1. INTRODUCTION

1.1. General introduction

The Republic of Senegal lays at the most western point of Africa. It is located between latitudes 12° 18´S and 16° 41´N. It covers 196 722 km^2 and is bounded on the north by Republic of Mauritania, on the east by Republic of Mali, on the south by Republics of Guinea and Guinea-Bissau, and on the west by the Atlantic Ocean. The Senegal River forms the border with Mauritania, and also with Mali, while the border with Guinea runs along the western spurs of the Fouta Djallon mountains massif.

General landscapes are low plains all over the country. In the extreme South East part altitude rises somewhat, on the Fouta Djallon's mountains.

The Harmattan blows in the dry season in inland areas, markedly raising the temperature and drying the air.

The whole of Senegal falls within the tropical Soudanian zone. Only the south western part, which is wetter, has any Guinean features. The north part, inclusive the Ferlo "desert" is Sahelian in character, with low and irregular rainfall.

Throughout the country there is a wet season and a dry season. Annual precipitation varies from the desert-like north region (300 mm, from july to september) to the humid south region (1.700 mm, from june to october). The influence of rain is manifested in Senegal's three forest zones: (1) the sparsely covered northern Sahelian zone; (2) the transitionary central Soudanian zone, which accounts for two-thirds of the total land area; and (3) the thickly forested southeast Guinean zone. The vast majority of Senegal's forests and woodlands are open savanna, which extends through Soudano-Guinean, Soudano-Sahelian and Sahelian vegetative zones.

In the south, the Soudano-Guinean savanna is characterised by species such as *Parkia biglobosa*, *Prosopis africana and Afzelia africana*. Further north, the characteristic species include *Anogeissus leiocarpus* and *Acacia sieberiana*, while in the Sahelian zone, the vegetation is dominated by species such as *Acacia senegal* and *A. seyal*.

Small areas of closed forest occur in the south-west Casamance region and comprise species such as *Parinari excelsa* and *Erythrophleum guineense* while large tracts of mangroves blanket much of the southern coast of the country, particularly around the Casamance estuary.

Senegal has a well-developed network of protected areas encompassing nine percent of the country's forest area. It is one of the few West African countries having protected areas that are fully representative of all its ecosystems.

The main important of the Senegal protected area is the national park of Niokolo Koba. It has been erected a Biosphere Reserve by UNESCO at 1981. It lays on 9,13 millions ha and it is estimated that it contains 1.500 vascular vegetal species. By its position, the national park of Niokolo Koba is expected to show all the

characteristics of woodland and savanna forest types. This situation makes it ideal for base-line studies of forest ecosystems in Senegal.

Several botanical explorations have been done on the flora. Ba & Noba (2001) have provided a very useful synthesis of the main studies. They highlight the taxonomic spectrum of the flora, which can be seen in the table below. They so calculate that there are 3.589 plant species and they estimate the total number to 4.000 species.

Table 1 Taxonomic spectrum of the flora in Senegal

Embranchements					NF	G	E	EE	EM
Protocaryotes				Cyanobactéries		34	104		
EUCARYOTES	THALLOPHYTES	CRYPTOGAMES	CELLULAIRES	Algues					
				Vertes		50	222		
				Brunes		94	527		
				Rouges		45	74		
				Total		189	823		
				Champignons	Indéterminé				
				Parasites		60	126		
				Mycorhizes		4	11		
				Total		64	137		
				Lichens	6	7	7		
	CORMOPHYTES			Bryophytes		9	19		
			Vasculaires	Ptéridophytes	17	22	38		
		Phanérogames		Spermaphytes					
				Gymnospermes	3	3	4		
				Angiospermes	162	997	2 457	31	50
				Total	165	1 000	2 461		

NF= Number of families, G= genus, E= species, EE= endemic species, EM= endangered species

The World Conservation Monitoring Centre (1989) estimates the number of plant species over 2.100 and the animal species to 550. Even if their estimations are less than Ba and Noba's, their conclusion is that Senegal is the most biologically diverse country in the Sahel.

Although Senegal has the richest biodiversity among sahelian countries (WCMC, 1992), it is facing progressively worse environmental problems. Forest areas are rapidly decreasing due to several factors. While desertification is the major problem in the northern Senegal, southern forests deal with wild fire, over-grazing, and competition with land farmers. All these factors threaten the forest and cause rapid loss of forest areas and also, biodiversity loss and species threatened. WCMC (1992) suspects that 32 plant, 11 mammal, 5 bird and 2 mammal species are threatened over Senegal. Ba & Noba (2001) estimate the phanerogam endangered species to 50 species.

At the contrary, no tree species is particularly endangered according to FAO. But at the same time, FAO notice that some tree populations like *Pterocarpus*

erinaceus, Acacia Senegal, Adansonia digitata, Cordyla pinnata, Saba senegalensis, etc. could be endangered because of hard selective harvesting.

The government of Senegal has successfully implemented a dense network of protected areas which aim to protect i) the biodiversity ii) some typical ecosystems and also iii) threatened species. These protected areas include the national parks and the 'protected forests'.

Many efforts are done to learn about the fauna in the parks, but very little about the vegetation of these sites. In fact it is clear that biodiversity assessment of forest species is of high need in order to have a truth and actual highlight on this topic. These highlights may give guidelines for taking care about biodiversity in forest management programs.

The total area of Senegalese forest is decreasing at an alarming rate. Available statistics suggest that 45.000 to 100.000 ha of forest areas are annually lost. This reflects the fact that the status of forest biodiversity, in terms of habitat, species, populations and genetic diversities seems to be endangered. The main causes of deforestation and forest degradation are:

Climate change

These last years, rainfalls have severely decreased in Senegal like in the whole sahelian and soudanean areas. Comparing the periods of 1930 to 1975 and 1968 to 1984, (Blanfort, 1990) shows how the isohyets moved down. De Wolf & Van Damme note also that the mean of annual rainfall was 1.216 mm on the 1922-1954 period, 1.025 mm on 1960-1993 period and only 873 mm for a period of time 1976-1991. Of course, this great decrease of rainfalls will have negative consequences on the forest welfare.

Figure 1 following (from Senegalese Agricultural Ministry) shows how rainfalls level decreases in Senegal from 1949 to 1994.

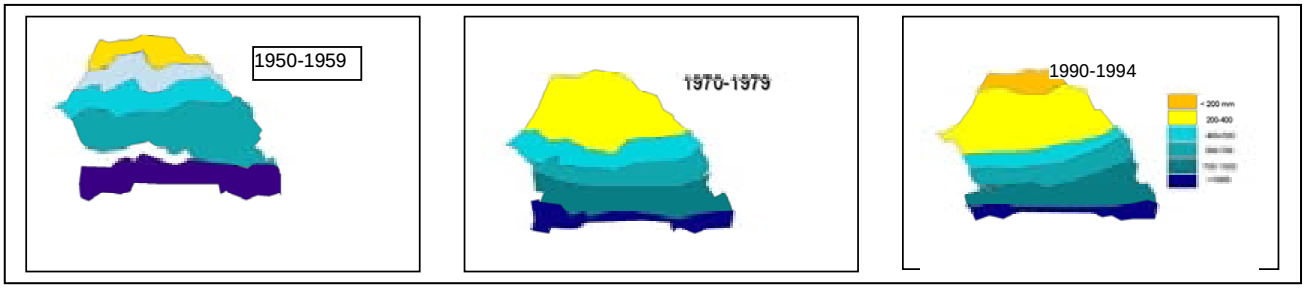

Figure 1: Illustration of rainfalls decrease from 1949 to 1994

Wild fires

Wild fires occur each year and almost all the forest areas are burned. Nevertheless some wild fires are involuntary, most of them are ignite, some by farmers for harvesting honey, some by hunters who want to see better the animals, or by farmers fighting against crops depredators. But one of the major causes of wild

fires remains the objective of increasing grazing. Then after the fire, the new pushes and livestock appreciate tree rejects, indeed those new pushes are very nutrient rich.

De Wolf & Van Damme (1994) explain the forest regression by the wild fire effects. Therefore, they notice that “the consequences of the recurrent wild fire would be a weak rate of renewal and a changing of the global aspect of the forest. The destruction of saplings and seedlings avoid any kind of renewal and cause damages to elder plants such as those plants cannot growth any more and they take a shrubby aspect. So are switching woodland and savanna woodland into shrub savanna.”

Pressure due to the demand of agricultural lands

Local population is increasing, due to natural growth, but almost due to immigration of farmers coming from other parts of the country and looking for productive cultural lands. Then elsewhere in Senegal, particularly in the peanuts basin drought and soil degradation prevent any profitable agriculture.

So new villages are created on low lands and each year more and more forest areas are clear cut and switched to farmer lands. Those low lands are the most species rich parts of the forest and species like *Morinda geminata*, *Saba senegalensis* etc. are exclusively located on these ecosystems.

Forest products harvesting

Many products are harvested from the forest: timbers, firewood, bamboo, fruits, and medicinal plants. Timber and firewood harvesting are the most destructive actions. Timber harvesting focuses on some selected species *(Pterocarpus erinaceus, Cordyla pinnata, Bombax costatum*) and most of the time, all these trees near of the villages or the roads are cut down without considerations of their girth. Furthermore, the straight and high trees are preferred; this may have negative consequences on availability of seeds for regeneration and also on the genetic diversity.

Fuel wood supply is also very damageable for the forest. Wood harvesting is almost done without any management plan; trees are cut over the rate that the forest could support and no attention is paid for the forest regeneration. This activity is one of the most harmful for the forest, it contributes at a high level to the fact that woodlands forests are switching into savanna forests.

Over-grazing

Some studies (Blanfort, 1990) have shown that pastoral charge is inferior to the potential capacity charge on rain seasons, but over charge is almost observed in the dry season. After the crop harvests, livestock are liberated over the forest and they browse all the tree regeneration.

Otherwise, the herder, to provide tree fodder to the livestock cuts down the branches of apetable species and sometimes, the whole tree. Therefore, on grazed areas, some species like *Hexalobus monopetalus* are rare or threatened.

All these factors enumerated may cause rapid and profound changes that endanger both the species diversity and genetic resources of forest ecosystems.

Thus, the conservation of biodiversity has become an important issue receiving national and international attention and it has been recognised that tropical forests are the major source of global diversity, and are the greater producers of biological resources of human welfare.

Some studies relating to forest biodiversity have been done in Senegal. BA & Noba (2001) provided a very useful synthesis of those studies. Almost all of these studies were dealing with classification for recognising and counting the number of species we have in Senegal or in specified forest areas. If this approach is important for knowing the overall plant diversity species ("how many living organisms there are"), it doesn't provide information on evenness and on the relations between the species, their relative abundance and their distribution on regard of some main environmental factors.

De Wolf & Van Damme (1994) have also conducted an important study with an ecological approach, explaining the environmental factors of tree species distribution and the impacts of some main structuring factors (wild fire, grazing, wood harvesting, etc.) on the vegetation of the southern forest areas. Nevertheless, their ecological approach doesn't allow getting enough information on tree species richness and evenness.

Species monitoring is necessary for i) knowing what is available and for ii) an adaptive management approach and the successful implementation of ecosystem management.

Despite their high importance, forest biological resources are still being destroyed at high rates. Therefore, appropriate measures are needed to conserve the existing biological resources, to maintain and to improve their productivity.

1.2. Definitions of biodiversity

The word '*Biodiversity*' is a contraction of 'biological diversity'. There are various definitions of biological diversity in the literature. Volland cited by Gaines et al (1999) defines biodiversity as "the variety, distribution, and structure of plant and animal communities, including all vegetative stages, arranged in space over time that support self-sustaining populations of all natural and desirable naturalized plants and wild animals." On the other hand, Wilcox also cited by Gaines et al (1999) used biodiversity to describe the variety of life forms, the ecological roles they perform, and the genetic diversity they contain. Boontawee et al (1995) gave a similar definition, when they said that "biodiversity is defined as the variety and variability among living organisms and the ecological system in which they occur".

The Rio Convention defined biological diversity as "variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems".

Pielou (1995) distinguish 'biodiversity' from conventional diversity. For him, "When investigating about communities that are narrowly defined in the taxonomic sense and which are confined to fairly restricted areas, it is desirable to measure

quantitatively an attribute of each community that can be called its diversity index and Biodiversity is a altogether different topic. It is concerned with the biota as a whole and the reasons for investigating it are in order to conserve it as it is in nature, by maintaining existent species in their natural habitat." She says that "Conceptually, diversity is a hypothetical topic; it is neutral value whereas biodiversity is part of applied ecology, and it weights different items according to their rarity".

Many others definitions of biodiversity exist, until yet no generally accepted definition has emerged.

1.3. Biodiversity measurements

Almost all ecologists agree with three hierarchized levels of biodiversity that could be the landscape or regional level, the species or taxonomic level, and the genetic level.

At the landscape level, attributes that could be monitored include the identity, distribution, and proportions of each type of habitat, and the distribution of species within those habitats. At the species level, richness, evenness, and diversity of species, guilds, and communities are important. In addition, at the genetic level, genetic diversity of individual organisms within a population is important.

1.3.1. Monitoring at Landscape level

Forman and Godron (1986) cited by Gaines et al (1999) define a landscape as a land area with groups of plant communities or ecosystems forming an ecological unit with distinguishable structure, function, geomorphology, and disturbance regimes. Landscape diversity is the number of ecosystems, or combinations of ecosystems and types of interactions and disturbances present within a given landscape.

Landscape features such as patch size, heterogeneity, connectivity, etc., have major implications to species composition, distribution, and viability (Noss and Harris, 1986). Because of this, it may be important that managers monitor elements of biodiversity at the landscape scale. Examples of monitoring questions at this level could include, what is the current level of landscape diversity and how does it compare with historic or sustainable levels? What are the trends in habitats or populations of a particular species? Moreover, what are the trends in landscape features such as the amount of edge, patch size, forest interior, etc.?

1.3.2. Monitoring at species level

Monitoring at this level is important to the maintenance of ecosystem functions and integrity that have been identified as a main theme of ecosystem management. Example monitoring questions could include how human activities have or natural disturbances affected species diversity in a particular community? Or where are the areas of high species richness, endemism, or rarity and how well are they protected?

A common way of assessing biodiversity is by measuring the number and relative abundance of species in a community or ecosystem, often referred to as species diversity. Species diversity is a function of the number of species present (richness) and the evenness or equitability (relative abundance) of each (Hurlbert 1971).

Various indices and models have been developed to measure diversity within a community. In general, three main categories of measures are used to assess species diversity:

(a) species richness indices, which measure the number of species in a sampling unit,

(b) species abundance models, which have been developed to describe the distribution of species abundance, and

(c) indices that are based on the proportional abundance of species such as the Shannon and Simpson indices. Methods for calculations of those indices will be detailed in next chapters.

1.3.3. Genetic monitoring

Genetic diversity refers to the breadth of genetic variation within and among individual populations and species. Genetic diversity is a necessary prerequisite for future adaptive change or evolution, and WCMC (1992) point out that populations and species that lack genetic variation are at greater risk of extinction.

Examples of monitoring questions that could be asked include, what is the genetic diversity within a population or among populations? How has habitat fragmentation affected the genetic structure of a population or species?

Most of the time however, the laboratory techniques are complicated, time-consuming, and costly. Gaines et al (1999) therefore recommend the following criteria in the selection of populations or species for this level of monitoring:

(a) species or populations that are limited in their numbers and distribution (e.g., endangered, threatened, and candidate species),

(b) populations that are naturally fragmented or have become fragmented as a result of human activities and the likelihood of genetic interchange among component populations is low,

(c) populations that are on the edge of a species range, and

(d) species that naturally occur at low densities but may have wide distribution.

The measurement of morphological variation is the most easily obtained indicator of genetic diversity. Morphological measurements can often be obtained in the field not requiring laboratory studies. However, the assumption that morphological variation is a reliable indicator of underlying genetic variation can be difficult to validate unless it is done in conjunction with allozyme or DNA analysis. The development of recombinant DNA technologies allows the direct measurement of genetic variation as opposed to being estimated from a phenotype.

The concept of biological diversity in an ecological context has to be made clear. WCMC (1992) provide some useful highlights.

1.4. Objectives of the study

The remaining forest areas in Senegal are under heavy and increasing pressure from human and animal populations. They are heavily extracted to meet basic needs such as firewood, building poles, traditional medicine and fodder. Sedentary activities are quickly changing many forest areas into millet, peanuts and cotton fields. At many points around the forest, agricultural activities have penetrated and fragmented the forest. Livestock grazing flood over the entire forest areas for the entire year, prevent any natural regeneration while animals are browsing on woody vegetation and herders are slashing branches and sometimes are cutting the whole tree of palatable species to make the fodder accessible to animals.

Due to the lack of management plans or even utilization guidelines and at the same time the missing of customary land laws to ensure sustainability of the resources, the forest areas in Senegal are being depleted rapidly. Both identified and unidentified ecosystems, species and their genetic resources are being rapidly eroded. So there is an urgent need to explore, identify, protect and manage the available forest diversity properly for maintaining the remaining forest biodiversity for sustainable utilization.

Nevertheless, before sustainable management strategies to protect Senegalese forest are defined, biodiversity studies can be developed. The structure, characteristics and functions of forest ecosystems must be better known.

Furthermore, no credible information is available on forest change in Senegal. People “see” that forest is rapidly decreasing and subsequently the biological diversity is being eroded, but no precise information is available. Then it is now high time to establish a monitoring system for this purpose. In the context of forest biodiversity, a monitoring process involves “the gathering of data to enable the detection of changes in the status, security and biological diversity for the purpose of improving the effectiveness of management of that diversity” (UNEP, 1993). Therefore, monitoring requires the building up of an information baseline in an incremental process. This information baseline would usually include habitats and species. Such an information baseline on forest biodiversity would allow for resource planning that is more enlightened. Continuous updating of the information baseline through repeated collection of data will be part of the monitoring process.

In the management fuel wood supply, the basic approach is to assess the standing stock of the forest and then divide the forest into blocks equivalent to the number of years in the cycle, on regard of the growth rate and the economic yield that should be produced. Blocks control wood harvesting, and some sylvicultural operations are undertaken to assist the growth of tree rejects and the remaining saplings. Despite the general intention, seldom, considerations are given to other resources or soil conservation. No attention is given to managing biodiversity, non-timber products or other environmental aspects in the wood production forest. A crucial question may be: Could tropical forest be managed for all purposes, inclusive biodiversity, at the same time?