 and then declined steeply until 1991. Nowadays, the shrimp fleet is exclusively French and has 63 trawlers. With the departure of the foreign fishing companies, shrimp production was directed to the European market where smaller shrimps were commercially acceptable, and the fishing activity tended to move into shallower areas (Moguedet *et al.* 1995, Béné 1996, Charuau *et al.* 2000). The two main species being exploited are *Penaeus subtilis* (the brown shrimp) and *Penaeus brasiliensis* (the pink spotted

shrimp), but *Penaeus schmitti* (the white shrimp) and *Penaeus notialis* (the pink shrimp) are also encountered in mixed catches from the area. The coastal shrimp *Xyphopenaeus kroyeri* (the sea-bob) is sometimes kept as a bycatch product for the local market. The maximum shrimp landings occur between February and June. Since 1999, however, the fishery has markedly declined, production falling by 30% from 1998 to 2000 (IEDOM 2001). The same decrease has been observed in the neighbouring countries and is, in part, linked to unfavourable hydroclimatic conditions affecting recruitment (Charuau in FAO/WECAFC 2001a, 2001b, 2002, Dintheer Kalaydjian 2002).

The continental slope shrimp fishery started in 1988. It is seasonal and very small (2 to 4 boats) and concerns 2 species: *Plesiopenaeus edwardsianus* (the scarlet prawn) and *Solenocera acuminata* (the orange shrimp) (Guegen 1991 a, b). Landings have been decreasing since 1988.

The second significant continental shelf fishery is that of the red snapper (*Lutjanus purpureus*). Other species (*Rhomboplites aurorubens* and *Lutjanus synagris*) are also found but less commercially exploited. This fishery is mainly practiced by Venezuelan long line trawlers.

About 30 species are commonly exploited by the small scale coastal fishery. The principal types are weakfishes (*Cynoscion acoupa*, *C. virescens*, *Plagioscion squamosissimus*), sharks (*Syphyrna* spp., *Carcharinus* spp.), sea catfishes (*Arius proops* and *A. parkeri*), Tripletail (*Lobotes surinamensis*), snooks (*Centropomus* spp.), Tarpon (*Megalops atlanticus*), mullets (*Mugil* spp.), Crevalle Jack (*Caranx hippos*), stingrays (*Dasyatis guttata*), and Giant grouper (*Epinephelus itajara*).

MARINE MACROFAUNAL POPULATIONS

DEMERSAL AND BENTHIC CONTINENTAL SLOPE ORGANISMS

Of the 40 Decapod (Crustacea) species observed during 4 surveys conducted over the continental slope between 200 and 900 m depth from August 1990 to July 1991, 2 deep-water shrimps have been the target of the industrial fishery since 1988: the orange shrimp *Solenocera acuminata* (Solenoceridae) and the scarlet prawn *Plesiopenaeus edwardsianus* (Aristeidae). The shrimp *A. antillensis* was also widely distributed in the muddy

sediments of the deep slope from 456 to 818 m depth (Guéguen 1991 a, b, 2001). In earlier trawling surveys (JAMARC; 1979-83) on the Suriname and French Guiana continental slopes, 68 species of Decapod and 63 of Molluscs were identified (Takeda & Okutani 1983).

DEMERSAL AND BENTHIC CONTINENTAL SHELF ORGANISMS

Four studies based on trawling surveys on the continental shelf concerned the demersal and sometimes the benthic macrofauna:

- In the first detailed study of demersal and benthic continental shelf macrofauna, Durand (1959) identified 21 Echinoderm species, 38 Crustaceans, 34 Molluscs, and 133 Osteichthyan species. From the analysis of the 400 stations sampled, the author concluded that there was a strong link between the fauna, the depth, and the substratum quality.

- An analysis of the 4 Japanese surveys conducted on the continental shelf of French Guiana, based on 144 sampling stations and using 143 taxonomic references, pointed out the predominant role of the depth and, secondarily, the nature of the sediment cover, in determining the composition of the demersal assemblages (Vendeville 1984).

- The results of the 1993-94 RESUBGUY surveys confirmed the roles of depth and substratum in determining the fish and invertebrate biodiversity between 20 and 60 m depths (Nérini, 1994; Moguedet *et al.* 1995; Guéguen 2000). The results revealed 3 distinct faunal assemblages: 1) a littoral (or shallow-water) community present from 0 to 30 m depth in coastal brackish waters of salinities < 25‰ characterized by muddy bottoms; 2) a middle-shelf community distributed from 30 to 50 m depth in turbid marine waters characterized by muddy bottoms; and 3) a lower-shelf community in deeper marine waters of low turbidity (depths > 50 m) characterized by sandy bottoms with occasional rocks. In an attempt to simplify this distribution pattern, Moguedet *et al.* (1995) proposed to distinguish between only 2 major types of demersal communities, coastal and deep-sea (Table I). Most of the 110 different macrobenthic species observed in that study had already been encountered in the 1980-81 Japa-nese

surveys, including 8 Decapod Crustaceans (5 Penaeidae, one Palinuridae, one Portunidae and one Calappidae), 2 Cephalopods (one Loliginidae and one Octopodidae), one sea turtle (Cheloniidae), and 99 demersal fish, mainly 9 Sciaenidae, 5 Ariidae, 5 Serranidae, 4 Lutjanidae, 6 Carangidae, and 9 Pomadasyidae. Despite the high species richness of the benthic and demersal macrofauna, most species showed a low count, and only 12 of them

comprised more than 80 % of the total captures obtained from 0 to 60 m depth: *Dasyatis americana*, *Orthopristis ruber*, *Macrodon ancylodon*, *Stellifer rastrifer*, *Upeneus parvus*, *Arius grandicassis*, *Arius rugispinis*, *Lutjanus synagris*, *Chloroscombrus chrysurus*, *Cynoscion simileis*, *Gymnura micrura* and *Xiphopenaeus kroyeri*. The most recent study carried out on the macrofauna was the preliminary survey cruise,

TABLE I. Summary of the specific composition of the principal demersal communities on the French Guiana continental shelf (from Mogue det *et al.* 1995 and Frouin 1997).

TABLA I. Resumen de la composici n espec fica de las comunidades demersales principales en la plataforma continental de Guyana francesa (de Mogue det *et al.* 1995 y Frouin 1997).

Demersal communities	Families	Species	
Coastal 0 – 30 m depth	Sciaenidae	<i>Cynoscion virescens</i> , <i>Nebris microps</i> , <i>Macrodon ancylodon</i> , <i>Stellifer rastrifer</i>	
	Ariidae	<i>Bagre bagre</i> , <i>Arius parkeri</i> , <i>Arius rugipinis</i>	
	Batrachoididae	<i>Batracoides surinamensis</i>	
	Clupeidae		
	Dasyatidae	<i>Dasyatis americana</i>	
	Penaeidae	<i>Xyphopenaeus kroyeri</i> , <i>Penaeus subtilis</i>	
	Gimnuridae	<i>Gimmura micrura</i>	
	Sciaenidae		
	25 – 30 m depth	Penaeidae	<i>Penaeus subtilis</i>
		Pomadasyidae	<i>Genyatremus luteus</i> , <i>Pomadasys corvinaeformis</i>
Engraulidae		<i>Anchoa spinifer</i> , <i>Anchoviella lepidentostole</i>	
Deep sea 30 – 60 m depth	Lutjanidae	<i>Lutjanus purpureus</i> , <i>Lutjanus synagris</i>	
	Gerreidae	<i>Eucinostomus argenteus</i>	
	Carangidae	<i>Chloroscombus chrysurus</i> , <i>Selene vomer</i>	
	Pomadasyidae	<i>Orthopristis ruber</i>	
	Bothidae	<i>Syacium papillosum</i>	
	Mullidae	<i>Upeneus parvus</i>	

GREEN 0, realised in April 1999. The role of bathymetry as the principal structuring factor of the benthic and demersal ecosystem, already identified in previous studies as mentioned above, was confirmed and defined by the observations made during the GREEN 0 cruise (Le Loeuff & Von Cosel 2000; Vendeville *et al.* 2000, 2002), which took place in the middle of the wet season and the period of maximum discharge of both the local estuaries and the Amazon River. The importance of the nature of the substrate was pointed out and the nyctemeral rhythm was also defined as a structuring factor. The salinity gradient probably does not have a direct influence on the spatial distribution of the benthic and demersal populations because the low salinity is localised in the upper layer.

During the CHICO 0 cruise, an inorganic nutrient layer was observed near the sea bottom, where shrimps were abundant. This may in part be explained by the remineralisation by heterotrophic bacteria of the organic matter arriving on the bottom as waste from shrimp fishing. As many as 107 benthic species (Cnidaria, Polychaeta, Crustacea, Mollusca, and Echinodermata) were then identified, as well as 139 demersal species belonging to 3 zoological groups (Cephalopods, Chondrichthyans, and Osteichthyans). An analysis of the specific richness and abundance of these communities showed that only a few species in shallow sea-beds are characterized by high abundances, whereas numerous species identified in the deep sea-bottoms are characterized by weak abundances. Four types of communities were distinguished, 3 of them being associated with the principal regional Penaeid shrimps: 1) Deep communities of the “clear waters” at 55 to 85 m depths, in mid and coarse-grain sands and coral reefs: shrimps (*Penaeus brasiliensis*), soles (*Gymnachirus nudus*), coral reef fishes, red snappers (*Lutjanus purpureus*), and grunts (*Orthopristis ruber*); 2) Mid-depth (55 – 65 m) communities, in fine-grain sands and rocks: lane snappers (*Lutjanus synagris*), grunts (*Orthopristis ruber*) and searobins (*Prionotus punctatus*); 3) Mid-shelf (45 – 55 m) communities, in muddy sands of fine and very fine grains: shrimps (*Penaeus subtilis*), some Sciaenidae (*Microgogonias furnieri*, *Stellifer rastrifer*, *Cynoscion similis*); 4) Littoral communities of “turbid waters” at 15 to 35 m depths, of mud and muddy sands: “seabob shrimp” (*Xiphopenaeus kroyeri*), Ariidae

(*Arius grandicassis*, *Bagre bagre*), with increasing numbers of Sciaenidae (*Cynoscion virescens*, *Macrodon ancylodon*, *Paralonchurus elegans*, *P. brasiliensis*), and Dasyatidae (*Dasyatis americana*). While the nature of the sediment layer is the principal structuring factor of the benthic and demersal communities of the French Guiana continental shelf, in shallow regions, the brackish coastal water has a great influence on the littoral communities. In the latter ecosystem, nyctemeral rhythms would be the third structuring factor. Therefore, the principal causes of the temporal variability of fishery resources have to be defined in terms of the strict spacial limits of this ecosystem. Definitely, 3 adjacent ecosystems seem to interact in controlling nutrient inputs and the biological cycle, and determining the productivity of the system: the continental shelf, the littoral zone, and the local rivers.

DEMERSAL AND BENTHIC LITTORAL ORGANISMS

During the 1994 littoral trawling survey, “Epaulard”, carried out between the coast and 15 m depth, 52 species were observed in the catches at the 81 stations sampled: 8 Crustaceans, including 5 shrimps, two Penaeidae (*Penaeus subtilis* and *Xiphopenaeus kroyeri*), one Palaemonidae (*Nematopalaemon schmitti*); sometimes very abundant), one Hippolytidae (*Exhippolysmata oplophoroides*) and one Sergestidae (*Acetes* sp.), two crabs, and one stomatopod.

Molluscs were represented by only one gastropod, *Bursa bufo*.

Three species represented Batoid fish, two species of Dasyatidae and one of the Gymnuridae. Among the 40 bone fish species encountered, the main families were Ariidae (7 species), Sciaenidae (9 species), and Carangidae (5 species). Most of the catches concerned young individuals. AFC and CAH analysis showed that bottom quality and hydrology (temperature and salinity) were structuring factors of these communities and, in particular, the role of Guianese river plumes in the distribution of these species (Vendeville 1995; Vendeville & Lhomme 1997). Most of the knowledge on coastal fish diversity comes from a study on small scale fishery landings (Blanchard *et al.* 2000).

FISH AND INVERTEBRATES IN THE INFRA-LITTORAL AREA
(COASTAL MARSHES AND ESTUARIES)

In 1971-72, preliminary investigations were conducted in a western coastal marsh near Mana in order to introduce brown shrimp (*Penaeus subtilis*) aquaculture. Biological data were collected on the juveniles and postlarvae of the brown shrimp and aquatic fauna (Rossignol 1972c). A later study by IFREMER in 1985 concerned mostly the brown shrimp (Dintheer 1986). A brief study in 1994 discovered that the marsh had evolved and that its function as a shrimp nursery had been greatly reduced (Le Cour Grandmaison 1995). The presence of predators of the brown shrimp (Mugilidae, *Tarpon atlanticus*, and *Centropomus undecimalis*) and of some juvenile fish (*Achirus achirus*, *Batrachoides surinamensis*, and *Hemigrammus ocellifer*) was noted.

A study of the life-cycle, recruitment, and young stages of the brown shrimp was carried out from 1988 to 1994. Bi-monthly samples were collected in several estuaries in order to assess the seasonal and interannual variations in its postlarval and juvenile abundances. The postlarvae entered the estuaries on the flood tide and left on the ebb tide. The recruitment of postlarvae occurred all the year round on the French Guyana coast with between 2 and 4 intensive periods, and it was concentrated more in the western area. Data on other shrimp and prawn species were also collected (*Xiphopenaeus kroyeri*, *Nematopalaemon schmitti*, *Acetes* sp., and *Macrobrachium* sp.).

The Kaw estuary was also sampled, between August 2000 and July 2001, for brown shrimp together with its associated fish community (Vendeville 2002). The sampling showed 3 seasonal peaks of brown shrimp postlarval abundance: in September, a weaker one in December with the third, also weaker, in February-March. These periods of abundance coincided with those which had been observed in other estuaries (Vendeville & Lhomme 1997). The transport of the postlarvae during a tidal cycle, as characterized in other estuaries, was also observed in the Kaw River estuary and extended to juvenile fish coming from the coastal zone.

A REVIEW OF MARINE ICHTHYOLOGICAL DIVERSITY IN
FRENCH GUIANA

Marine fish species are not systematically studied in French Guiana and it is difficult to quantify fluctuations in the populations. IFREMER (Cayenne) focused its studies mainly on the exploited fish (targeted species and incidental catches). Species associated with rocky substrates remain badly identified, as are pelagic species and the small benthic species of the littoral. In particular, some uncertainties persist with regard to certain families such as the Scianidae (*Plagioscion* genera), Mugilidae, Serranidae, Engraulidae, Clupeidae, and Gobiidae.

The data available on the ichthyological fauna comes from various sources, not all published, and are enriched by information gathered during scientific surveys conducted by French and foreign institutions throughout the 20th century (see earlier paragraph on the history of biological oceanography in French Guiana). Fourmanoir (1971) provided the first record of Carcharhinidae species in French Guiana waters. The atlases of the freshwater fish of French Guiana published by the MNHN (Paris) (Keith *et al.* 2000; Le Bail *et al.* 2000, Planquette *et al.* 1996), and some INRA publications (Le Bail *et al.* 1984a, b, Rojas-Beltran 1984, Boujard & Rojas-Beltrán 1988) allow an approximate estimation of the number of brackish water fish species found in the littoral to be made. Information is at present being compiled by M. Léopold (IFREMER) on fishes of the Guiana continental shelf. This list could be updated and supplemented in the next few years if the project of the Ichthyological Inventory of French Guiana led by the MNHN (Paris) materializes, and also if the planned GREEN cruises (PNEC program) take place.

A 2 nautical mile margin around the Connétable Islands (4°51'N, 51°26'W) to protect the bird population constitutes the only real marine reserve of French Guiana. These small islands are colonized by a large community of sea birds (frigates, terns, noddies, and gulls) that feed on certain fish species. No study has yet been made of its marine fauna but a survey could take place soon of the numbers of the giant grouper, *Epinephelus itajara*, there.

PLANKTONIC BIODIVERSITY IN COASTAL WATERS

THE ECOLOGY OF THE MICROPLANKTON IN COASTAL AND ESTUARINE WATERS

The coastal waters of French Guiana are subject to large inputs of dissolved and particulate matter from the Amazon River, from the local hydrological system, and also from the extensive mudflats by resuspension processes (Froidefond *et al.* 1988). Of these, the Kaw River carries most of the drainage from the Kaw swamp. Near the littoral mudflats, the high levels of suspended particulate matter limit light penetration, modify the N/P mineral balance due to the adsorption of phosphate (Guiral & Plenecassagne 2002) and reduce phytoplankton growth (DeMaster *et al.* 1991). A zone of high chlorophyll and primary production has been observed outside the turbid coastal waters on the continental shelf (Cadée 1975, Ternon *et al.* 2001, 2002). Artigas & Guiral (2001, 2002) carried out a comparative study of the phytoplankton and bacterial biomasses present during 2 extreme seasonal conditions. At the end of the wet season (July 2000), the high levels of degraded pigments in the riverine and transitional zones suggested the presence of large amounts of allochthonous matter from the flooded lands and the Kaw swamp, and forest marshes and wetlands. This would have been in an advanced state of degradation and thus stimulated bacterial production leading to large numbers of these microorganisms associated with the very low chlorophyll *a* concentrations. Transport from the mudflats and young mangroves seems to contribute to the high pigment concentrations measured, in July 2000, in the mudflat littoral waters. The resuspension of benthic diatoms and/or their grazing by benthic organisms might explain the prevalence of large forms and degraded pigments. In November, mean total estuarine chlorophyll concentrations were up to 10 times higher than in July, and were correlated, along the estuarine gradient, with bacterial abundances. The highest photosynthetic rates in coastal waters were observed in November, probably due to the combination of senescence and the grazing of a large phytoplankton bloom enhancing and diversifying the pathways of organic matter transfer between photoautotrophs and heterotrophic bacteria. New studies of phytoplankton species cycles and their

productivity and competition with heterotrophic bacteria for nutrients are in progress.

THE BIODIVERSITY OF THE PHYTOPLANKTON IN THE MARINE AND BRACKISH WATERS OF FRENCH GUIANA

Only a few surveys of the phytoplankton species have been made. The first data for the area came from the adjacent zones (Teixeira & Tundisi 1967; Margalef & González-Bernáldez 1969) and, only later, from 1976 to 1979, were the microplankton of local marine and brackish waters studied (Paulmier 1993).

Skeletonema tropicum was prevalent in the estuarine zone with *Chaetoceros subtilis* var. *abnormis*, *Dytilum sol*, *Thalassionema nitzschioides*, *Coscinodiscus jonesianus*, *C. aculeatus*, *C. oculus-iridis*, *C. curvatulus*, and *Odontella mobiliensis* also present. Resuspended benthic diatoms (pennate forms) and thycopelagic (centric and pennate) forms together with sessile or pedonculata types were characteristic of the estuarine waters. The most representative taxa were the Naviculaceae and Nitzschiae-*Navicula* sp., *Entomoneis alata* var. *pulchra*, *Nitzschia* sp., *Nitzschia longissima*, *N. sigma* var. *intercedens*, *N. circumscuta*, *Bacillaria paradoxa*. Some Cyanobacteria (*Lyngbya* and *Oscillatoria*) were also occasionally present in samples. The Dinophyceae were rare except for *Scrippsiella* sp.

The coastal zone includes the archipelagos (Connétable Is., Rémire Is., Salut Is.). Although the hydrographical parameters have wide ranges (salinity varying from 12 to 35‰ for instance), this zone is more stable and highly productive, especially the surface waters. Pelagic diatoms are predominant in the phytoplankton, though the Dinophyceae are also important during certain seasonal periods. *Skeletonema tropicum* is responsible for major blooms in May that are often coupled with lower numbers of *Ceratium fusus* (Dinoflagellate). *Coscinodiscus asteromphalus*, *Thalassionema nitzschioides*, *Odontella mobiliensis*, *Chaetoceros subtilis* var. *abnormis*, and *Cerataulina dentata* (Diatomophyceae) are also present in this area, as are *Noctiluca scintillans*, *Ceratium lineatum*, and *Protoperidinium oblongum* (Dinophyceae). *Dytilum sol* is dominant in August, associated with *Nitzschia pungens*, *Chaetoceros appendiculata*, and *Ceratium lineatum*. In October, *Coscinodiscus jonesianus* is

the dominant species, associated with *Coscinodiscus karstenii*, *Chaetoceros appendiculata*, *Thalassio-nema nitzschioides*, *Diplopeta bomba*, and *Ceratium lineatum*.

The shelf province (>50 m depth) is dominated by a single diatom, *Thalassionema nitzschioides* and a cyanobacterium, *Oscillatoria (Trichodesmium) cf. thiebautii*; the other secondary species belong to different pelagic genera: *Proboscia (Rhizosolenia) alata*, *Pseudosolenia (Rhizosolenia) calcaravis*, *Hemialus sinensis*, and *Climacodium fraufeldianum*. Dinoflagellates are also characteristic of this system, especially *Ceratium tripos* var. *atlantica*, *C. massiliense*, *C. trichoceros*, *C. vultur*, *C. contortum*, etc. Paulmier (1993) indicates that the dominant species in the coastal area from December to July are the “*Skeletonema-Thalassio-nema-Coscinodiscus-Ceratium* society” which corresponds to Group II of Margalef & González-Bernáldez (1969) who characterized a similar phytoplanktonic coastal community in Venezuelan waters. This is temporarily followed by a “*Coscinodiscus* association”.

The oceanic area is dominated by the species *Nitzschia pungens* and the genus *Rhizosolenia*. This association corresponds to Group II as defined by Dandonneau (1971) for the Ivory Coast waters, confirming the ubiquity of the tropical Atlantic species. Even if the phytoplankton is dominated by Diatomophyceae (Chromophytes) and by Dinoflagellates (Pyrrhophytes), other taxa such as Euglenophytes (*Euglena* spp.), and Chlorophytes (*Spirogyra* spp., *Closterium* spp.) are often present in brackish estuarine and littoral waters. The Chrysophyceae is particularly important with *Phaeocystis* (Order: Prymnesiales) represented by 2 species, *P. pouchetii* and a larger form which is very abundant under certain hydrochemical conditions. The Cyanobacterie of the Schizobacteria group also periodically constitute a significant biomass in pre-oceanic neritic waters and in the littoral area.

Maia de Oliveira (2000) studied the phytoplankton in 2 estuarine systems (the Sinnamary and Iracoubo Rivers). The effect of tidal changes on the phytoplankton diversity of the Kaw River estuary, were reported by Vaquer (2000). At neap tides, the dominant genera were large *Coscinodiscus*, *Thalassionema*, and *Odontella*, whereas at spring tides, the community was domi-

nated by *Skeletonema* associated with *Odontella*. These species were also detected in the sub-surface layer of shelf waters, associated with the genera *Denotula*, *Hemialus*, *Chaetoceros*, *Rhizosolenia* (Diatoms), and *Ceratium furca* and *C. fusus* (Dinophyceae). Very low cell abundances characterized the wet period. The majority of the fresh water genera were represented by different Desmidiidae (*Closterium*, *Pleurotaenium*, *Micrasterias torreyi*, *M. furcata*, *M. abrupta*, and *M. laticeps*, *Staurodesmus*, *Staurastrum*, *Xanthidium*, *Desmidium*, *Cosmarium*, *Sphaerosozma*, *Spondylosium*), Chlorophyceae (*Eudorina*, *Ankistrodesmus falcatus*, *Botryococcus braunii*), Euglenophyceae (*Lepocinclis*, *Traochelomonas hispida*, *Euglena*, *Phacus*), and Dinophyceae (*Ceratium*, *Peridinium*).

ZOOPLANKTON IN THE ESTUARINE AND COASTAL WATERS OF FRENCH GUIANA

Protozoans make up an important part of the pelagic biomass and are normally flagellates, dinoflagellates and diatom consumers, such as the Sarcomastigophora, classes of the Rhizopoda and Actinopoda represented by the genera *Granuloreticulosia* (Foraminidae), Radiolarians and Acantharians, and also the Ciliophora comprising the Spirotriches (Tintinnidae). The genera *Tintinnopsis*, *Favella*, and *Coxiella* are common in estuarine and littoral waters, whereas *Rhabdonella*, *Epiplocytilis* and *Eutintinnus* are more oceanic (Paulmier 1993). In the estuarine zone, zooplankton population's maxima are in May, July, and December and, very often, consist of holoplanktonic larvae, such as copepod nauplii and adults of the genera *Oithona*, *Cyclops*, and *Paracalanus* (*P. cf. crassicornis*). The Cladocera e.g. *Bosminia* probably originate from freshwater. The Rotifers and especially the Tintinnidae, *Tintinnopsis karajacensis*, *Tintinnopsis* sp., *Codonaria fimbriata*, and *Favella panamensis* are the other major representatives of the zooplankton. The composition of the zooplankton is mostly homogeneous from the coastline out to 50-60 m depth. *Oithona* sp., *Acartia tonsa*, the nauplii of various copepods and *Tintinnopsis* sp., are the most frequent species of this area. The zooplankton is very much more diversified in the oceanic area and includes pelagic

molluscs. Two size-classes were considered by Lam Hoai & Rougier (2000, 2002) in their study of the zooplankton: microzooplankton (40-150 µm) and mesozooplankton (>150 µm).

The mudflat station is different from the 2 other stations of the Kaw River estuary, in the channel of the river itself and in the Paul Emile creek which drains a mature mangrove. During the wet season and high flow period, the Kaw River estuary becomes an extension of the riverine ecosystem. The drainage waters from the Kaw swamp are characterized by very low abundances and biomasses of zooplankton with a strong predominance of Rotifers, in terms of abundance. Sixty-one taxa corresponding to 27 taxonomic groups have been identified. *Tintinnopsis* is the principal genus present in microplankton assemblages. The dominant species of Copepods were *Paracalanus crassirostris*, *Oithona ovalis*, and *Acartia giesbrechti* whereas the dominant Tintinnids were *Codonellopsis* and *Favella* in neap-tides and *Tintinnopsis* in spring-tides. The pelagic copepods, *Paracalanus crassirostris*, *Acartia giesbrechti*, and *Oithona ovalis*, provided 63% of the total biomass in neap-tides as opposed to only 31 % in spring-tides. Rotifer populations were represented in neap-tides by *Synchaeta* and *Trichocerca* but were practically absent in spring-tides. On the other hand, the Chaetognatha *Sagitta frederici* constituted a major part of the biomass in spring tides. The detection of rare taxa such as *Pseudodiaptomus marshi*, Ostracods, *Oikopleura*, Cletodidae, Diosaccidae, Canthocamptidae, the hydromedusa *Obelia*, the Copepod *Eucalanus*, Decapod larvae, Polychaeta larvae, Anthomedusa, Isopod larvae and Nematods varied greatly between flow and ebb tides and day and night periods. This hydrological context for the wet season is radically different from that of the dry season and the reduced flow of the river when the estuary is regularly subjected to tidal intrusions of saline water. This period is characterized by relatively significant estuarine biomasses of zooplankton whereas populations and biomasses upriver are considerably smaller. This seasonal enrichment of the estuarine zone is thus related directly to the penetration of the littoral waters which fertilize and increase the local productivity and also transport the zooplankton communities present in both the littoral and coastal waters.

LITTORAL BENTHIC COMMUNITIES AND POPULATIONS OF FRENCH GUIANA

LITTORAL MANGROVE ECOSYSTEMS: THEIR STRUCTURE AND ECOLOGICAL FUNCTION

When the massive migrating mud waves, which stretch 1,100 km along the northeast coast of South America, from the mouth of the Amazon River to that of the Orinoco River, settle out, they produce the mudflats that are progressively colonized by mangroves which extend along almost all of the 320 km coastline of French Guiana (Fig. 3; Prost 1989), occupying a band from a few meters to about 15 km wide (Vignard 2001). The mudflats are rapidly covered by mats of microalgae that find the light conditions optimal for their growth. These microalgae, dominated by colony forming diatoms, have the ability to migrate into the sediments, according to the tidal and daily irradiation cycles. Progressively, a benthic community of Nematods, Tanaidacea, and Foraminifera becomes established within the mudflat (Vignard 2001, Guiral 2002). A number of species use the tidal cycles to benefit from these resources: limicole birds and crabs at low-tide, and numerous fish and postlarval and juvenile shrimp at high water. Despite high levels of species biodiversity in the ecosystem as a whole, the number of plant species is relatively few in the coastal mangroves, only 4 indigenous genera being represented-*Avicennia*, *Rhizophora*, *Laguncularia* and *Conocarpus* (Dodd et al. 1998). Five species of mangrove trees have been identified: the red type (*Rhizophora mangle* and *R. racemosa*, Rhizophoraceae), the grey-black type (*Laguncularia racemosa*, Combretaceae), and the white type (*Avicennia germinans*, Verbenaceae). A very rare species, *Conocarpus erecta* (Combretaceae), is located at only one site in French Guiana. These may be separated into coastal and estuarine mangroves (de Granville 1986). The white type predominates in coastal mangroves, but recently deposited mudflats are colonized firstly by the grey-black type and only later by *A. germinans*. The genus *Rhizophora* dominates upstream from the estuaries. In parallel with the changes in hydrography, a sequence can be recognised in the shoreline-mainland direction: young trees growing on the even, fluid muds in the intertidal zone, then mature forests of large trees (medium density and low mortal-

ity). On the older alluvia are the senescent stages of the trees (high mortality). The aim of the ongoing mangrove study (PNEC program, Fromard *et*

al. 2003) is to analyse the process of mangrove colonization and to identify its role within the coastal food webs.

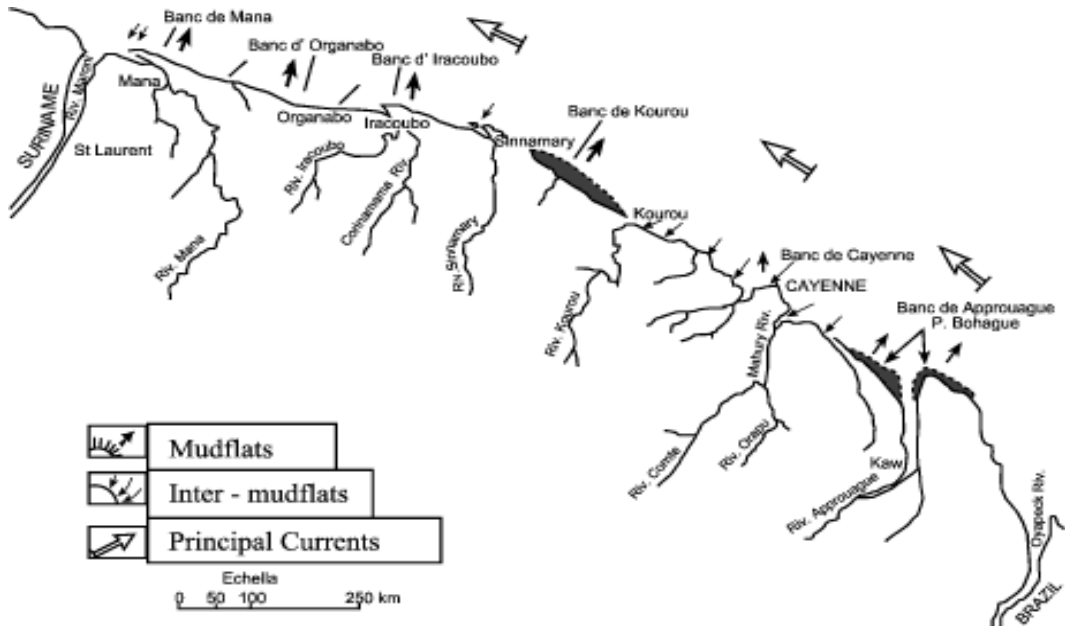


FIGURE 3. Migration of the mudflats along the Guianese Littoral. Situation in 1988 (from Prost 1989, in Frouin 1997).

FIGURA 3. La migración de las marismas a lo largo del litoral de Guyana; la situación en 1988 (de Prost 1989, en Frouin 1997).

THE PHYSICAL CHEMISTRY OF THE LITTORAL MUDFLAT WATERS AND ITS ECOLOGICAL IMPLICATIONS FOR BIODIVERSITY

As already mentioned, in the dry season, “marine” waters contribute to the transport of phosphate into the rivers, whereas, in the wet season, the ebb tides carry particulate suspended mineral and organic matter out to sea (Vignard 2001, Guiral 2002); in this context, a large part of the phytobenthos could also be moved within the water column.

The water draining from the coastal mangroves is rich in nutrients and suspended matter and tends to be brackish though its salinity varies greatly, depending on the rainfall. The fauna which live in these habitats is thus characterized by euryhaline species. According to Rojas-Beltrán (1986), the mangroves in French Guiana shelter some 100 spe-

cies of fish and 34 species of crabs and shrimps. Some of them live in these habitats permanently, while others, e.g fish and crustaceans, temporarily visit the mangroves to feed (Hogarth 1999), to protect themselves from predatory pressure (Primavera 1997), or to achieve part of their life cycle. Thus, various species find that these systems provide the best conditions to ensure part of their development cycle: shrimps (Primavera 1998), postlarval and juvenile fish, and the adult stages of crabs (Jones 1984). The young stages of these species are mainly detritivores (Rojas-Beltrán 1986) and are therefore at the base of the trophic chain of the estuarine system. Significant populations of *Penaeus subtilis* and *Plagioscion* sp. of small average size and the absence of sexually mature individuals indicate the role of the mudflats as nurseries for these species. These two taxa make up the largest trophic level,

their juvenile stages being omnivores capable of feeding on detrital material produced by the surrounding mangrove. The adults of *Platystachus cotylephorus* and *Potamotrygon hystrix* constitute a secondary trophic level, the primary being carnivores. Lastly, the adults of *Plagioscion* sp. and *Centropomus* sp. are intermediate carnivores (Rojas-Beltrán 1986). Of the 22 species found in this mudflat system, 9 are considered to be permanently estuarine, seven mainly freshwater, and six mainly marine. Based on the stage of maturity and the diets of the taxa in samples described by Odum & Heald (1972) and (Rojas-Beltrán 1986), it would appear that 41% of the captured species would be shrimp consumers when adults (*Caranx* sp., *Lutjanus* sp., *Centropomus* sp., *Arius* sp., *Plagioscion* sp., *Platystachus cotylephorus*, *Potamotrygon hystrix*, *Gobioides* sp., and the crabs, *Callinectes* sp.).

PROKARYOTE DIVERSITY AND AN ANALYSIS OF COMMUNITY STRUCTURE IN THE MOBILE MUD DEPOSITS OF FRENCH GUIANA

Venkateswaran *et al.* (1998) were the first to have isolated a bacterium (*Shewanella amazonensis*) from Amazonian shelf coastal muds in the northern Amapá region where shore-attached mud waves are first formed. Madrid *et al.* (2001) have since provided a molecular census of prokaryotes in a shore-attached coastal mud wave, 3-4 m thick, migrating to the northwest over a relict mud surface. These authors examined the relationships between the inferred microbial community and a range of seabed sedimentary and geochemical properties, and its potential as an indicator of hydrodynamic processes. A sequence analysis, extracted from a subsurface sediment layer (10-30 cm) of 96 non-chimeric sequences showed the majority of the microbes to be bacteria. The diversity was high, with 64 unique sequences, and Proteobacteria were dominant. Bacterial sequences belonged to the *Cytophaga-Flexibacter-Bacteroides* group, Actinobacteria, Planctomycetes, Cyanobacteria, low-GC Gram-positive, K, Q, and N subdivisions of Proteobacteria. A sizeable fraction of sequences from the Kourou-Sinnamary library are normally found in water column populations, reflecting the frequent entrapment of suspended debris into the underlying sediments. Dominant

sequences were related to *Gelidibacter algens* (*Cytophaga-Flexibacter-Bacteroides* group), Actinobacteria, *Sulfitobacter* and *Ruegeria* spp. (K-proteo-bacteria), all of which are chemo-organotrophs, consistent with abundant labile organic carbon. Frequent resuspension, reoxidation of bottom sediments, and re-deposition, coupled with the entrapment of allochthonous organic particles including organisms, create transient environmental complexity and promote high microbial diversity. Further work on the microbiology and biogeochemistry of these mobile muds is being planned.

The productivity and adaptation of the photosynthetic biofilms that colonize the littoral mudflats. Strong ecological interactions, including competition, exist between microphytobenthos and mangrove vegetation. Photosynthetic biofilms, one mainly consisting of cyanobacteria and another of diatoms, were sampled on a mudflat of the Kaw estuary (Guiral *et al.* 2001, Sygut 2002). Four sediment samples were taken from the Kaw mudflat: one from the central part of the mudflat in the course of being colonized by a phytobenthic community including diatoms and cyanobacteria, another from the upper sector colonized by a phytobenthic mat, very largely dominated by Chlorophyceae, a third from the central part of this sector dominated by mobile pennate diatoms within the sediment, depending upon the irradiance, and the last from the lower part, where there was only one settlement of very large centric diatoms, inherited from of the oceanic area. A fifth sample, taken from the zone of a mature *Rhizophora* and *Avicennia* mangrove, was of a sediment very partially colonized by cyanobacteria and actively exploited by crabs. New studies are planned to determine the factors which control the development of autotrophic biofilms and their productivity.

DIATOM DIVERSITY IN THE MUDDLATS AND MANGROVES OF THE KAW RIVER ESTUARY

The diatom communities in 85 samples of surface sediments taken from habitats ranging from mobile mud to stabilized mangroves of the Kaw River estuary during 3 cruises-at the beginning of the dry season (July 2000) and in the rainy season (January 1999 and December 2000)- were studied by

Sylvestre *et al.* (2002). 178 taxa belonging to 51 genera were identified. The diatom communities were dominated by periphytic species; only 34 species were identified as holoplanktonic forms. The tychoplanktonic species were represented by 2 types of *Synedra* in 3 samples. All of the identified species were characteristic of saline conditions. The strictly marine forms were all planktonic. Most of the periphytic forms were species observed in littoral as well as in continental saline situations whereas the diatom communities were all characteristic of coastal systems. Five species (*Coscinodiscus centralis*, *Cymatodiscus planetophora*, *Cyclotella stylonum*, *Gyrosigma peisonis* and *Thalassionema nitzschooides*) were present in all of the samples.

The periphytic forms were mostly of the genera *Gyrosigma*, *Pleurosigma* and *Nitzschia*; these live both on and in the mud, their migration into the sediment depending upon sediment resuspension and the irradiance conditions. A freshwater species (*Eunotia* spp.) was observed in only one sample taken upstream of the estuary. The samples taken on the unstabilized mudflat contained the typically marine planktonic species, *Coscinodiscus centralis*, *Cyclotella stylonum*, and *Thalassionema nitzschooides*, which are characteristic of the Atlantic Ocean. These are found, however, not only on unstabilized mudflats also in mature mangroves and are indicators of the penetration of oceanic waters far into the estuary. The samples taken on the fluid mudflat and the slikke were dominated by *Gyrosigma* spp., which possesses a high degree of mobility within the sediment. Finally, in the samples from the mangrove swamps stabilized by vegetation, *Nitzschia* spp., considered to be mobile epipelagic forms, and *Navicula* spp., characteristic of muddy shores, were predominant. The mature mangrove samples were characterized by a greater specific richness and a greater diversity than those from the other locations. The parameters such as salinity, nutrient concentrations, and pH have a great influence on species diversity. This study suggests that the motile epipelagic species (*Gyrosigma* spp. and *Nitzschia* spp.) are indicators of fluid mudflats, with a gradation from the oceanic influenced area mostly dominated by *Gyrosigma* spp. to progressively more stable areas dominated by *Nitzschia* spp. Species of the

genus *Navicula* characterize the settling areas which are subject to higher variations of the environmental parameters. This study demonstrated that the penetration of oceanic waters has a big influence on the ecosystems of the Kaw estuary, purely freshwater habitats occurring well upstream from the estuary.

FORAMINIFERAL BIODIVERSITY

In the 37 surface sediment samples collected in January 1999 and July 2000 for the study of the microfaunal biodiversity in the mangrove swamps and mudflats of French Guiana where strong seasonal variations occur, 44 species were identified (Debenay *et al.* 2002). The main factor regulating the distribution of foraminiferal assemblages is the hydrodynamics of the estuary, characterized by the influence of both saline coastal water and low calcium fresh water, with major seasonal differences. The coastal end member is dominated by the calcareous species *Ammonia tepida*, *A. parkinsoniana*, and *Cribolephidium* spp. whereas the continental (freshwater) end member is characterized by the agglutinated species *Miliammina fusca* and *Trochammina irregularis*. The calcareous species penetrate the estuary, even as far as the mangrove forests, during the dry season but totally disappear from the estuary during the rainy season. The other factor affecting the distribution of the Foraminifera is their vertical elevation which determines the period of aerial exposure and the colonization by mangrove trees. Foraminifera are very rare on or even absent from exposed mud banks containing cracks, but begin to grow as soon as young *Avicennia* are present. Both the canopy and the detritus of the mangrove forest protect the sediment from heating and drying and, thus, increase in salinity caused by the sun and wind. The distribution of the agglutinated species in the mangrove swamps is, as a result, closely related to the presence of the mangrove trees.

MEIO- AND MACRO-BENTHIC BIODIVERSITY IN THE LITTORAL MUDFLATS OF FRENCH GUIANA

The meiofauna of the Kaw mudflats are largely dominated by Nematods (Ragot 1999, Boucher 2000). The "marine slikke" zone has significant populations of adult and nauplii stages of

Harpacticoidae Copepoda (Crustacea) and Turbellariae (Annelida). Due to their high individual biomasses, the insect larvae found within the inner mudflats represent 50% of the total biomass. The importance of the Tanaidacea at some locations on the Kaw river mudflat and the “estuarine slikke” of the mudflat were confirmed by a comprehensive meiobenthic survey that included the young stages of this group.

The Nematods were the numerically dominant group of the meiobenthic fauna. A total of 66 species were identified with a mean of 16 species per sampling site and a maximum of 28 species in the mature *Rhizophora* mangrove. The Monhysteridae family was the most abundant and this characterizes the nematofauna as a community of non-selective detritivores. Two species of this family represented over 25% of the nematods analyzed. The second community is represented by the specific epistratum grazers, *Dicromodora* and *Metacrhomadroides*. These genera are adapted to the grazing of diatoms and are dominant on the marine slikke.

Justou (1999), Glevarec (1999) and Clavier (2000) have reported the presence of 26 macrobenthic taxa in the Kaw mudflat area. The Tanaidacea Crustacea is the most abundant taxa, representing 75% of the total abundance, followed by the Polychaeta and Oligochaeta (Annelids). The communities were found to be low in diversity though the populations covered a wide range of abundances; this structure is common in an environment subject to a major physical constraint. It was possible, as a result, to differentiate between the stations of the stabilized mudflat, the mangrove and mudflat at the young stage of tree colonization, the mudflat marine slikke, and the areas colonized by the dense communities of Tanaidacea. The total biomass was very low over the mudflat (a factor of 10 less than the mean biomass) except within the drainage channels. The macrobenthic biomass was, on the other hand, high in the estuary border slikkes and, especially, in the mangrove zones.

The small-sized macrobenthos was dominated by depositivores, mostly little Peracarid Crustacea and Capitellidae Annelida. Suspensivores were very rare and only some Cirripidae (Crustacea) and Mytilidae (Mollusca) were observed on floating branches. The low numbers of suspensivores are

related to the highly turbid littoral and estuarine waters.

THE CARCINOLOGICAL FAUNA OF A FRENCH GUIANA MUDFLAT COLONIZED BY MANGROVES

The extremely rapid establishment of a mangrove makes it possible to follow, on a very short time scale (3 to 5 years), the progressive transformation of an unstabilized mudflat into a mangrove inhabited by the carcinological fauna specific to this type of habitat. The interactions between vegetation and crabs is demonstrated by the occurrence of species which depend first on the shade provided by the trees and then on the production of leaves and litter which constitute their food (Amouroux & Tavares 2002): *Goniopsis* sp. feeds on the young foliage of trees and *Ucides* sp. consumes decomposed leaves, whereas *Aratus pisonii* depends on the primary production of *Rhizophora* trees and the epibiontes of their stilt roots.

The gradual disappearance of *Uca maracoani* is related to changes in its habitat. Initially, the loss of mud without vegetation narrowed its surface and the mud covered with vegetation became compacted. *Uca maracoani* is now, therefore, confined to the sloping edges of the river. Its place has been occupied by other *Uca* spp. and also by *Ucides cordatus*. The settlement of *Rhizophora* at the edge of the river allows the development of *Aratus* sp. The population densities of the various species increase as the mangrove develops. The appearance of *Ucides* sp. and the anastomoses of the burrows of *Uca* sp. in 2001 were indications of increasing bioturbation. The survey of this mudflat made it possible to show a process of faunal succession and colonization of the different habitats near the littoral mudflats. There are plans to continue this research, as part of the PNEC program, over a longer period, to supplement it with a study of the river margins colonized by *Uca* sp., and to follow it up with a senescent mangrove area.

STUDIES ON PARTICULAR PROTECTED SPECIES CONSERVATION STRATEGIES

The coast of the Guianas is a mix of vast mudflats, narrow sandy beaches, mangrove swamps, wet savannas, and brackish water creeks. The mangrove forests of the Guianas are among the most important and least degraded in the world and are home

to millions of North American migratory birds. Off-shore, the strong Guianas Current flows east to west carrying the nutrient-rich mud of the Amazon and the local smaller rivers and creeks. In a continual process of erosion and rebuilding, the Guianas Current seasonally creates and then washes away huge mudflats and wide stretches of sandy beach (Fig. 3). This process is important because the Guianas provide nesting sites and feeding grounds for some of the largest remaining populations of 4 species of sea turtle. Mangroves provide critical habitats for many marine species such as shrimp, tarpon, bonefish, and rays. Within the Guianas, the main threats to biodiversity are the removal of mangroves; over-hunting of turtles, birds, and other mammals; incidental catches of turtles by shrimp trawlers and fisheries activities, the poaching of turtle eggs; over-fishing; increasing pesticide and fertilizer use in expanding rice fields; bauxite mining operations; and land clearance for livestock. In addition to the known threats, there is the possibility that other industries, such as sandmining, goldmining, and oil development may also be diminishing the biodiversity of this ecoregion.

STUDIES OF THE BIOLOGY AND ECOLOGY OF MARINE TURTLES (FROM THE WWW SITE OF WWF ©)

Together with partners at STINATSU (the Foundation for Nature Conservation), indigenous communities in Suriname, and KAWANA in French Guiana, the WWF has been supporting sea turtle conservation in the Guianas for over 20 years. Since 1999, with the assistance of WWF Guianas, this regional approach has gradually taken shape. In recent years, local organizations and communities have begun to play an even more pivotal role in the conservation and management of these species (Talvy *et al.* 2001, Fretey *et al.* 2002); recently, they have completed a Regional Sea Turtle Conservation Strategy that will provide the regional program with a framework and goals for future conservation work. In all 3 countries, sea turtle conservation activities include research and enforcement, and developing ecotourism and alternatives to unsustainable fishing practices and the harvesting of turtle meat and eggs. Classic research techniques, such as surveys, and new research techniques, like satellite tracking, PIT-tagging, and genetic research, are enabling

Guianese and WWF scientists to better understand turtle biology. In French Guiana, sea turtle conservation activities are coordinated by the DIREN (the Ministry of Natural Resources for French Guiana). Partners working with DIREN include associations such as SEPANGUY and Amerindian organizations such as Kulalasi. The Amana Nature Reserve, WWF, ONCFS, Kwata, Université d'Orsay and CNRS are also active partners in local sea turtle conservation.

Leatherback (*Dermochelys coriacea*), green (*Chelonia mydas*), olive ridley (*Lepidochelys olivacea*), and hawksbill (*Eretmochelys imbricata*) turtles nest on the beaches of French Guiana. With the exception of the hawksbill, for which there are not enough data, the nesting seasons are well-known: green turtles (January-May), olive ridleys (May-September), and leatherbacks, almost all the year round but divided into two distinct nesting seasons, with a minor peak in December/January and a major peak during April-July.

The primary nesting sites in French Guiana are located at Awala-Yalimapo, along the Point-Isère/Organabo coastline, and at the urban sites of Kourou and Cayenne. The Awala-Yalimapo Beach (Amana Nature Reserve) is historically considered the most important single nesting site in the world for the leatherback sea turtle; during the primary peak season (May-June), more than 200 of them may nest there in a single night. It is also an important nesting site for green turtles, though this species has not been formally monitored. Olive ridley turtles (on average, less than 10 nests per year) and hawksbill turtles appear to be only occasional nesters. WWF-France has gradually refocused its activities on to the protection of nesting females during the leatherback egg-laying season (the Kawana Campaign, Talvy *et al.* 2001), in collaboration with Kulalasi (an Amerindian organization based in Awala-Yalimapo) and the Amana Nature Reserve staff.

Beaches along the Pointe-Isère/Organabo coastline shift with changes in the shoreline structure, making consistent monitoring difficult. Nevertheless, the area is known to be an important nesting habitat and is considered to be the main nesting area for green turtles in the country.

Finally, there are 2 important "in-town" sea turtle nesting sites, in Kourou and Cayenne, in French Guiana. They nest on 4 beaches, covering a distance of about 4 km, in the vicinity of Kourou. In Cay-

enne, nesting sea turtles are currently using 6 main sites, spread over about 12 km. These beaches are in an urban setting with buildings and other man-made structures often only a few meters away from the nests. Two local organizations, KWATA and SEPANGUY, are monitoring these sites. Their reports show the importance of these sites for olive ridleys and leatherbacks (Talvy *et al.* 2001).

THE DISTRIBUTION, HABITAT, AND CONSERVATION STATUS OF THE WEST INDIAN MANATEE IN FRENCH GUIANA

The manatees, *Trichechus manatus*, may be less abundant than in the recent past (de Thoisy *et al.* 2002), but are still present and regularly sighted all along the coast and in estuaries, up to 80 km inland from the open sea. The main habitats for the manatees are estuarine mangroves. At the moment, their secretive behaviour, fairly undisturbed estuarine habitats, species scarcity, and protection laws create an optimistic outlook for the future of the manatee populations in French Guiana. The manatees are also encountered on nearby rocky shores (Cayenne Island, Malmarouny, Ilet-la-Mère and Rocky point at Kourou) and up to 80 km upstream in some of the larger rivers as the Maroni, the Approuague and the Oyapock. As the alluvial coastal plain is quite narrow, their habitats are naturally restricted.

A STUDY OF *SOTALIA FLUVIATILIS* (CETACEA, DELPHINIDAE) IN COASTAL WATERS

The results of a bibliographical study coupled with field work (direct observations and the collection of data since 1997) on the distribution and possible threats to *Sotalia fluviatilis* in the waters of French Guiana have been reported by S. Bouillet (2002). These dolphins are observed along almost all of the littoral area. They seem to be present all through the year towards the east of the French Guiana coast but seem to be more frequent in the dry season towards the west; this could be connected with the occurrence there of less turbid water and better food stocks. They are rarely observed at the mouths of and within the principal rivers (Oyapok and Maroni) where river traffic is rather heavy, but more frequently within the mouths of the secondary rivers (Larivot and Mahury) and around the “du Salut” and “Connétable” Islands. Habitat destruction seems to be less important than the 3 year decline in the

shrimp populations, which has greatly reduced a major food supply for the dolphins.

THE BIRDS OF THE LITTORAL ZONE OF FRENCH GUIANA

More than 200 of the 700 species of birds which populate French Guiana are essentially or completely habitants of the littoral wetland areas (Hansen & le Dreff 2002), and more than two-thirds of the 30 birds cited in the “Red book of the endangered species of the French overseas regions” (Thiollay 1988) live in these wet coastal systems. The wildlife of the littoral of French Guiana, which has been less studied than that of the rainforest, presents a very particular evolutionary dynamic which constantly modifies its structure.

Three of the 10 species of ducks (Anatidae) observed in French Guiana are strictly migratory *Anas discors*, *A. americana*, and *A. clypeata* (Hansen & le Dreff 2002). *Dendrocygna autumnalis* and *Anas bahamensis* are nesting species in French Guiana. The great majority of the Anatidae are located on the western part of the coast and particularly in the Mana lagoon. This particular location has been protected by creating the Amana Regional Natural Reserve, as well as the Kaw swamp Regional Natural Reserve.

The emblematic red ibis, *Eudocimus ruber*, is a protected species along the whole of the French Guiana coast and lives at the mouths of rivers or in the coastal marshes. Not less than 24 species of herons are present in French Guiana, occupying various habitats such as mudflats and littoral lagoons, freshwater marshes and forest creeks. The most abundant species are *Egretta thula* and *E. caerulea*. These species share their habitats and nesting sites with 6 other species, e.g. *Egretta tricolor*. *Egretta alba* is frequently observed in marshes and rice plantations as well in the littoral. *Ardea cocoi* is the most numerous representative species of the Ardeidae in South America.

Among the rarest species, the pink “spatule”, *Ajaia ajaja*, is present at littoral sites of difficult access and *Mycteria americana* is mostly observed in coastal lagoons. Some small groups of pink flamingos (*Phoenicurus ruber*) are regularly seen coming from Suriname and Amapá State in Brasil. *Nycticorax nycticorax*, *N. violacea*, and *Cochlearius cochlearius* are small Ardeidae species that live in dense mangroves and reproduce with other Ardeidae and the red ibis.

Some birds, not strictly marine, inhabit the littoral freshwater marshes; typical of these are *Ixobrychus involucris*, *I. Exilis*, *Botarus pinnatus*, and *Zebrilus undulatus*. On the other hand, *Butorides striatus* is a very common green heron that occupies different parts of the coastal plain, as does *Bubulcus ibis*.

Twenty-seven species of North American limicolous birds have been recorded in French Guiana. "Small" limicolous birds include most of the sandpipers, *Calidris pusilla* being the most abundant, and then *Charadrius semipalmatus*. Recent new censuses of limicoles were carried out by ONFCS and GEPOG. Small species arrive during their post-nuptial migration between August and October. Thereafter, a part of the community migrates towards the Brazilian coast and, in January-February and April, they return to the Arctic. Some of the large limicoles observed are *Tringa flavipes* and *T. melaneuleuca*, *Arenaria interpres* and *Calidris canutus*.

The rocky islands in the coastal zone of French Guiana provide refuges for marine birds such as *Fregata magnificens* that travel up to 100 km away from the coast, following the shrimp fishing vessels, as do seagulls. Nearly 500 couples of *F. magnificens* are observed all through the year in the "Grand Connétable" Marine Natural Reserve. The numbers of the seagull, *Larus atricilla*, in French Guiana represent 20% of the Caribbean population and the most southerly community of this species.

The Cayenne stern, *Sterna eurygnatha*, is one of the most endangered species in the "Grand Connétable" Natural Reserve, as very few nesting colonies are known. An international cooperative conservation program has been established with Aruba Island off the Venezuelan coast which hosts a similar sized colony of this stern. *Sterna fuscata* is represented by 250 couples on "Grand Connétable" island. Like *Anous stodilus*, this species often flies away from the highly turbid littoral areas as far as 90 km offshore. The royal stern, *Sterna maxima*, is often seen associated with the Cayenne stern on the "Grand Connétable".

DISCUSSION AND PERSPECTIVES

The information about marine biodiversity in French Guiana which has been described in this paper is the result of studies carried out by re-

search teams coming from Metropolitan France, together with some local scientists, temporarily based in French Guiana, working for various research institutions (IRD, IFREMER, CNES, Institut Pasteur, Université Antilles Guyane - UAG, CNRS, etc.), Governmental Agencies (DIREN, Natural Regional Parks) or different types of Non-Governmental Organizations, national (KWATA, GEPOG, SEPANGUY, etc.) and international (WWF). These scientists were or still are involved in projects of limited duration (PNEC, PNRZH, LITEAU, etc.). Therefore, except for the programs that dealt with species of particular commercial interest or those already identified as endangered species, the present review describes the outcome of mainly short-term studies which focussed on specific parts of the different ecosystems under precise hydroclima-tological conditions. There is, therefore, a need for a more generalized long-term series inventory of the existing data (including geographical distributions) and a more detailed assessment of marine biodiversity at the ecological, population and genetic levels. In addition, the available information needs to be compared with and, indeed, extended to the neighbouring countries of the "Amazon-Guiana Ecotone" or marine "Guianas Province", from the mouth of the Amazon River to that of the Orinoco River and the southern Caribbean Sea. A large reservoir of existing expertise could be called upon for carrying out these studies, if there were greater financial and logistical support from national French scientific institutions (Universities, CNRS, IRD, IFREMER, MNHN, INSU, and CNES). The creation of new academic careers to deal with the environment, planned for the near future by the local university, UAG, together with the formation of a local unit of the National Research Council (CNRS) and the renewal of IRD and IFREMER research groups in French Guiana, involving a significant number of local and metropolitan French scientists, are elements that should ensure the success of projects of medium-term duration involving also neighbouring countries, financially and scientifically supported by national and inter-regional programs. At present, only the ECOLAB network, initiated in 1993, is improving coastal studies in all disciplines through the communication and collaboration between scientists from northern Brazil, French

Guiana and Suriname. Cooperation in marine research between an institute in French Guiana and another in Venezuela has also been proposed.

All these ongoing initiatives could be strengthened within the CoML Program. First of all, some studies could be carried out at the ecological level for a better understanding of the functioning and energy and material fluxes in the different estuarine, littoral, coastal, and open sea ecosystems already individually studied in previous and ongoing programs. Existing data, at different levels and scales, need, first of all, to be brought together in a common Geographical Information System data base. Coastal oceanographic cruises covering the entire area, supported by satellite imaging, would then be a good strategy for integrating local studies, though the protocols used for data gathering would need to be standardised in order to compare the measurements and estimations of stocks and fluxes made in the different countries of the region.

A major research effort is required to increase and coordinate field observations of the littoral, not only by scientists but also by the local populations that know and benefit from these ecosystems. In this way, an improved inventory of the known and still unknown marine species, from microbes to turtles, dolphins, and birds, could be produced. For this, it would be essential to cross fertilize the capabilities of all of the scientists involved in the area. It is also important to stress that most classifications are changing rapidly as microscopic (SEM, TEM) and biochemical and genetic probe techniques improve our knowledge and ability to discriminate between different species and taxa in general, and between microbial organisms in particular. Moreover, assessments of genetic diversity could be made by means of international cooperation, in order to establish the *in situ* diversity of communities and populations. This would allow the accurate identification, classification, and incorporation into an inventory of the organisms present at different locations and during the various seasons. The exchange of scientists and of students involved in postgraduate studies and research should be facilitated in order to improve the global vision of the personnel studying marine biodiversity in South America. Finally, comparative research on the biodiversity of analogous littoral and marine ecosystems in South America (large river coastal plumes, upwelling zones, estuaries, narrow or extended shelves, shelf

edges, characteristic habitats of the littoral) would allow the development and application of common strategies for the assessment and management of the marine biological richness of the continent.

This could begin with different strategies at local, interregional, and international levels, within a medium-term project such as the CoML program (10 years), which envisages two or three projects as are currently being developed in French Guiana. The first need would be to compare capabilities in order to see how much each participant can achieve once the goals and time scales have been defined. The aim would be to identify what local studies can be made fairly quickly in order to prepare the different stages in the research strategy during the next 10 years and thereafter.

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