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The Effects of Anthropization on the Coastal Island Vegetation: The Example of the Mangrove Forest of the Bay of Fort-de-France (Martinique)

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Abstract **- At the Land-Sea interface, the mangrove forests represent unique but very threatened ecosystems. In the tropical island systems as to the biosphere scale, the mangrove forests and related biocenoses are relevant anthropization markers. The pressures and the direct and indirect damage are also multiple and varied. Generally, the coastal ecosystems of the French West Indies are in constant evolution. The effect of natural factors is increased by human activities. In these small, densely populated and urbanized areas, the mangrove forests are part of the last unoccupied areas. Faced with growing development needs, they represent an area to use, exploit and impact. The human footprint is high and sometimes it has irreversible consequences. The human impact mainly translates into the erosion of biodiversity and ecosystem services. Facing these imbalances, the study of the mangrove ecosystem using conservation ecology stands as an essential approach for the preservation of Martinique's coastal ecosystems.**

Keywords **- Lesser Antilles, Martinique, island ecosystems, coast, wetlands, mangrove forests, biodiversity, anthropization**

I. INTRODUCTION

On the biosphere scale, the mangrove forests occupy an area of approximately 180 000 square kilometres [1-2] and are present on all continents [3] and in 112 countries [2]. They range from 30° North 30° South [4], [2]. However, mangrove forests have developed beyond these latitudes: in Japan (31° 22' N), in the Bermuda (32° 20'N), New Zealand (38° 03's), in Australia (38° 45's), and on the East coast of South Africa (32° 59's) [3], [5], [2] (Fig. 1).

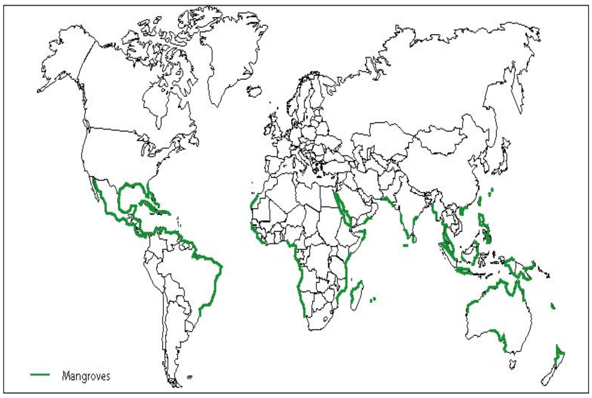

Fig. 1 - Distribution of mangrove forests in the world
Source: From UNEP (United Nations Environment Programme)

Unique ecosystems, the mangrove forests are subject to numerous aggressions and are very threatened [6]. Man and his multiple activities is the one principally responsible for it [7]. The structure, functioning and dynamics of mangrove forests have been and continue to be deeply changed [8-9]. The development and expansion of the industrial and urban areas, port facilities, the digging of canals and channels, the over-exploitation of wood, energy production, agriculture, salt production, aquaculture, shrimp farming, tourist facilities as well as many other sources of damage led to the reduction of this ecosystem's surfaces in the tropical world [10], [6], [8]. At least 35% of the mangrove areas have disappeared in the last two to five decades [11], [1]. The annual mangrove loss rates are highly variable due to the margins of error in most evaluations [1].

The world environmental issues linked to the mangrove forests affect Martinique as well as part of similar processes. For example, from 1979 to 1988 Martinique moved from 2500 hectares mangrove to 1840 hectares [12], [5]. From 1951 to 1998, 15% of the original mangrove areas from the Bay of Fort de France disappeared [5]. The majority of commercial and industrial activities, the service activities, the villages, municipalities and habitats developed on the coast: the littoralisation phenomenon [13]. Many mangroves plots were therefore destroyed and drained for the benefit of infrastructure and habitats (construction and widening of airports, roads and highways, construction of tourist sites, commercial and industrial areas).All the damage resulting from multiple human activities are destructuring factors of the mangrove ecosystem and have irreversible consequences on its operation and biocenosis.

The objective of this article is to show the main impacts of human activities on the Fort -de-France mangrove forest, in principal on its structure, its dynamics, its specific richness for the purpose of future sustainable management.

II. THE STUDY SITE

The Bay of Fort-de-France is located on the West coast of Martinique. Opening on the Caribbean Sea, this Bay has an area of 70 km² and stretches along the coastline for circa 100 km, between Schœlcher in the North and Cape Salomon to the South. The Bay of Fort-de-France mangrove forests cover 1200 hectares and extend over four municipalities: Lamentin, Ducos, Rivière-Salée and Trois-Ilets (Fig. 2). This mangrove forest has three entities: the “Cohé du Lamentin”, the central area (south of the airport) and the Bay of Génipa. An alluvial forest as it is created byimportant watercourses; it represents 65% of Martinique’s mangrove forests [14].

Fig. 2 Martinique in the Lesser Antilles and the study Site

III. METHOD

This study is based on the analysis of aerial photographs but also on observations and floristic inventories. We were able to reveal changes in the landscape on the outskirts of the Bay of Fort-de-France mangrove forests and observe its spatial-temporal evolution between 1951 and 2004. We defined the mangrove forest perimeter using the 1951 aerial photographs taken by IGN[1]. This perimeter was superimposed on transparent paper on a 2004 IGN aerial photography and on a 2004 topographic map (IGN) to a scale of 1: 25 000. To appreciate the floristic diversity of the mangrove forest and its structure, quantitative surveys were conducted in two sites corresponding to two transects divided into quadrats: site1 (Fig. 3) and site 2 (Fig. 6). Several descriptors were considered for each transect: species, individuals, height, diameter, health status.

IV. RESULTS AND DISCUSSIONS

A. Analysis of the floristic surveys of the two sites

A.1. Site 1

Site 1, covering 2750 m² is colonized by three mangrove species:*Rhizophora mangle (832 individuals)*, *Avicennia germinans (1040 individuals)* and*Laguncularia racemosa (406)*. The *Rhizophora mangle*species that usually colonizes the seafront is present in quadrat no. 6 (Fig. 3). It is absent from quadrat 11 to quadrat 16 and in the quadrats where it is found (quadrat 17 to the sea front), it exhibits variations in density. *Rhizophora mangle* is the dominant species in quadrats 20 to 25, 34, 35, 43, 44, 45, 46, 49 and forms the first floristic belt of this mangrove forest (quadrats 50 to 55; Fig. 3). *Avicennia germinans* is present in quadrat 1 to quadrat 49 (Fig. 3) and is the most abundant species (Fig. 3). From the point of view of individualdensity per quadrat, it has a different structure from that of the previous species(Fig. 3). The *Laguncularia racemosa* is a species which prefers areas with low salinity. It usually develops towards the interior of the land. However, in this transect, it is present beyond this zone and meets the *Avicennia germinans* and sometimes the *Rhizophora mangle*. Apart from quadrats 28 and 29, this species is seen in quadrats1 to 47. It is the only species in quadrat 2 and the most abundant species within quadrats 1, 11, 12, 15 and 16 (Fig. 3).

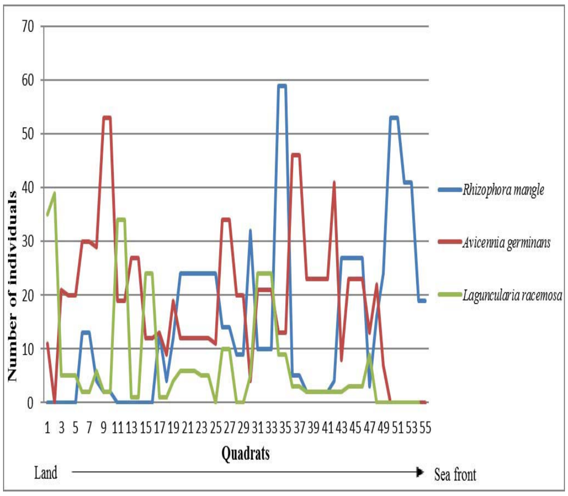

Fig.3 The distribution of mangroves on site 1

The overall biomass of this station is low (Fig. 4). More than 2/3 of individuals have a diameter less than or equal to 15 cm (81.50%): individuals with a section of 5 and 2.5 are the most numerous (1/3 of individuals are of class 5 cm or 33.36%). There are only ten individuals between 50 and 80 cm in diameter: three individuals classed at 50 cm, two individuals classed at 55 cm, three individuals classed at 60 cm, an individual classed at 70 cm and an individual classed at 80 cm (Fig. 4).

The majority of site 1 individuals (98.8%) have a height less than or equal to 15 metres (Fig. 5). More than half of the specimens have a height comprised between 2 to 8 metres (52, 50%). Only one of them rises to 28 meters (class 25-35 meters), which corresponds to the maximum height in this site.

[1]Institute Géographique National (France)

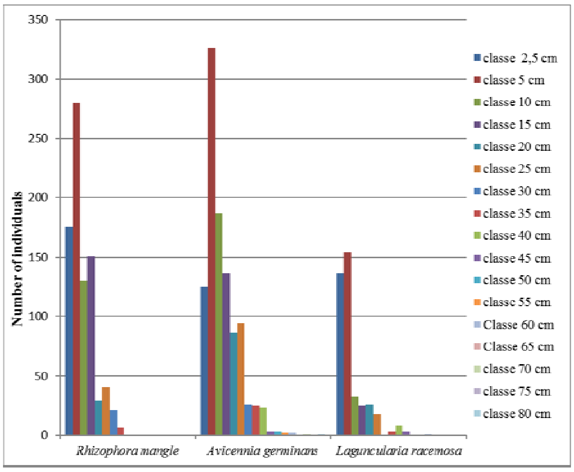

Fig. 4 Distribution of diameters in site 1

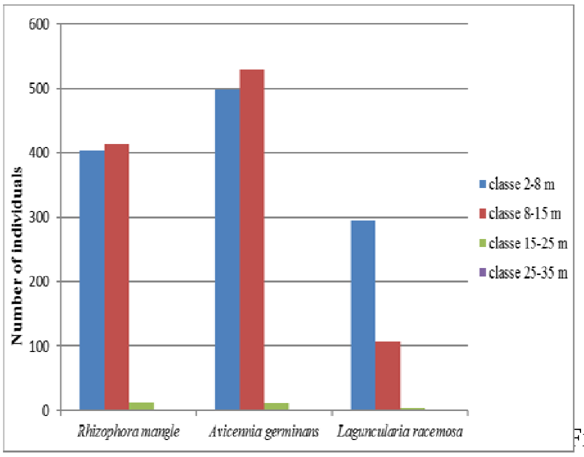

Fig 5

Distribution of heights in site 1

A.2 Site 2

On site 2 with a surface of 1200 m² we find the same mangrove species (Fig. 6): 23 *Laguncularia racemosa*, 315 *Rhizophora mangle*and 1382*Avicennia germinans*. The one species of quadrats 2 to 17, *Avicennia Germinans* is the most distributed because it is present from quadrat 1 to quadrat 21 (Fig. 6). Its density is variable throughout the site but is largely dominant in quadrats 1 to 19. The *Rhizophora mangle* mainly colonizes the seafront (from quadrat 19 to 24) with an increase in the density value. Contrary to the*Avicennia germinans* and the *Rhizophora mangle*, the *Laguncularia racemosa* is characterized by low populationsalmost on all quadrats. However, a few individuals of this species have been recorded towards the sea front, in the last two quadrats (23 and 24) while it is normally a species with a low affinity for salt.

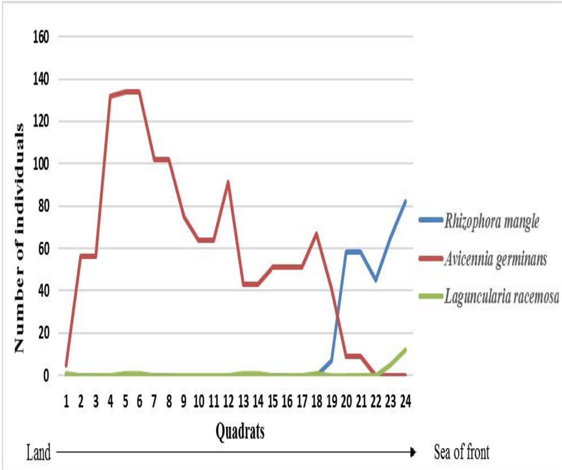

Fig. 6 The distribution of mangroves in site 2

The biomass of this mangrovelot (site 2) is also low (Fig. 7). The individuals with a diameter less than or equal to 15 cm (95.91%) are the most numerous including 5 cm ones (41.62%). Apart from seven *Avicennia germinans* with a 17 meter height (class 15-25 m), more than half the individuals range between 1 and 8 meters (63.72%) (Fig. 8).

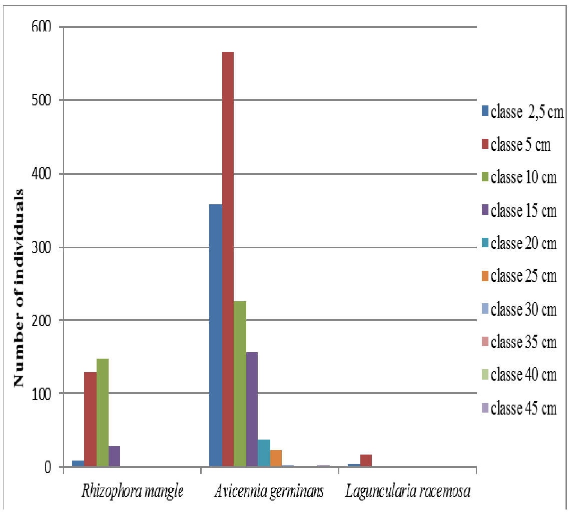

Fig. 7 Distribution of diameters in site 2

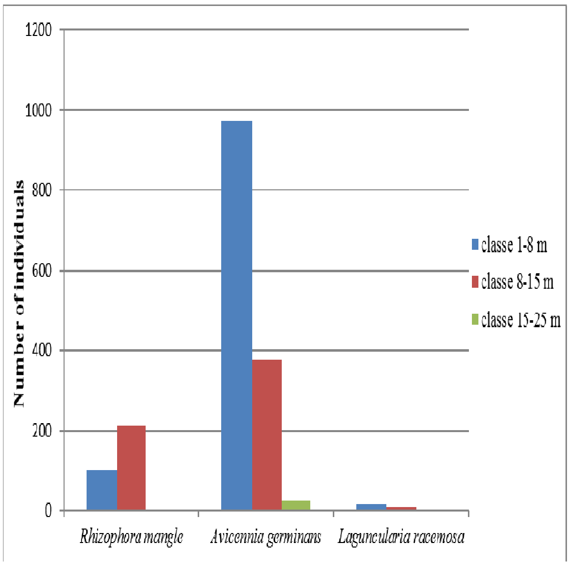

Fig. 8 Distribution of heights in site 2

A.3 General synthesis

The differences between transect and as a consequence between quadrats are significant from a structural, architectural and bio-demographic point of view. The mangrove forest is therefore a complex, heterogeneous and original environment. The distribution of species populations seems random as demonstrated by the two lists (Fig. 3 & 6). Thus, we cannot define a unique mangrove forest structure scheme in terms of space series. The structure and spatial distribution of the species depend on many factors including anthropic ones. In fact, the artificial channels have changed the structure of this mangrove forest. The alluvial-terrigenous contributions throughout these latter are at the origin of the development of *Rhizophora mangle*in its interior. This anthropisation has influenced the general ecosystem structure, the dynamics and the mangrove distribution.

The Bay of Fort-de-France mangrove forest is a low biomass mangrove forest. This is in relation to populations whose the majority of individuals have sections between 5 and 15 cm. Nevertheless, we cannot speak of a young mangrove forest even if a good proportion of the individuals are regeneration trees (low diameters and heights). This low biomass results from the effects of Hurricane Dean which struck Martinique in 2007. Many units of this mangrove forest are going through regeneration.

B. Diachronic evolution of the Fort-de-France mangroves

The diachronic analysis using aerial photographs shows a decrease of the mangrove forest surface between 1951 and 2004. This decrease has a dual cause: the establishment and extension of land plots dedicated to the cultivation of sugar cane and the development of peri-urban areas: a parcel has been drained out more than 40 years ago in order to build housing and others have been converted into cultivated surfaces dedicated to the culture of sugarcane (Fig. 9). There is still an increase in certain sectors (Fig. 9). In fact, the analysis reveals a mangrove advance towards the waterfront (Fig. 9). This phenomenon is due to terrigenous sediments on the bosom of the Ocean near the coastal masses which favour the development of mangrove seedlings and participate in mangrove progradation. *Rhizophora mangle* is the only species involved in this process. In some terrigenous hyper-sedimentation situations this species produces "tombolos". To protect the mangroves mainly from commercial buildings, the National Forests Department of France (NFB) has strengthened the mangrove back land by planting *Genipa Americana* (genipas, Rubiaceae).

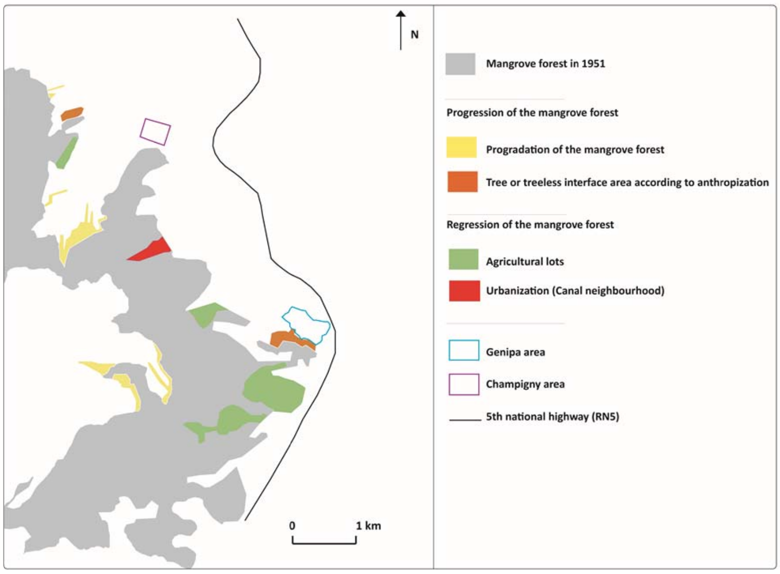

Fig. 9 Sketch of the spatial dynamics of the Bay of Fort-de-France mangroves

C. The effects of human impacts on the Bay of Fort-de-France mangroves

Industry, agriculture, urbanization and domestic pollution as well as commercial activities, road infrastructure and landfills are sources of disturbance and/or damage to the Fort-de-France mangroves (Fig. 10, 11 & 12). All these activities have adverse effects on the coastal ecosystems.

Fig. 10, 11 & 12 Examples of pollution in the Bay of Fort de France

There are several industrial, commercial and craft areas and numerous amenities near the Bay of Fort-de-France mangrove forest (Fig. 2).In addition, several acres of sugar cane adjoin Génipa Bay (a component of the Bay of Fort-de-France; Fig. 2): in Lamentin, 700 hectares of sugar cane and banana have been identified, in Ducos we find 130 hectares of sugarcane and 170 hectares of banana and at Rivière Salée 673 hectares of sugarcane [15] (Fig. 2). Cattle and pigfarms are also present in the three municipalities. Moreover, within the Bay basin, particularly in communes such as le François or Saint-Joseph we can see banana, cane sugar crops and less important vegetable crops and cattle, pig and goat farms. All the pollution sources from these activities contribute to the contamination of various environment elements [16] (Fig. 13).

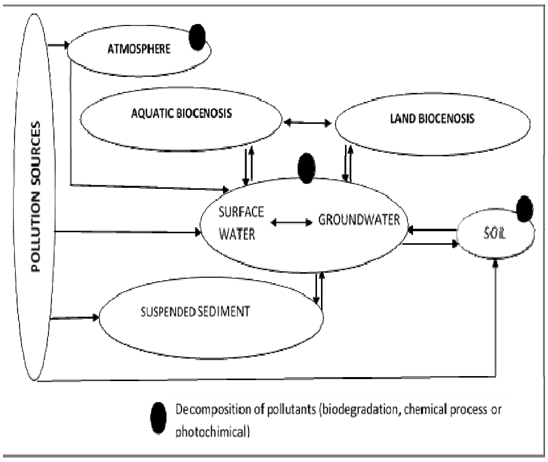

Fig. 13 The flow of pollutants into the main terrestrial compartments Source: Starting from [16]

The hydrographic network consists of several rivers of different sizes (Fig. 14). The runoff on the topographic surfaces covered with agricultural plots transfers terrigenous particles and organic material (food, abattoirs and quarrying industries) and hydrocarbons (power stations, refinery and port activities), heavy metals (chemical industries, car garages, port and road infrastructures), phosphates and nitrates (distilleries) in these rivers. These last two chemical elements are involved in the eutrophization phenomenon. This runoff is a factor which aggravates the pollution. Like most of Martinique's rivers, those which have their outlet in the Bay of Fort-de-France are also polluted (TABLE I & Fig. 15).

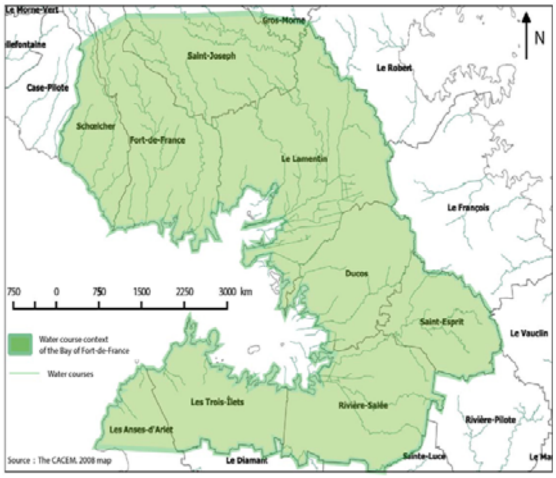

Fig. 14 The water context of the Bay of Fort-de-France Source: [17]

TABLE I

The State of certain water courses of the Bay of Fort-de-France according to the 2010 SDAGE Source: [18]

Name of the watercourse	Ecological status	Declassing parameters	Chemical status	Declassing parameters
Lézarde RiverDownstream	Bad	Chlordecone	Bad	HAPs[2]
Lézarde RiverMedian	Bad	Chlordecone	Bad	HAPs
Lézarde RiverUpstream	Good		Bad	TBT[3] cation
Blanche River	Good		Bad	TBT cation
Monsieur River	Poor	Total phosphorus Copper Zinc	Poor	HAPs Chlorpyrifos
Madame River	Poor	Total phosphorus Copper Zinc	Poor	HAPs Chlorpyrifos
Case Navire RiverUpstream	Good		Good	
Case Navire RiverDownstream	Good		Good	

[2]PAHs : Polycyclic aromatic hydrocarbons
[3] TBT: tributyltin

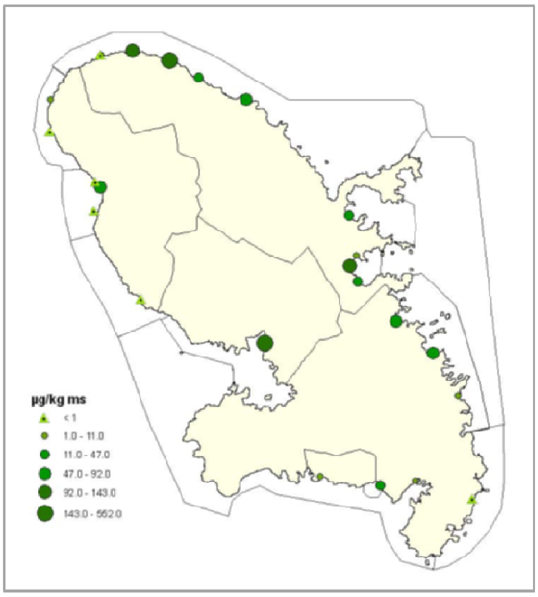

Fig. 15 Distribution of the Chlordecone concentration in the sediments of Martinique's rivers in 2008 Source:[19]

The rivers on the Bay of Fort-de-France slopes drain a large volume of alluvial-terrigenous sediments. These sediment contributions are not distributed homogeneously in the mangrove forest back land because they depend on topography (slopes), hydrology (floods), ocean currents as well as on human actions. The hyper-sedimentation of the Bay of Fort-de-France results in part from the decrease of the vegetation cover of the adjacent water basin due to human impact. For example, according to a study conducted by the Martinique Departmental Direction for Equipment in 1984, each year "la Lézarde" deposited 100,000 m³ of sediments in the Bay of Fort-de-France [17](Fig. 16).

In different areas as well as near the outlet of certain streams, the Bay of Fort-de-France contains notable levels of micro-pollutants [20]. For example, the Bay of Flemands (Fort-de-France) and the estuary of the Madame river are the areas most affected by levels of copper, Zinc and lead[20] (Fig. 2 & Fig. 16). In the "Cohé du Lamentin" and in the Bay of Génipa (Fig. 2 & Fig. 16) the zinc, copper and chromium are abundant[4] [20], [17]. Near the "Petit Ilet" in the Bay of Génipa (Fig. 2 & Fig. 16) the concentrations of heavy metals and hydrocarbons are high [20], [17]. The vicinity of the international airport of Fort-de-France is characterized by high hydrocarbon concentrations [20], [17]. We should also note thatthe "Cohé du Lamentin" presents a strong hyper-sedimentation level and rates high in heavy metals, hydrocarbons and pathogen micro organisms[20], [17]. All this chemical pollution has consequences on the aquatic biodiversity (TABLE II).

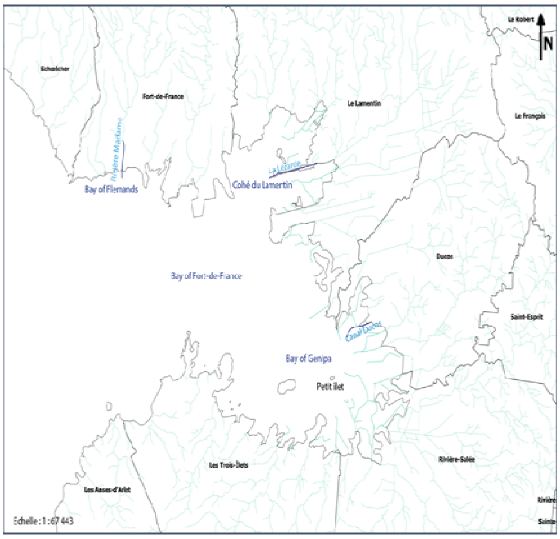

Fig. 16 The rivers of the Bay of Fort-de-France

TABLE II
Example of Chlordecone levels in the aquatic environments and Land-Sea interfaces Source: [21]

Aquatic organisms	**Number of samples**	**De-tection rate**	**Median[5] values (mg/kg of fat)**
Fish stock/River fish	13	69%	0.072
Crayfish	9	56%	0.028
Marine fish	48	13%	0.004
Crustaceans (lobsters, crabs)	15	47%	0.020

Therefore, the ecological state of the Bay of Fort-de-France mangrove forest is more or less disturbed because the situations vary from one floristic entity to

[4]There is also siltation in these two areas.

[5]Number ranging in the middle of the set of values, in other words there are as many items below and above this number

another [22]. According to certain criteria[6], the ecological state of the Génipa mangrove forest is considered "little disturbed”[22](TABLE III). In other words, the ecological state of this mangrove forest would be the right one. Nevertheless, a good environmental status does not systematically mean the absence of species contamination by toxic pollutants. In the Génipa mangrove forest, near the Canal Ducos district and the Canal Ducos stream and near Petit Bourg (Fig. 16), there are areas of high concentrations in pathogens and phosphorus and nitrogen nutrients[20], [17]. The ecological state of the “Cohé du Lamentin”mangrove forests is considered “slightly disturbed”[22] (TABLE III).

[6]Rate of siltation and organic materials, presence and abundance of terrestrial fauna, seagrass beds presence and state of health, etc.

TABLE III

Ecological state of some mangrove forests from the Bay of Fort-de-France compared with other mangrove forests in Martinique Source: [22]

Mangroves	**Vase rate (MW rate) in %**	**Characteristics of the endofauna**	**Ecological status**	**Comments**
Cohé du Lamentin	60 (4.4)	Biomass and high density. Dominance of bivalves	Slightly disturbed	Very strong vulnerability and heritage interest
Génipa	>85 (1.03)	High biomass, dominance of bivalves and echinoderms-rich	Little disturbed	Reserve project
Trou Manuel	<60 (3.46)	High biomass and abundance	Slightly disturbed	Small vulnerable deposits of bivalve of interest.
Massy-Massy	64 (3.29)	Low biomass and abundance. Rich in polychaetes	Slightly disturbed	High vulnerability Very high heritage value
Paquemar	76 (2.79)			
Bay du Trésor	72 (3.56)	Very high biodiversity. Strong biomass and density	Slightly disturbed	Average vulnerability High heritage interest
Bay du requins	56,58 (4.23)	Diversified, balanced biomass and density	Undisturbed	DCE reference site

The destruction of buffer areas for agricultural purposes and the spread of human activities on the outskirts have weakened the Génipa mangroves: in principal the cutting of trees. Accordingly, due to nibbling, the area directly influenced by the ocean environment is no

longer protected from pollution by the mangrove back area. All these problems increase the vulnerability of this wetland ecosystem and lead to the erosion of its ecosystem services [23](Fig. 17). In fact, the hyper-sedimentation in certain areas of the Bay of Fort-de-France or the Bay of Génipa (Rivière Salée and Petit Bourg) is one of the consequences of the surface retreat of the mangrove forests. The latter no longer carries out its function of sediment filtering properly in other words it no longer stores them. Generally, the Bay of Fort-de-France mangrove forests no longer fully stabilize the sediments they receive from the runoff in order to limit access to the Bay. Therefore, the significant sedimentary flows affect the corals and the sea grass which are very sensitive to turbidity. Faced with pollution and no longer protected as before, the Fort-de-France mangrove forests currently suffer from deep ecological imbalances and can no longer carry out their eco system tasks as they did before and therefore they represent the anthropic deregulation of the connected coastal bio systems which become increasingly vulnerable (Fig. 18). For example, the hyper-sedimentation, the nutrients (phosphates and nitrogen), hydrocarbons, pesticides and other pollutants are elements of river degradation and therefore of the quality of marine waters, mangroves, seagrass and coral. Due to their characteristics these elements are anthropization markers.

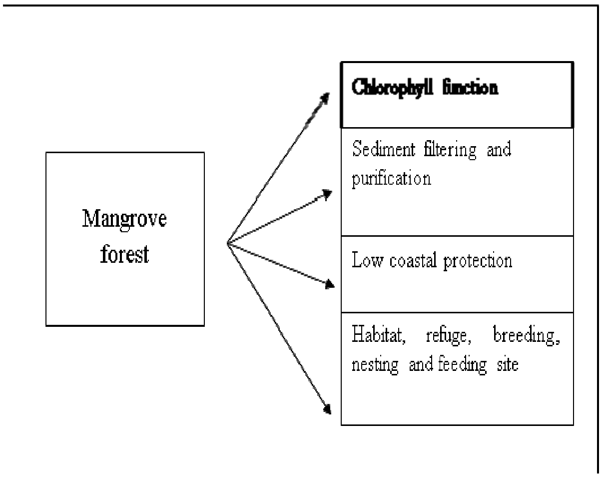

Fig. 17 Diagram of the mangroveecosystem services

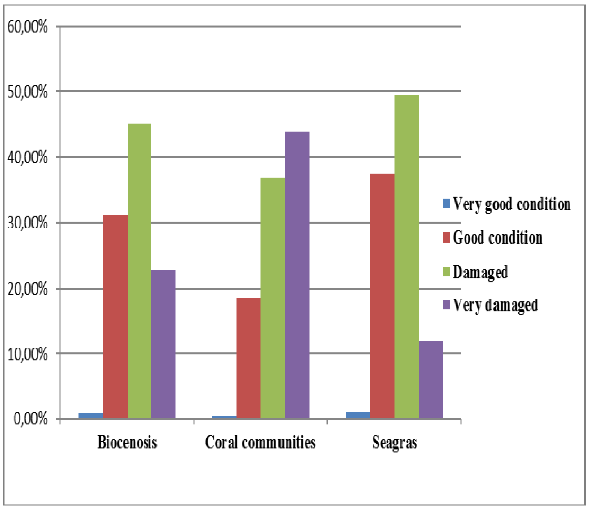

Fig.18Distribution of benthic biocenosis health conditions onthe coast of Martinique, 2006-2008 [the "Biocenosis" field shows the percentage of health conditions for the two combined communities (coral and seagrass communities)]. Source: [18]

Irreversible anthropogenic damages also have a serious impact on biodiversity, its structures, its functions and its evolution process. This could be a handicap for the future development [11], [1],[14]. In fact, the mangrove forest is an ecosystem that is home to a rich and varied biodiversity like specific birds, crustaceans, fish and insects. Together with the plants, the latter form an eco-complex supplying primordial homeostatic functions. It absorbs carbon dioxide, emits oxygen and traps particles in suspension in the air and protects the low coasts from marine erosion by stabilizing sediments [3], [23]. It is also a refuge, a place of breeding, nesting and feeding and a habitat for fish, birds and other animal species[3], [7], [24].

D. What future governance for this ecosystem?

Currently, the Fort-de-France mangrove forests are under no protection. They are not classified as a national or regional nature reserve and are not part of the spaces acquired by the Littoral Conservation authority. They are not subject to any specific prefectural decree and are not classified as natural Zone with Fauna and Flora of Interest (ZNIEFF). However, for several years, one of its components, the Génipa mangrove forest, has formed the object of a regional nature reserve project because it is the most interesting unit from an ecological and biological point of view (less disturbed). The regional natural reserve is in place, as the most suitable regulatory tool for preserving this mangrove forest, its biodiversity and its biological and ecological balance. This tool will contribute both tothe protection and the management of the environment. It may be supplemented by requirements of the Littoral Conservation authority and the biotope decrees of the French State.

However, pending the classification of the Génipa mangrove forests as a regional reserve which will protect it from damage, we should strengthen its mangrove back-land bordered by growing commercial and agricultural activities which represent vulnerability factors. It should be noted that the good ecological state of the rivers that feed the Génipa mangrove forests and the adjacent Bay with terrigenous sediments is vital. Therefore, the pollution and pressures on the water basin must be reduced. In the context of sustainable development, we must find a way to reconcile the economic activities, land planning and the respect for the environment. We must achieve a balance between Nature and Human Society as a territory emptied of its plant and animal wealth is a poor territory.

V. CONCLUSION

The regression of Martinique's mangrove forests is the result of economic growth, rapid urbanization and increased human density in the twentieth century. Population pressures in small areas affect all ecosystems. Together with the littoralisation phenomenon, it is one of the causes of the regressions of the island mangrove forests. In fact, in a few decades, Martinique's landscape has been transformed. The island has moved from an agricultural economy to a service and natural spaces economy against an urban-based economic development. This landscape modification could mainly be observed around the Bay of Fort de France between 1951 and 2004(Fig. 2 & Fig. 9).

All the problems caused by human activities have adversely affected the mangrove forests and the associated ecosystems. In fact, the rivers, mangrove forests, bays, seagrass beds and coral reefs suffer from deep ecological imbalances. In the face of all these pressures, it is imperative, even urgent to protect the Bay of Fort-de-France mangrove forest, the last large mangrove forest of the island. Martinique's heritage ecosystems must be preserved because they can represent a factor of future economic development by means of a controlled development based on a balance between the Environment and Human Society.

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