Ecological assessment of riparian forests in Benin:

Phytodiversity, phytosociology, and spatial distribution of tree species

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To

My mother,

Gwendoline,

Kévin.

CONTENTS

Chapter 1

GENERAL INTRODUCTION

A.K. Natta

Chapter 1

GENERAL INTRODUCTION

1.1. RESEARCH BACKGROUND

The loss and fragmentation of tropical forest is the single greatest threat to the world's biological diversity (Whitmore 1990, Huston 1994). In 1992, the *Convention on Biological Diversity* highlighted that measures must be implemented for the conservation of natural ecosystems, especially for tropical forests, which are famous for being the most species rich ecosystems on earth. Although many species have been described, very little is known about their ecology (Sayer & Wegge 1992). In Africa the most species-rich forests, at least for woody plants, are in the wetter areas of West Central Africa (from the base of Mt Cameroon South East into Gabon), and in the North East of Madagascar (Gentry 1992). Unfortunately this diversity is characterised by a deforestation rate of 0.7 %, more than twice the world average of 0.3 % (FAO 2000).

In West and Central Africa, the rain forest block is interrupted between South East Ghana and South West Nigeria. Biogeographers call this discontinuity the Dahomey-Gap. Innumerable animals and plants are common to Central Africa and upper Guinea, showing that the two forests blocks have been connected in the past. However, this does not mean that the forests are identical. The two rain forests blocks are characterised by special endemic species to confirm that they have not only been isolated but are intrinsically different (Kingdon 1990). On the other hand, the West-African countries located in the Dahomey-Gap, such as Benin, are characterised by the absence of tropical rain forests and a low percentage of dense semi-deciduous forests. In consequence the need to conserve the biological diversity of remaining fragmented forests, represented by sacred forests, few protected dense semi-deciduous upland forests and riparian forests, in this dry wedge cannot be underestimated.

All over the world, and particularly in tropical savanna, the natural vegetation associated with waterways and mostly represented by riparian forests (or RFs) is credited to be among the most species-rich ecosystems (Meave & Kellman 1994, PGRN/IUCN 1994, Roggeri 1995, Nilsson *et al.* 1997). Riparian forests are important areas for global biodiversity (Sala *et al.* 2000), because they protect key resources for mankind, such as water sources and quality, and stream environment (Vought *et al.* 1994, Lowrance *et al.* 1997, Montgomery 1997, Trimble 1999), and harbour a diversified flora and physical structure (Gibbs & Leitão 1978, Gregory *et al.* 1991, Bersier & Meyer 1994, Kellman *et al.* 1994, Meave & Kellman 1994, Woinarski *et al.* 2000, Kokou *et al.* 2002). Ecologists have also examined the value of riparian forests as habitats for many animals, and recognised them as a priority area for conservation of terrestrial mammals (Doyle 1990, Darveau *et al.* 1998, de Lima & Gascon 1999, Darveau *et al.* 2001), as well as birdlife (Stauffer & Best 1980, Gates & Giffen 1991, McGarigal & McComb 1992, Larue *et al.* 1995, Murray & Stauffer 1995, Darveau *et al.* 1995, Whitaker & Montevecchi 1997, Saab 1999, Woinarski *et al.* 2000).

As tropical forests become more fragmented due to deforestation, riparian forests play a crucial role in providing habitat corridors between forest patches to increase landscape connectivity (Forman & Godron 1986, Forman 1997, Machtans *et al.* 1996). In proportion to their area within a watershed, they perform more ecological and productive functions than do adjacent uplands (NRC 2002). The vital ecological, hydrological and biogeochemical vital functions of these forests bordering waterways are now largely acknowledged. In recognition of these roles, they have been increasingly protected by policies and legislation (DNRE 1996, de Lima & Gascon 1999, NRC 2002, Natta *et al.* 2002). Unfortunately, they are under severe threat worldwide (Sparovek *et al.* 2002), and current management strategies, particularly in the tropics, seem to have limited effects.

A large body of work has demonstrated that riparian forests play a critical role regulating interactions between terrestrial and aquatic components of temperate zones landscapes (Gregory *et al.* 1991, Gilliam 1994, Naiman & Décamps 1997), however there have been relatively few studies dedicated to them in the tropics (Bowden *et al.* 1992, McDowell *et al.* 1992, McClain *et al.* 1994, Chestnut & McDowell 2000, Groffman *et al.* 2001) in general, and Benin in particular.

Flora and fauna reserves represent 11% of Benin surface area, and the flora is estimated to have 3,000 species (PFB 1997), which is relatively poor in comparison with neighbouring humid countries. The natural wooded vegetation represented by savanna and open forests occupy 72.2 % of the country, but dense semi-deciduous forests and riparian forests cover only 3.42 % of the country (CENATEL 2001). During the preparation of Benin's Environmental Management Plan, it was noted that the lack of scientific knowledge of the country's environment constituted a major obstacle to the realisation of the plan and measurement of the effectiveness of the proposed actions. In 1994, following the spirit of the Rio conference, the sustainable development agreement between Benin and the Netherlands emphasised on the knowledge and valorisation of the biological diversity. In 1995 this agreement has retained, as emergency programs, scientific surveys of plant species and the compilation of Benin's flora. The flora is known to be a major component of a region's or a country's biodiversity. Scientific research on species diversity is of great importance in providing accurate information and can enhance the management and sustainable use of phytogenetic resources, especially for endangered ecosystems (PFB 1997), such as riparian forests, which are among the most important forest ecosystems in the majority of degraded woodlands and mosaic of savanna landscapes (Natta 2000).

In Benin the rapid changes in land use have led to the progressive destruction and fragmentation of riparian forests, which provide fertile soil for cultivation, give an opportunity for irrigation, and shelter a wide range of valuable and scarce plants and animals. Therefore, they are systematically targeted for illegal selective tree cutting, hunting and conversion to agriculture. Also, when the riparian forests degrade, forest species become sparse, leaving the vegetation open for the savanna species to invade. Their rich biological resources, especially plant species, are disappearing before they can be inventoried and assessed (Natta 2000). We see that riparian forests can be classified among the endangered ecosystems of Benin because they are marginal among the wooded vegetation and because of their advanced state of degradation. In spite of the fact that there is growing recognition of the ecological, hydrologic, biogeochemical, socio-cultural, economic and aesthetic importance of RFs in Benin, they have remained insufficiently studied (Mondjannagni 1969, Paradis 1988, Sokpon *et al.* 2001) and managed as key vegetation formation for biodiversity protection (Natta et *al*. 2002). Riparian forests have often been ignored, or excluded from vegetation studies in favour to upland forests. RFs flora is poorly known, and no published account concerning the diversity, ecology and spatial distribution of species in riparian forests is available in Benin. We often don't even know which species are present, which one are abundant, rare and what are the underlying ecological factors that govern their presence along waterways.

1.2. OBJECTIVES AND APPROACH FOR THE ASSESSMENT OF RIPARIAN FORESTS BIODIVERSITY IN BENIN

The overall objective of this research is to contribute to a better knowledge of the flora, diversity and ecology of riparian forests in Benin. The specific objectives are to (a) compile a preliminary riparian forests plant species list, (b) assess plant species and ecosystem diversities, (c) investigate plant communities, (d) clarify the structural and floristic relationship of riparian forests with adjacent plant communities, and (e) assess the ecology of certain endangered tree species in riparian forests.

'Biological diversity', in short 'Biodiversity' is defined as "the variability among organisms from all sources including, inter alia, 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". Also Biological resources include genetic resources, organisms or parts thereof, populations of species or any other component of ecosystems with actual or potential use or value for humanity (UNCEB 1992).

In this thesis, the term 'Riparian Forests (or RFs)' does not refer exclusively to dense vegetation dominated by woody species in which grasses are virtually absent (i.e. moist evergreen or dense semi-deciduous tropical forests). Instead, it stands for any topographic (lowest parts of a landscape occupied by waterways) and edaphic (moist soil dependent) woodland at stream/river edges, which is made of a mosaic of plant communities, dominated by woody species in open or closed canopy. Under Benin conditions, open canopies and degraded woodlands at streamside are dominant. Also, light coming from aside allows many heliophytic and pioneering species to grow in riparian forests.

The compilation of the RF plant species list is made through the collection of flowering or fruiting plant growing inside RFs. Field observations coupled with empirical knowledge about the ecology of each RF species allow to find out which species are most frequent, rare, valuable, endangered, endemic, or show a specific adaptability to riparian habitat. Plant species diversity (or phytodiversity) is assessed using several parameters: species richness and abundance, diversity index (Shannon), Equitability index (Pielou), species abundance models, differences in site diversities (comparison of Shannon index), basal area, stem density, life forms and geographical affinity. The diversity of plant communities was assessed through the Braun-Blanquet phytosociological approach combined with multivariate analysis of floristic data.

1.3. ORGANISATION OF THE THESIS

Chapter 2 introduces the study area that covers about 70% of the total area of Benin. Chapters 3 to 10 are self-contained and cover introduction, methods used for data collection and analysis, results, discussion and conclusions. Chapter 3 presents an overview of riparian forests in Benin, as unique but endangered ecosystem. Chapter 4 and 5 highlight the floristic diversity and variability of structural parameters within riparian forests. Chapter 6 assesses plant communities' diversity using the Braun-Blanquet phytosociological approach, and ordination and classification of floristic relevés. Chapter 7 deals with the ecology of *Pentadesma butyracea* Sabine (Clusiaceae), a tree species rare in Benin. Chapter 8 and 9 focus on the variability of species composition and structural parameters across riparian forests. In chapter 10, sampling methods are compared to estimate the density of two *Khaya* species. A general discussion and conclusions are presented in chapters 11 and 12, respectively.

Chapter 2

STUDY AREA

A.K. Natta

Chapter 2

STUDY AREA

2.1. LOCATION OF THE STUDY AREA IN BENIN

Benin is located at the so-called Dahomey Gap, in which Sudan-type savanna vegetation extends as far as the sea, through a hiatus in the West African rain forest over some 200 km from South East Ghana to South East Benin (Guillaumet 1967, Schnell 1976, Onochie 1979, Whitmore 1990, Martin 1991, Maley 1996). In the entire Dahomey Gap, the present day pattern of vegetation is very much obscured by the omnipresent impact of dense human settlements and ever developing agriculture and fishing (Jenik 1994, Kokou & Caballé 2000). Nevertheless forest islands and riparian forests stretching along the rivers contain many humid forest elements (Adjanohoun 1968, Kokou 1998, Kokou *et al.* 1999, Sokpon *et al.* 2001). The conservation of forest patches and forest species is this dry wedge is of great ecological and economic importance (Natta *et al.* 2002). Forest patches of varying size, including riparian forests, and large trees of *Antiaris toxicaria, Diospyros mespiliformis, Milicia excelsa,* on firm ground indicate the potential climax of the semi-deciduous closed-canopy forest (Hall & Swaine 1981, Sokpon 1995). Figures 2.1 and 2.2 present Benin republic in West Africa and in the Gulf of Guinea, respectively.

An extensive preliminary field reconnaissance of riparian forests in all the ecological regions of Benin was made. It appears that South of 7º N (i.e. Littoral, Atlantic, Ouémé, South-Plateau, Mono, and South-Couffo provinces) riparian forests are very degraded and sites at least 1 ha large (i.e. in which we can installed > 20 plots each of 500 m^2) are uncommon. Therefore to fit with the present-day distribution pattern of riparian forests, and for practical reasons, several large and least degraded sites North of 7º N were selected for intensive data collection. This study area stretches from 7º to 12º20 N, and covers about 70% of the total Benin area. It is subdivided into 3 ecological zones:

1 - The Guinean region: from 7º N (South of Abomey latitude) to about 8º N (at Savè latitude);

2 - The Sudano-Guinean zone: from about 8º N to about 9º10 N (at Pénéssoulou-Bétérou latitude);

3 - The Sudanian region: from about 9º10 N to the extreme North of the country (12º20 N at Karimama latitude).

In comparison with the Sudano-Guinean and Sudanian regions, the vegetation in the Guinean region has been surveyed many more times:

- Coastal zone (Adjanohoun 1966, 1968, de Souza 1979, Paradis 1975a, 1976, 1979, 1981, 1983, FAO 1980, Akoègninou 1984, Adjanohoun *et al.* 1989, Djego 2000, etc.);
- The complex of lakes, lagoons and inundation valleys (Paradis & Adjanohoun 1974, Paradis 1975a, 1975b, 1979, 1980, 1983, FAO 1980, Paradis & Rabier 1979, Texier *et al.* 1980, Adjanohoun *et al.* 1989, Guinko 1974, Essou 1991, Sinadouwirou 1997, etc.);
- The Niaouli forest (Mondjannagni 1969, Akoègninou 1984, Hountondji 1998, etc.);
- The Lama forest (Paradis & Houngnon 1977, FAO 1980, Adjanohoun *et al.* 1989, Agbani 2002, etc.);
- The Pobè forest (Akoègninou 1984, Adjanohoun *et al.* 1989, Sokpon 1995, etc.);
- The Ouémé, Dogo and Kétou regions (apart from the Pobè forest) (Paradis *et al.* 1978, FAO 1980, Paradis 1983, Akoègninou 1984, Adjakidjè 1984, Adjanohoun *et al.* 1989, Bossou 2001, etc.);
- The plateau of Allada (Paradis 1983, Adjakidjè 1984, Adjanohoun *et al.* 1989, etc.);

- The Kouffo zone (FAO 1980, Paradis 1983, Akoègninou 1984, Adjakidjè 1984, Adjanohoun *et al.* 1989, Amétépé 1997, etc.).

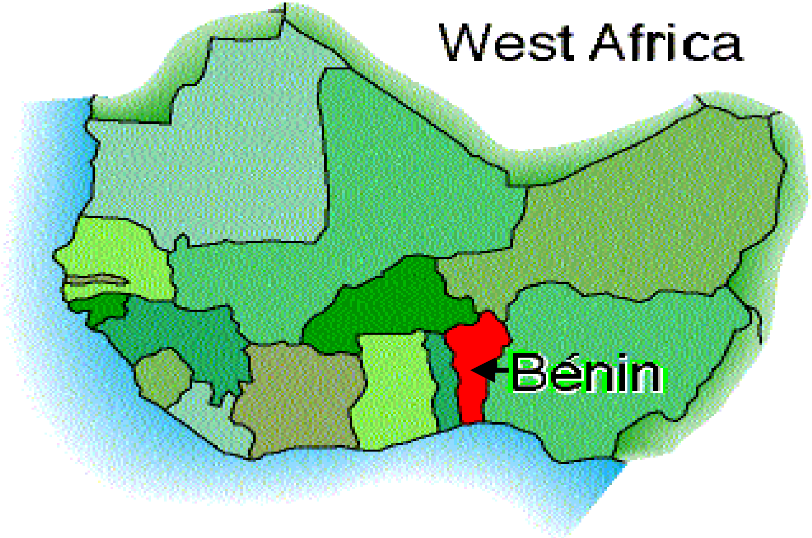

Figure 2.1: Benin in West Africa

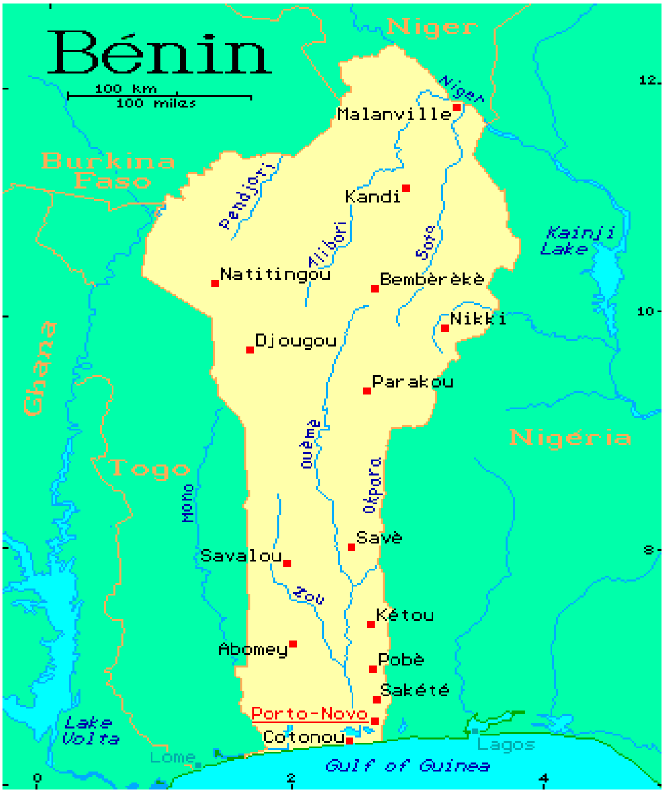

Figure 2.2: Benin with its rivers

Until recently, riparian forests in the three zones of the study area have rarely been studied as compared to other vegetation types. This study is concerned with edaphic and hygrophile forests along fresh water bodies. Therefore the study area does not include the coastal complex, which consists of several littoral cordons, marshy shoals, mangroves, lagoons (e.g. Porto-Novo and Ouidah), and lakes (e.g. the Nokoué, Ahémé, Toho, Togbadji, Azili, Sélé, etc.). Likewise, the 'barre' region that adjoins the coastal plain through an uneven embankment where there is a depression referred to as the 'Lama forest' is excluded from the study area.

2.2. GEOMORPHOLOGY

Geologically, the study area can be divided in three parts: the Northern plateau of South Benin, the crystalline plateau in the Centre and North, and the Niger River basin in the extreme North.

The Southern part of the study area corresponds to the Northern plateau (Aplahoué, Abomey and Kétou) of Southern Benin, which corresponds to the West African continental terminal. It reaches 100-150 m in altitude, with red sandy argillaceous soil and lateritic crusts (Paradis 1983).

The major part of the study area, from the North of Bohicon to Kandi, is occupied by the crystalline plateau, which has tropical ferruginous soils. Within this vast peneplain there are many residual inselberg landscapes (300 - 400 m high with convex sides) including the hills of Dassa-Zoumé, Savalou, Savè, Yaoui, Ouari-Maro, Bembèrèkè and Sinendé. The North West part corresponds to the Atacora region dominated by a series of mountain chains that reaches an elevation of 600 m.

The Northern part of the study area corresponds to the Niger River basin, which ranges from the Goungoun village latitude to the Niger River. It is a sandy plateau with an average altitude of 200 to 250 m. Sedimentary formations predominate, with here and there cuirass hills of about 270 m high. There are also important valleys of variable lengths with alluvial soils along the Sota, Alibori and Niger Rivers.

2.3. CLIMATE

Benin is a hot tropical country under two influences: the humid maritime wind that blows from April to November in South-North direction and the dry continental trade wind, the Harmattan, that blows from the Sahara desert in the North-South direction. The Harmattan is the main cause of drought. The mean temperatures are constantly high (25° C) with daily amplitude below 5° C in the South and 10° C in the North. The largest temperature variations occur during the days of Harmattan. Nowadays, the country is characterised by a great irregularity of annual rainfall from one year to another and within each year. In the South-North direction annual rainfall decreases (1300 to 800 mm) while evapotranspiration and temperatures increase. The climate is of two types (Guinean in the South and Sudanian in the North) separated by a transitional Sudano-Guinean zone (from about 8° to 9° N).

The South of the study area, (7° to 8° N), has a sub-equatorial (or tropical humid) climate subdivided into four seasons of unequal length: two rainy seasons (from April to July, and September to October), and two dry seasons (from November to March, and end of July to August).

The North, from about 9° to 12° N, is the domain of Sudanian (i.e. dry tropical) climate with two seasons: a rainy season from May to September-October, and a dry season from October to April. The annual rainfall varies from 1100 to 800 mm. The rainy season is shortened as latitude increases toward the Niger River basin in the extreme North. In the

Sudanian region higher rainfalls are linked to relief (e.g. Atacora region, Bembèrèkè and Nikki with 1200 to 1300 mm). The extreme North (Malanville - Karimama) is the domain of the North-Sudanian climate, with an average annual rainfall of 800 mm, and up to 2000 mm of evapotranspiration, aggravated by the Harmattan winds.

Between the Guinean and Sudanian regions (about 8° to 9° N), there is a gradual climatic change characterised by the disappearance of the short rainy season and the fusion of the two peaks of rainfall that are typical for the sub-equatorial climate of Southern Benin. Annual rainfall varies from 1100 to 1300 mm and evapotranspiration between 1400 to 1500 mm.

2.4. HYDROGRAPHY

The study area includes three hydrographic basins: 1) the medium and upper parts of the Ouémé basin in South and Central Benin; 2) the Niger River and its tributaries (i.e. the Mékrou, Alibori and Sota) in North Benin; and 3) the upper part of the Pendjari basin in North West Benin.

The river network is presented in Figure 2.2. Every year the rivers are at their highest level and cause inundation from August to December in the South, and August to November in the Centre and North; while streams are characterised by daily submersion following storms or heavy rains. Streams in Benin are generally temporary; meanwhile some have a permanent regime linked to the relief (e.g. headwaters in the Atacora mountains region). In valleys, depending on the topography, and volume of water in rivers and streams, inundation and emersion alternate. Along the Pendjari and Niger rivers there are vast flood plains.

2.5. HUMAN INFLUENCE

From 1979 to 2002, the population of Benin has doubled from 3.3 to 6.7 millions of inhabitants. The average annual population growth is 3.5 %. The South of the country has the highest population density with 150 inhabitants per km^2, while the Centre and the North have only 20 inhabitants per km^2 (INSAE 1979, 2002).

Farming, tree cutting, as well as a high incidence of fire have reduced the original woodland to their current state. In recent years the deterioration of vegetation formations within Benin has increased at an alarming rate (CENATEL 2000). Each year about 100,000 ha of natural vegetation are degraded and the tendency is not decreasing (CENATEL 1995). In the whole country, farming on marginal lands, deforestation of riparian forests and savanna woodlands for cotton and yam cultivation, excessive pruning of valuable trees and uncontrolled bush fires are on the increase. In the South, the present-day pattern of vegetation is very much obscured by the omnipresent impact of dense human populations.

There are many small relict groves (i.e. sacred forests) and remnant semi-deciduous forests (e.g. Lama, Pobè, Itchédé, Dangbo, etc.) of varying size scattered all over the area (Sokpon 1995). In Central Benin, original forests have been cleared and replaced by a mosaic of savanna and dry forests, while the North with a much drier climate, is unfavourable for forest establishment, and is therefore dominated by Sudanian savanna. The process of natural resources degradation leads to the impoverishment of biodiversity due to the loss of wooded vegetation and their replacement by shrub savanna, which is known to have much less ecological potential.

2.6. VEGETATIONS

As for the whole country, the study area vegetation is characterised by a great variety and a fragmentation of phytocenoses caused, on the one hand, by climatic, topographic and edaphic factors and, on the other hand, by human influence on the environment.

The South of the study area prolongs the derived savannah (Jones 1945) and Southern Guinean zone of Nigeria (Keay 1959). It is the domain of:

- Humid semi-deciduous forests with *Antiaris toxicaria, Strombosia glaucescens, Triplochiton scleroxylon* and *Terminalia superba* (Northern part of the Guinean sub-zone IIA of Adjanohoun *et al.* 1989);
- Dry semi-deciduous forests and derived savanna with *Anogeissus leiocarpus, Afzelia africana* and *Lonchocarpus sericeus* (Northern part of the Guinean sub-zone IIB & C of Adjanohoun *et al.* 1989);
- Dry forests with *Anogeissus leiocarpus* and *Daniellia oliveri* (Guineo-Sudanian transitional sub-zone IIIA of Adjanohoun *et al.* 1989);
- Woodland savanna (with *Ceiba pentandra, Milicia excelsa* and *Daniellia oliveri*), and tree and shrub savanna (with *Daniellia oliveri, Elaeis guineensis* and *Lophira lanceolata*) (FAO 1980);
- Savanna on hills (with *Afrotrilepis pilosa, Ficus abutifolia, Hildegardia barteri* and *Aeollanthus pubescens*) (Yédomonhan 2002).
- Tree and shrub savanna (with *Anogeissus leiocarpus, Vitellaria paradoxa, Daniellia oliveri, Isoberlinia doka* and *Parkia biglobosa*) with high incidence of cultivation (FAO 1980).

The Centre of the study area is a prolongation of the Northern Guinean zone of Nigeria (Keay 1960) and a small part of the dry semi-deciduous forest, the fire sub-type of Hall & Swaine (1981). It is the domain of:

- Patches of semi-deciduous forest with a few big stems of semi-deciduous trees (e.g. *Antiaris toxicaria, Milicia excelsa, Cola* spp.*, Khaya senegalensis* and *Celtis* spp.) in the Bantè, Ouèssè and Bassila districts (FAO 1980). Particularly, a facies of dry semi-deciduous forest is seen in the Sudano-Guinean region of Bassila with *Khaya grandifoliola, K. senegalensis, Albizia* spp.*, Cola gigantea, Antiaria toxicaria, Milicia excelsa, Erytrophleum guineensis, Anogeissus leiocarpus,* etc. (variant of sub-zone IIB of Adjanohoun *et al.* 1989);
- Open forests with *Isoberlinia* spp.*, Pterocarpus erinaceus, Khaya senegalensis* and *Monotes kerstingii* (Centre and North of the sub-zone IIIB of Adjanohoun *et al.* 1989);
- Woodland, tree and shrub savanna (with *Anogeissus leiocarpus, Vitellaria paradoxa, Daniellia oliveri, Isoberlinia doka* and *Parkia biglobosa*) (FAO 1980).
- Tree and shrub savanna with high incidence of cultivation (FAO 1980).
- Savanna on hills South of Alafiarou, and in the Kouffé Mountains reserve forest (FAO 1980).

The North of the study area is a prolongation of the Sudanian zone of Nigeria (Keay 1949) and the plains of Northern Togo (Ern 1979). The Sudanian region (or dry continental zone, FAO 1980) is the domain of typical savannas, or dry forests on deep or rich soils:

- Open forests with *Isoberlinia* spp.*, Pterocarpus erinaceus, Khaya senegalensis* and *Monotes kerstingii* (Northern part of the sub-zone IIIB of Adjanohoun *et al.* 1989);
- Sudanian savannas with *Afzelia africana, Burkea africana, Anogeissus leiocarpus, Parkia bigblobosa, Vitellaria paradoxa, Terminalia* spp.*, Daniellia oliveri, Combretum* spp.*, Crossopteryx febrifuga, Acacia* spp.*, Balanites aegyptiaca, Sclerocarya birrea,* etc. and numerous grasses (sub-zone IVA and IVB of Adjanohoun *et al.* 1989, FAO 1980); The sub-zone (IVB) includes the Atacora mountains chain;
- Savannas and dry forests with Combretaceae of the Gourma (or Pendjari) plain in North West Benin, along the Togo and Burkina-Faso borders (sub-zone IVC for Adjanohoun *et al.*

1989). In the West of the Pendjari complex, there is a facies of tree and shrub savanna with *Anogeissus leiocarpus, Combretum* spp.*, Acacia* spp.*, Balanites aegyptiaca* and *Ziziphus mauritiana* (FAO 1980);
- Tree and shrub savanna with high incidence of cultivation (FAO 1980).

The extreme North of the study area (very dry continental zone with 6-7 dry months, FAO 1980) is dominated by:
- Woodland, tree and shrub savanna (with *Anogeissus leiocarpus, Combretum* spp.*, Acacia* spp.*, Balanites aegyptiaca* and *Ziziphus mucronata*).
- Tree and shrub savanna with high incidence of cultivation.
- Saxicolous tree and shrub savanna (with *Adansonia digitata, Combretum* spp. and *Acacia* spp.).
- Shrub savanna and prairie (with *Echinochloa stagnina, Vetiveria nigritana,* etc.) in the Niger River inundation plain.

The annual crops (maize, cassava, yam, millet, sorghum, cotton), the perennial plantations (oil-palm from the last two centuries onwards in the South), the gathering of firewood, production of charcoal, selective cutting of valuable trees and uncontrolled bush fire, have brought about the destruction of forests and woodlands and replaced these by tickets and grassy phytocenoses. The result is a mosaic of savanna, bush fallow and cultivated areas in which remnant forest and savanna species are frequently seen. Meanwhile, the important hydrographic network still allows the presence of many riparian forests, widely distributed all over the country.

2.7. SITES OF DATA COLLECTION

Representative sites of the largest and least degraded riparian forests were chosen along several rivers and streams in the Guinean region (Samiondji and Bétécoucou), the Sudano-Guinean zone (Toui-Kilibo, Idadjo, and Pénéssoulou) and the Sudanian region (Bétérou, Onklou, Daringa, Ouaké, Affon, Yarpao, Boukombé, Toukountouna, Pendjari Biosphere Reserve, Kandi, Gbèssè and Malanville; see Figure 4.1).

Chapter 3

RIPARIAN FORESTS, A UNIQUE BUT ENDANGERED ECOSYSTEM IN BENIN

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Chapter 3

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ABSTRACT

Riparian forests are often small in area, but are of extreme ecological and economic value for local people. The interest of riparian forests lies in their resources: basically fertile and moist soils, water, wood and non-timber forest products that are utilised by neighbouring populations to satisfy their basic needs and as source of income. Their abusive overuse is widespread and growing in Benin. As a result rich biological resources, especially plant species, are disappearing before they can be inventoried and assessed. Most recent management plans for protected areas barely consider the conservation of riparian forests. The forest law in Benin recognises their uniqueness, but several problems arise in the implementation of the rules in these particular areas. The most common and widespread tree species in riparian forests in Benin are *Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Berlinia grandiflora, Elaeis guineensis, Manilkara multinervis, Xylopia parviflora, Dialium guineense, Diospyros mespiliformis* and *Parinari congensis*. Waterways and their forested banks are rich in birdlife, and serves as a focal point for primates and animals of many kinds. Site-specific studies at ground level are essential to assess riparian systems because their narrow linear shapes generally require data on plant community structure, floristic composition and animal presence. Details of vegetation layers under the dominant trees cannot yet be detected by remotely sensed data. This paper presents an overview of the biological diversity of riparian forests in Benin and discusses several issues associated with their protection and conservation.

Key words: riparian forests, flora and fauna diversity, biodiversity protection, Benin.

3.1. INTRODUCTION

The current state of knowledge about species and ecosystems in the tropics is far from complete. Detailed knowledge about the ecology of plants, floristic composition and diversity of plant communities, that would be the obvious first step in understanding and conserving them, is still incomplete or lacking. It is generally agreed that species extinction is largely related to the reduction and fragmentation of their habitats (SWAMINATHAN 1990). Therefore the protection of species can best be done through protecting habitats. In order to formulate policies or take measures to tackle the decline of biodiversity it is important to identify the ecosystems, which have a high diversity value, and are endangered. It is needed to investigate their ecology, assess their current diversity and understand the factors and processes of their impoverishment. In Benin, savanna is the dominant wooded vegetation. The narrow strips of often fragmented woodland that border streams and rivers, - the riparian forest - are good examples of such shrinking and endangered ecosystems.

The rapid changes in land use in Benin have led to the destruction and fragmentation of riparian forests. They are classified as endangered ecosystems because they are marginal among the wooded vegetation and of their high degradation state. Their importance in the functioning of river/streams ecosystems and biodiversity protection is recognised by several authors (ADJANOHOUN 1965; FORMAN & GODRON 1986; BAKER 1990; TABACCHI *et al.* 1990; POLANSKY 1994). Although small in size, riparian forests are important in the conservation of numerous plants and animals. Usually situated on fertile and moist soils near water, their economical interest lies in the supply of wood and non-timber forest products.

Despite their wide distribution in Benin and large economic and ecological value, riparian forest ecosystems have, until recently, remained largely ignored and unmanaged as key ecosystems in biodiversity protection. This is partially due to the insufficient scientific knowledge about species occurring in riparian forests, which hinders appropriate planning, and conservation initiatives dedicated to them. Although the government of the Republic of Benin decreed a new forest law in 1993, the implementation of the law related to the protection of riparian vegetation, especially in non-protected areas, leaves to be desired.

3.2. FORESTS IN BENIN

Centuries of intense human activity accompanied by a drying climate resulted in the loss of most of Benin's closed forests long ago. Small patches of moist forest remain today only on moist soils, or as numerous sacred forests and riparian forests. FAO estimated in 1980 that only 470 km^2 (only 0.4% of Benin's land area) remained under natural cover of closed broad-leaved forest. Of this, only 140 km^2 was considered to be undisturbed. Flora and fauna reserves occupy 21,440 km^2 (PGRN/IUCN 1994). Benin's flora is estimated to have close to 3,000 species (PFB 1997), which is relatively poor in comparison with more humid neighbouring countries.

Benin is said to be a non-forestry country because tropical rain forests are absent and dense semi-deciduous forests are rare among wooded vegetations (SOKPON 1995). In fact, Benin is located at the discontinuity of the tropical forests zone in West Africa, '*the Dahomey gap*', which is the product of topographic, oceanographic and climatic interactions (JENIK 1994). For ERN (1988), this gap includes essentially the drier types of the Guineo-Congolian forest belt in South-Eastern Ghana, Southern Togo and parts of Southern Benin. As a result there are no evergreen tropical forests or rain forests in Benin. At the same time there is an increasing demand of wood material to satisfy the need for fuel and construction. In the South of Benin, increasing population pressure on natural ecosystems has led to rapid degradation of woodlands. The remaining forest patches include the Lama and Pobè relict forests (ERN 1988; SOKPON 1995). In Central Benin, original forests have been cleared and replaced by a mosaic of savannas and dry forests. The North, with a much drier climate, is unfavourable for forest establishment, and is therefore dominated by more thinly wooded Sudanian savanna.

Meanwhile, the important hydrologic network allows the presence of many riparian forests widely distributed all over the country. The hydrographic network includes the Atlantic Ocean watershed with the Ouémé, Couffo and Mono Rivers and their tributaries, while the Niger River, takes in the waters of the Sota, Alibori and Mékrou Rivers. In the North West of Benin, the Pendjari stream starts in the Atacora mountains and ends in the Volta River in Ghana. In the South there is an important complex of coastal lagoons, lakes and swamps areas. Most streams are seasonal.

3.3. DEFINITION AND DESCRIPTION OF RIPARIAN FORESTS

Riparian (from the Latin ripus, bank; as of a river) points to the banks and other terrestrial areas adjacent to watercourses, fresh-water bodies, and surface-emergent aquifers whose transported waters provide soil moisture in excess of that otherwise available locally, sufficient to support a mesic (moist soil dependent) vegetation distinct in structure and/or floristics from that of the contiguous and more xeric uplands (WARNER 1979). The regional and temporal dimensions of climate, geomorphology, topography and biogeography mould both structure and floristics of the riparian systems (WARNER & KATIBATH 1980).

Different authors have used several terms to designate riparian forests: ripicole forests (GREEN 1979a, DEVINEAU 1984), gallery forests (ADJANOHOUN 1965; DEVINEAU 1975, 1976, 1984, GREEN 1979b; KELLMAN *et al.* 1994; NATTA 2000; SOKPON *et al.* 2001); riverbank forests (GREEN 1979a), riverine forests (ADJANOHOUN 1965; DEVINEAU 1984; VARTY 1990; MONNIER 1990; MEDLEY 1992; SOKPON 1995; NATTA 2000; SOKPON *et al.* 2001), riverine woodlands (VAN ETTEN 1999). Other authors (e.g. BAKER 1990; TABBACHI *et al.* 1990; LEINARD *et al.* 1999) have used riparian vegetation in the sense of any plant community occurring along rivers or streams. The inter-African agreement on the definition of tropical vegetation types at Yangambi (ref. 1956) classified riparian forests among edaphic (soil dependent) forest formations (TROCHAIN 1957).

Riverine forests are dependent on river processes including inundation and transport of sediments. They occur in narrow strips along river courses, and are created and maintained by groundwater seepage from the river and by periodic flooding. In the Jubba Valley (Southern Somalia) riverine forests occur in small isolated patches rarely more than 300 m wide (VARTY 1990). In the same region, MEDLEY (1992) described the Tana riverine forests (in Kenya) as fragmented patch-mosaic forests within a narrow corridor defined by the groundwater hydrologic regime, floods and meandering pattern of the stream.

In the West-African region, MONNIER (1990) described the riverine forests as deciduous forest characterised by a linear shape, a structural originality and a microclimatic specificity. In the forest-savanna ecosystems of Côte d'Ivoire, ADJANOHOUN (1965) qualified riverine forests at both riversides as strips dominated by big trees and liana species, belonging almost exclusively to dense forest. They appear to be one of the most important ecosystems in the majority of savanna landscapes where they underline the course of rivers.

In the Benin context, where savanna is the most dominant ecosystem, we suggest to use the term 'riparian forest' for any forest type occurring at river banks and along streams. This may include semi-deciduous forest, dry deciduous forest and woodland savanna located at river or stream banks with more or less sharp limits in respect to adjacent plant communities. Although these plant communities, dominated by trees, are often fragmented and degraded, there are still good examples of undisturbed riparian forests (e.g. at Yarpao, Pénéssoulou and the Bondjagou forest in the Pendjari National Park). In many regions high human pressure has reduced the width of riparian forests up to a single tree, so they are often extremely narrow and quite linear (strip-like) in configuration. Floristic data and the distinction between core and edge species may be important to describe the limit of riparian forests when the structure is uniform beyond the riparian forest.

The main characteristics of typical riparian forest ecosystems can be summarised as:

- Location along rivers and streams in close contact or not with the water flow;
- Combination of mesic terrestrial vegetation, dependent animal life, and local microclimate and dynamic water and soil processes;
- Multi-layered vegetation structure dominated by moist-dependent trees, which form a distinctive physiognomy in the landscape, particularly in the savanna region. Associated with these mesic trees is a host of mesic understorey, shrub and ground cover species;
- Floristic composition often includes the plant species of the region that require most moisture.

We do not consider wetland vegetations occurring in swamp areas (shrubs, grass savanna, marsh, mangrove vegetation, etc.) as riparian forests. The distinction between several riparian forest stands can be expressed in plant communities on the basis of their physiognomic, floristic, and structural characteristics through phytosociological surveys.

These are compiled on the basis of abundance-dominance by allocating a coefficient to each plant species according to the ratio of species density to the area surveyed.

3.4. ECOLOGICAL AND ECONOMIC IMPORTANCE OF RIPARIAN FOREST ECOSYSTEMS

Biodiversity is often seen as an indicator of the well-being of ecological systems, as well as a useful tool in environmental monitoring and assessment. The role played by biodiversity is strongly related to natural ecosystems, which are often the only viable locations for the conservation of certain natural variability (SALLEY & NIENG 1997). Water and vegetation are central components of tropical ecosystems (OTTO 1993), which in turn are key repositories of global biodiversity. In the sub-Sahara savanna region, where small patches and fragmented woodlands often represent remnant forests, riparian forest stands are sites of important ecological and economic values. Also, resource managers understand the interrelationships between the four components of an ecological site: landscape position (physiography), climate, soils and vegetation. These basic relationships must still be considered for riparian areas, as must landform, fluvial geomorphology and hydrology. Thus soils, fluvial geomorphology and climate are the most reliable indicators of riparian vegetation potential (LEINARD *et al.* 1999).

More than other vegetation types, riparian forests are well-known for their role in controlling water sources, watersheds, water runoff and quality, mineral nutrient flows (PIEGAY 1997), stream bank erosion (VAN ETTEN 1999). They influence sedimentation, bank stabilisation, flood and hydrologic regimes, pollution, water shading and cooling, sediment filtering, aquifer recharge, and transport of sediments (MEDLEY 1992). According to THOMAS (1996), typical riparian forest tree species are dependent on river flows, a shallow aquifer, and the community and population structure of riparian forests are related to spatio-temporal patterns of flooding. They are under the influence of fluvial geomorphology processes (BAKER 1990). Also they usually act as routes for movement of terrestrial plants and animals across the landscape (FORMAN & GODRON 1986) and serves as the most suitable area for plant species adapted to a moist climatic regime (MEDLEY 1992).

On riparian systems in general, the United States Council on Environmental Quality stated ‘no ecosystem is more essential to the survival of fishes and wildlife’ (WARNER & KATIBATH 1980). Although small in size (VARTY 1990; MONNIER 1990), riparian forests are important in the conservation of a large range of plants and animals. Not only do they constitute a natural habitat or the last refuge for many species, but also they contain many endemic species and extinction-menaced species (ROGGERI 1995). Some authors have discussed the necessity to preserve plant diversity in riparian forests as a means to protect certain animals. In the Tana River National Primate Reserve of Kenya, Medley (1992) showed that the preservation of key resources in riverine forest, such as the endangered Tana River red colobus (*Colobus badius rufomitratus*) and crested mangabey (*Cercocebus galeritus galeritus*), should be coupled with protection of forest heterogeneity that characterises this dynamic landscape.

3.5. DESTRUCTION AND LOSS

Misuses of riparian systems are global, chronic and accelerating (WARNER & KATIBATH 1980). Decades or centuries of human influence are usually seen as the main causes that have reduce riparian forests in both size and structural complexity. The result is a poorer biodiversity and landscape impoverishment. Their rich biological resources, especially plant species, are disappearing before they can be inventoried and assessed (NATTA 2000). As a consequence, this affects ecological equilibrium especially at local level (MONNIER 1990).

The interest of riparian forests lies in their resources: basically fertile and moist soils, water, wood and non-timber forest products that are utilised by neighbouring populations to satisfy their basic needs and as source of income. The fertile soil, the presence of water and moist soils, the supply of sediments from inundation, allow certain human activities such as shifting cultivation, irrigation and cattle ranching. Also the presence of a variety of plants and animals related to water regime, such as valuable and rare tree and animal species, enables selective tree cutting (for timber, traditional fuel gathering for sale, honey collection) and hunting. The collection of all the seeds of valuable tree species (e.g. *Pentadesma butyracea*, SINADOUWIROU 2000) is an additional threat to the survival of their population. Also disruption of watershed vegetation, damming of watercourses and/or diversion of stream flow, excessive lowering of aquifer levels through pumping, channelisation and levee construction on watercourses often cause significant damage to riparian systems. As a result indigenous multilayered plant communities have been completely removed in many parts and replaced by weeds, open field, shrubs or grass savanna with much less ecological value and economic potential.

3.6. PLANT COMMUNITIES AND FLORISTIC COMPOSITION OF RIPARIAN FORESTS IN BENIN

Following the work of ADJANOHOUN et *al*. (1989), HOUINATO *et al.* (2000) divided Benin in ten phytogeographic districts with distinctive geomorphologic, plant communities and flora. For each district an overview of riparian forest flora is presented.

The coastal region is the domain of marshlands, lakes, lagoons, coastal thicket or scrub and a number of small relict groves. The present-day pattern of vegetation is very much obscured by the omnipresent impacts of dense human populations. This flat region lacks typical riparian forests, as defined above. The Pobè district is the domain of dense semi-deciduous forests and is a continuation of the lowland rain forest zone of Nigeria. SOKPON (1995) studied the structure and floristic composition of plant communities in the protected forest of Pobè, typical of this South-Eastern part of the country. He identified a riverine forest dominated by *Cleistopholis patens, Ficus mucuso, Elaeis guineensis* and *Cercestis mirabilis.*

The Ouémé and Kouffo districts prolong respectively the derived savanna and the Southern Guinea zones of Nigeria. Here *Pterocarpus santalinoides, Cola laurifolia, Parinari congensis, Antidesma venosum, Napoleonaea vogelii, Syzygium guineense, Dialium guineense* and *Cynometra megalophylla* are the dominant tree species in riparian forests. The Zou district is a transition zone between the Guinean and Sudanian climates. Riparian forest physiognomy is similar to the dense semi-deciduous forests. The most frequent species are *Berlinia grandifolia, Elaeis guineensis, Hexalobus crispiflorus, Pouteria alnifolia, Cola gigantea, C. millenii, Lecaniodiscus cupanioides, Napoleonaea vogelii, Pterocarpus santalinoides* and *Uvaria chamae.*

The South Borgou district corresponds to the North Guinean zone of Nigeria and the riparian forest flora here contains numerous tree species of lower and much wetter latitudes such as: *Berlinia grandifolia, Parinari congensis, Detarium senegalense, Diospyros mespiliformis, Dialium guineense, Khaya grandifoliola, K. senegalensis, Millettia thonningii, Albizia zygia, Albizia glaberrima, Trilepiseum madagascariense*. The North Borgou district, which prolongs the Sudanian zone of Nigeria, is characterised by the omnipresence of riparian forests similar in physiognomy with those of South Borgou but with a different flora. Dominant species are *Syzygium guineense, Uapaca togoensis, Berlinia grandifolia, Brenadia salicina, Khaya senegalensis, Elaeis guineensis, Manilkara multinervis, Vitex doniana, Mimusops andongensis, Diospyros mespiliformis, Synsepalum passargei, Fadogia agrestis, Ficus spp., Celtis toka, Borassus aethiopum* and *Raphia sudanica*.

The Atacora chain oriented North-North-East/South-South-West is characterised by hygrophile riparian forests at the foot of the hills. Their structure and composition present some similarities with the ones of North Borgou. Common species are *Syzygium guineense, Uapaca togoensis, Berlinia grandifolia, Brenadia salicina, Pentadesma butyracea, Chrysobalanus atacoriensis, Eriocoelum kerstingii, Khaya senegalensis, Ficus spp., Diospyros mespiliformis, Anogeissus leiocarpus* and *Vitex doniana.*

The Pendjari district corresponds to the North West of the Atacora province. It includes the major part of the Pendjari National Park and the Western plains up to the Togo Border. In the Pendjari National Park, GREEN (1979b) identified several plant associations among riparian forests. The most important are *Cola laurifolia, Morelia senegalensis* and *Syzygium guineense* association at its maximum development in the unique and species rich riparian forest of Bondjagou*; Khaya senegalensis, Diospyros mespiliformis* and *Anogeissus leiocarpus* along the Pendjari stream in the Atacora chain; *Celtis integrifolia, Kigelia africana* and *Diospyros mespiliformis, Garcinia livingstonei* and *Mitragyna inermis* along the Pendjari stream North of the Bondjagou forest; *Anogeissus leiocarpus, Combretum nigricans* sometimes with *Terminalia glaucescens* along several streams in the park; *Anogeissus leiocarpus* and *Crossopteryx febrifuga* along small streams around the Bondjagou forest, in the centre of the park and at the foot of the hills. In the Western plains towards the Togo border, riparian forests are dominated by *Anogeissus leiocarpus, Mitragyna inermis, Elaeis guineensis, Ficus spp., Sarcocephalus latifolius, Vitex doniana* and *Terminalia macroptera* (NATTA 1997).

In the Centre and North of the W National Park in Northern Benin, riparian forests along streams are the most important ecosystems in the majority of shrub savanna dominated by Mimosoideae and Combretaceae. Here, riparian forests have the structure of woodland savanna less than 15m high along the Mékrou, Alibori and Pako streams. They are extremely narrow and quite linear with often only a single tree at stream banks. The most frequent species are: *Cola laurifolia, Syzygium guineense, Morelia senegalensis, Pterocarpus santalinoides, Combretum lecardii, Crateva adansonii, Borassus aethiopum, and Vitex chrysocarpa*. *Oxytenanthera abyssinica* is sometimes seen in the Mékrou and Alibori beds (PGRN/IUCN 1994). GREEN (1979a, 1979b) also identified several plant associations along the Niger river and streams of the W National Park such as *Khaya senegalensis, Diospyros mespiliformis* and *Borassus aethiopum*; *Anogeissus leiocarpus, Combretum nigricans* with sometimes *Sclerocarya birrea* in the North of the Park along the Mékrou stream; *Anogeissus leiocarpus* and *Crossopteryx febrifuga* along the Niger river, the Mékrou stream and small streams; *Cola laurifolia, Morelia senegalensis, Syzygium guineense, Anogeissus leiocarpus, Feretia apodanthera, Anogeissus leiocarpus* and *Balanites aegyptiaca*.

Trilepiseum madagascariense, Cleistopholis patens, Albizia glaberrima, Antidesma venosum, Sterculia tragacantha, Cynometra megalophylla, Drypetes floribunda and S*yzygium guineense* are common species of semi-deciduous forests on ferralitic soils or vertisols in the Pobè and the Ouémé districts South of 7°10 N, (AKOÈGNINOU 1984; SOKPON 1995). These trees are also found almost exclusively along rivers and streams at higher latitudes. Such is the case in the Toui-Kilibo, Pénéssoulou, Ouari-Maro, and Ouémé Supérieur protected areas. *Dialium guineense,* a typical species of the plateau and tops of slopes in dense semi-deciduous forests (SOKPON 1995), is found exclusively in riparian forests between 7°20 and 11° N. Also *Elaeis guineensis* is widespread in the South, but is found in gallery forests in the Centre and North of the country. S*yzygium guineense* is always found in gallery forests as far as in the W National Park. These examples tend to confirm the hypothesis of FORMAN & GODRON (1986) that riparian forests usually act as routes for movement of plants across the landscape, especially at less moist latitudes.

Despite decades of neglect, the Mounts Kouffé reserve still contains dozens of small patches of riparian forests and dense moist forests. These remnants appear undisturbed internally and therefore have a very high biodiversity value (PGRN/IUCN 1994). GREEN (1979a) and PGRN/IUCN (1994) have recommended to extend the South-Eastern limit of Pendjari National Park beyond the Atacora chain to protect the riverine forest and adjacent mountains, thereby increasing biodiversity by adding rich habitats and beautiful landscapes to the park. Also a buffer zone should be created along the Ouémé River, including its forested banks to conserve the riverine forest and to maintain a physical corridor between the Ouémé Supérieur and Ouari-Maro forest reserves.

Summing up, the most common and widespread tree species in riparian forests in Benin are *Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Berlinia grandiflora, Elaeis guineensis, Manilkara multinervis, Xylopia parviflora, Dialium guineense Diospyros mespiliformis* and *Parinari congensis.*

3.7. WILDLIFE IN RIPARIAN FORESTS

The Ouémé river and its forested banks are rich in birdlife, and serves as a focal point for primates and animals of many kinds. The Mounts Kouffé with its contiguous Ouari-Maro and Ouémé Supérieur protected forests are said to have the highest ranking of biodiversity as compared with all the other protected areas in Benin (PGRN/IUCN 1994). It is very likely that the 215 bird species and the potential 150 additional ones, reported by the PGRN/IUCN mission of 1994, have riparian forests as their main habitat.

In the North of Benin and the South of Burkina Faso, flood plains, shallow lakes and riparian forests are the principal habitats of the 278 bird species found in the Pendjari and Arli National Parks (ROGGERI 1995). Riparian forests are reportedly the main habitat of certain animals such as the bushbuck (*Tragelaphus scriptus*), red-flanked duiker (*Cephalophus rufilatus*) and vervet monkey (*Cercopithecus aethiops tantalus*) (LEVAUX 1990). Also in the protected areas, certain animals depend on the dispersion of fruits of riparian forest trees. It is the case e.g. of elephants and baboons that use *Borassus aethiopum* seeds in the Pendjari National Park.

3.8. THE USE OF REMOTE SENSING IN DETECTING AND MAPPING RIPARIAN FORESTS

Remotely sensed data and geographical information systems (GIS), which deal with spatial data, have considerable utility in acquiring vital information especially on vegetation. They have a great potential in providing up-to-date and accurate information that can be used for plant communities management and monitoring activities.

We have conducted a study in the Toui-Kilibo protected area (Central Benin) to assess qualitatively and quantitatively the usefulness of satellite imagery (Spot XS image) for identification and classification of land cover types in riparian forests and neighbouring vegetation types (see NATTA 2000). It was possible to differentiate between several land cover types from the aerial photographs and satellite images along the river, but not along streams. Although results seem promising in terms of spectral separability of gallery (along streams) and riverine (along rivers) forests, differences in tree species structure and floristic composition, as observed in the field, could not always be made out from the remotely sensed data.

The coarse spatial resolution of SPOT XS image (20 m) and the unknown spectral signatures of species or group of species have lowered the accuracy records. The great spatial resolution of predictive vegetation maps obtained from digital image classification exclude small patches and narrow strips of vegetation such as riparian forests, and therefore limit the use of the current civilian satellite imagery in riparian forests study. WARNER & KATIBATH (1980) have already found that satellite imagery allowing vegetation mapping with a scale range between 1:80,000 to 1:35,000 was only of limited use; meanwhile they found that an aerial photograph at 1:6,000 is the most useful for detailed riparian system inventory. In our case study we found that even aerial photographs with a scale of 1/20,000 or larger are useful to identify and map broad stands of riparian forests in a savanna landscape.

Because data on plant communities' structure (dominant trees, understorey, shrub cover and ground cover), floristic composition, as well as associated animal life, are generally required ground level surveys are an essential component of any detailed riparian system assessment. Site-specific studies in the field are required to assess riparian forests because their narrow linear shapes generally require data on plant community structure, floristic composition and animal presence. Details of vegetation layers under the dominant trees cannot yet be detected by remotely sensed data.

3.9. PROTECTION, AND RESTORATION OF RIPARIAN ECOSYSTEMS RESOURCES

In the new Benin forest law (no. 93-009 of July the 2nd of 1993, Ref. RB 1993), clearance of wood and shrubs is not allowed within 25 m at both sides of any water course and stretch of smooth water (article 28). This limit seems to be too short, in reality stands of riparian forests can be wider than 50 m. A reasonable limit, without any clearance or selective tree cutting from watercourses, of 100 m will provide sufficient guarantee for the protection of watercourses and riparian resources.

In the management plans of Goun-Goun, Sota and Goroubi, Toui-Kilibo, Ouémé Supérieur and Pénéssoulou forest reserves, gallery forests will be left uncut, and rare species outside the gallery forests will not be cut either. In the meantime, foresters and rural extensions workers must give the good example and promote local people's rights and duties specified by the forest law, especially to help local people respect the restrictions concerning protected or valuable trees (e.g. *Milicia excelsa, Khaya senegalensis,* and *K. grandifoliola* at stream sides).

Still several questions remain with regard to the implementation of the forest law: Do local people respect the restrictions on riparian forest utilisation? Are alternatives provided to neighbouring people, particularly farmers, not to overuse or destroy riparian forests (e.g. when seeking for fertile soils or water for irrigation)? Are private forestry developers aware of protection of riparian forests in unprotected areas? How far can foresters enforce the law in applying the punishments to those who illegally destroy riparian forest resources? Can any suggestions be given to improve the efficiency of the law in protecting riparian forests resources in the terrain?

To protect, improve, and restore in a sustainable way the riparian vegetation resources, several objectives have to be addressed:

- identify the major riparian forests in the country and determine their historical extent;
- make inventories of their floristic and faunistic resources;
- identify causes of riparian forests destruction and threats to their resources maintenance, with special attention to local people's views;
- implement activities for the sustainable conservation of riparian forests in partnership with neighbouring inhabitants.

Information needed

To achieve these objectives, data should be collected on different topics related to riparian forest such as:

- location, extent, climate, soils types, river/stream bank conditions;
- vegetation structure, floristic composition, and vegetation condition (species distribution, abundance, size, reproduction strategies, evolution trends, etc.);
- fauna with their characteristics and ecological requirements;
- river and /stream water quality, hydrologic characteristics;
- adjacent land uses and their impacts on riparian resources (effects of farming, tree cutting, fire, hunting, channelisation, hydrologic manipulations and other discernible threats);
- measures to be taken for riparian resource protection, improvement, and restoration (possible solutions to the major threats at local, district, provincial and national levels, restoration potential for the riparian systems).

Stakeholders

Several stakeholders have to be involved in this task: the forest and natural resource management authorities, foresters, projects, research institutes and Non-Governmental Organisations (NGO's) dealing with natural resources protection, local population and forest resources users (e.g. timber gatherers, hunters), etc. Effective conservation actions can best be achieved if the local residents are either collaborating or in control. Therefore initiatives have to be taken to rise local people's awareness concerning their interests/benefits in protecting riparian forests (landscape beauty, watershed protection, water sources protection, conservation of valuable or rare floristic and faunistic species). This can be done through the empowerment of local forest management committees through participatory approaches.

The implementation and improvement of the forest law are primarily the task of foresters in the terrain. The application of the law and good collaboration with local natural resources management committees, if effective, will surely provide positive effects on forested areas including riparian systems.

Role of the Forest and Natural Resource Management (NRM) Department and Research Institutes in the implementation of the forest law concerning riparian forests

Their attributions could be:
- Definition of thematic objectives (e.g. riparian forests fauna, flora, river and stream hydrology, reforestation, socio-economic aspects, etc.);
- Setting up of criteria for the assessment and monitoring of riparian forests resources;
- Creation of a data-base on riparian forests in the framework of any NRM program;
- Monographs of specific species (e.g. *Chrysobalanus atacoriensis*, *Pentadesma butyracea,* etc.) or resource.

Role of research projects and NGOs dealing with natural resources protection

Projects and NGOs dealing with natural resources protection are certainly very important for the protection, improvement, and restoration of riparian vegetation resources. Their actions could focus on:
- Inventory of natural resources in riparian forests;
- Vulgarisation of the forest law regulations on riparian forests and effective actions to fight against the depletion of riparian forest resources in collaboration with local people;
- Empowerment of local forests management committees through participatory approach;

- Alternatives to reduce the depletion of riparian forest resources (e.g. cheap and easy to use irrigation systems for farmers, agroforestry in uplands, appropriate techniques to improve soil fertility, beekeeping, etc.);
- Experimentation on husbandry of rare or native riparian forest species;
- Participatory reforestation of degraded riparian forests and revegetation of stream banks with rare or native riparian forest species (e.g. *Khaya grandifoliola*, *K. senegalensis, Pentadesma butyracea).* Exotic plants (e.g. teak*, Gmelina arborea, Anacardium occidentale* and *Mangifera indica*) should not be avoided;
- Valorisation of riparian forests in National Parks and forest reserves for ecotourism, recreation, research and sport fishing (e.g. construction of a viewing tower near the Bondjagou forest);
- Protection and valorisation of rich riparian forests outside protected areas, especially around human settlement. Indigenous riparian forests around cities should not to be converted to settlement, instead be managed (delineated and protected) as natural parks for recreation, research, education, etc.;
- Improvement to the forest law.

Some improvements can be given to the forest law. It is urgent to put under protection or extend the protected areas of Ouémé Supérieur, Mounts Kouffé, Ouémé-Boukou, Dogo, Kétou to the second side of the Ouémé River that is not currently included in the reserves. This disposition can be extended to any other stream or river harbouring important riparian vegetation (e.g. Yarpao). Also the principle of regulated tree harvest in riparian forests might be accepted (e.g. up-rooted trees, old or dying trees at river/stream edges) followed by special care to rare or useful tree species regeneration.

3.10. CONCLUSIONS

In line with the Convention on Biological Diversity (UNCED 1992), which emphasised the need for every country to take responsibility for conserving its own biodiversity, a prudent approach to biodiversity conservation necessitates preserving all potential rich or endangered ecosystems. Therefore Benin's relict forests, especially riparian forests, are important conservation sites that need more care than currently available. In the majority of savanna ecosystems, efforts toward the conservation of riparian forests will increasingly become a priority in land use planning (NATTA 2000), this will allow a wide range of plants and animals to benefit from the protection of forests along rivers and streams. Riparian systems are at the same time so important as a collection of natural resources and so limited in individual size that they both merit and require higher resolution inventory procedures than those deployed for other larger ecosystems (savanna and upland forests). The responsibility of different actors, (e.g. forest division, research institutes, projects and NGO's dealing with the conservation of biodiversity in Benin in collaboration with local residents), should be drawn to seek for appropriate initiatives to preserve the remaining rich and diverse riparian forests, especially in non-protected areas.

Chapter 4

ASSESSMENT OF RIPARIAN FOREST FRAGMENTS PLANT DIVERSITY IN WEST AFRICAN SAVANNA REGIONS: AN OVERVIEW FROM BENIN

Submitted to the *Journal of Biogeography*

Natta, A.K. and van der Maesen, L.J.G.

Chapter 4

ASSESSMENT OF RIPARIAN FOREST FRAGMENTS PLANT DIVERSITY IN WEST-AFRICAN SAVANNA REGIONS: AN OVERVIEW FROM BENIN (*)

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ABSTRACT:

Aim: To assess the flora and plant diversity of riparian forests. To compare the diversity of several riparian forest sites.
Location: From 7º10 to 12º20 N in Benin (West Africa).
Methods: The largest and least disturbed forest fragments along rivers and streams were surveyed in the three ecological (i.e. Guinean, Sudano-Guinean and Sudanian) regions of Benin. In total 373 phytosociological relevés (each of 500 m^2) were made from 1999 to 2002, using the Braun-Blanquet method. A plant species list was made from these relevés. Biodiversity was assessed through species richness, Shannon index (H'), Equitability index of Pielou (E), and species abundance models.
Results: In all 1003 species (about 1/3 of the estimated number of species in the flora of Benin), 120 families, 513 genera, and 224 tree species (i.e. dbh ≥ 10 cm) were identified. The richest (sub) families were the Papilionioideae, Poaceae, Rubiaceae and Euphorbiaceae. Riparian forests are characterised, on the one hand, by a flood-dependent flora, and on the other hand by many species from semi-deciduous forests and savannas. Shannon index varied from 2.4 to 5.8 bits and Pielou's equitability from 0.51 to 0.86. Species richness varied from 129 to 358 while tree species richness ranged from 27 to 99 per ha.
Main conclusions: This study showed that in fire-prone environments, such as Benin, relatively large numbers of species still are maintained in small forest fragments along waterways. Riparian forests are characterised by a diversified flora, and specific plant species that should be used for the restoration of degraded stands.

Key words: riparian forests, flora, diversity, species abundance model, Benin.

4.1. INTRODUCTION

Benin is located in 'the Dahomey gap', which is a break of the West African rain forest belt between Nigeria and Ghana. This interruption permits the incursion of savanna towards the coast as a result of the dry conditions prevailing in Southern Benin, Togo and South-Eastern Ghana (Onochie, 1979; Ern, 1988; Jenik, 1994; Kokou *et al*., 1999; Kokou & Caballé, 2000). As a result there are no evergreen tropical forests in Benin (Sokpon, 1995; Tossou, 2002). High incidences of farming as well as tree cutting and fire have reduced the original woodland to their current state.

Flora is a major component of a region or a country's biodiversity. It is historically the result of a long process of natural selection (Braun-Blanquet, 1972) in relation with climatic and edaphic conditions as well as human interference. In the majority of degraded woodlands and mosaic of savanna landscapes, riparian forests (hereafter RFs) belong to the most important forest ecosystems, which follow the outline of rivers and streams (Natta, 2000). The flora of Benin is incompletely known (PFB, 1997), and the diversity, relative rarity and threats of many hot-spots in vegetation, such as riparian forests, have remained insufficiently studied (Mondjannagni, 1969; Paradis, 1988; Sokpon *et al*., 2001). This lack of information to the scientific community and managers hinders appropriate planning and conservation initiatives dedicated to them (Natta *et al.,* 2002).

The aim of this paper is to investigate the flora of riparian forests through several parameters: plant species richness and abundance, endemic, valuable and threatened plants, adaptability to a specific habitat, Diversity Index (Shannon), Equitability Index (Pielou), differences in sites diversities (comparison of Shannon indices), and species abundance models. This research also intends to provide accurate floristic data for riparian forests biodiversity protection and restoration in different ecological regions.

4.2. METHODS

Surveys were made in all ecological regions of Benin excluding the coasts, beaches, coastal lagoons, lakes and marshlands. The study area (Figure 4.1) covered the latitudes 7º10 to 12º20 N. The largest and least disturbed forest fragments along rivers and streams were surveyed in the Guinean region (Samiondji and Bètèkoukou), Sudano-Guinean zone (Toui-Kilibo, Idadjo, Bétérou and Pénéssoulou) and Sudanian region (Yarpao, Pendjari Biosphere Reserve, Gbèssè). In total 373 plots (each of 500 m^2) were installed in several RF stands using the phytosociological approach of Braun-Blanquet, but tree height and diameter at breast height (i.e. dbh) were measured in 304 plots (Table 4.1). About 19 ha of RFs were surveyed for the compilation of a plant species list. Rectangular plots, with variable length and width, were preferred to circular ones to fit with the shape of waterways and width of riparian forests. The identity of each plant was recorded in the field and specimens taken as vouchers for the National Herbarium of Benin and the National Herbarium of the Netherlands, Wageningen University Branch. Species names mainly follow Keay & Hepper (1954-1972), Brunel *et al.* (1984), Berhaut (1967), and Lebrun & Stork (1991-1997). Stem diameter at breast height (dbh) was measured at 1.3 m above the ground, or above buttresses when present for trees (dbh ≥ 10 cm).

In the present paper the assessment of plant species diversity in RFs encompasses species richness, Shannon diversity index (H'), Equitability index of Pielou (E), and species abundance models (also called Dominance-diversity curves). Here species abundance models test the statistical difference between observed pattern within the floristic data (tree species abundance and families richness) and expected pattern as described by each model. Visual inspection of rank-abundance figures suggested two predictors of species abundance models: the geometric and log series. The χ^2 test compared the two distributions, the expected and observed number of each species in each abundance class.

We compared the diversity of RF sites (1 ha per site), using a t-test based on the Shannon Index and its variance (cf. Hutcheson, 1970; Magurran, 1988; Kent & Coker, 1992). This method was already successfully used on RFs in Benin and Ivory Coast (cf. Natta, 2000; Porembski, 2001; Natta & Porembski, in press, see chapter 9). The usefulness of multivariate methods (e.g. classification and indirect ordination), in detecting trends and subdivisions within riparian forests floristic data, was assessed in another paper (cf. Natta *et al.,* in press, see chapter 6).

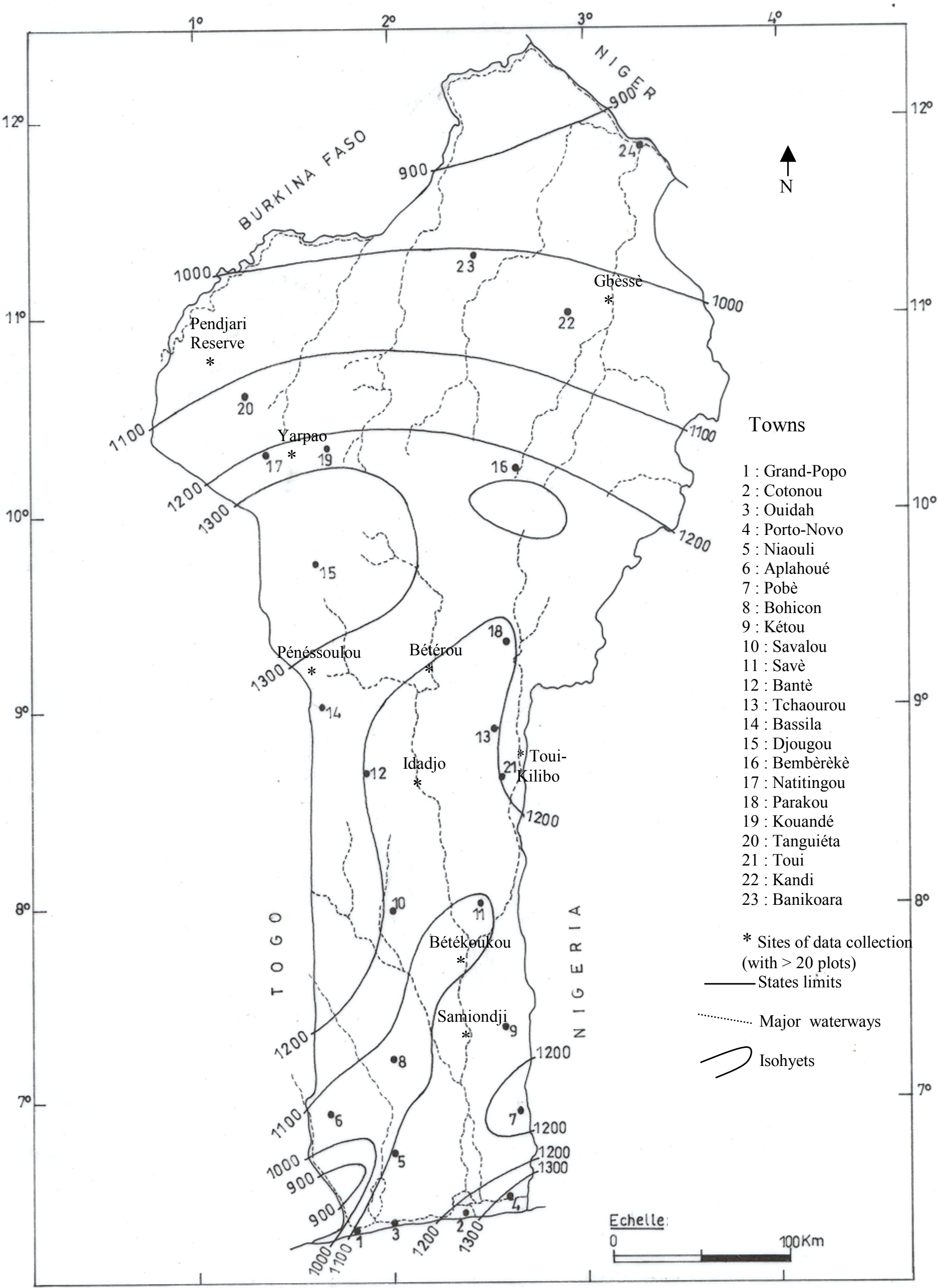

Figure 4.1: Study sites where data were collected in riparian forests in Benin

4.3. RESULTS

4.3.1. Floristics and stand characteristics of riparian forests throughout Benin

In Benin, RFs vary in their width along the watercourses, which they fringe. Some are no more than a few meters wide and have an open canopy, while others are much more extensive and have a closed canopy and a well-developed structure. The floristic and stand characteristics of riparian forest are summarised in Table 4.1. Species richness (SR) per ha varied from 129 to 358. Tree density and basal area per ha varied from 253 to 785, and from 23 to 59 m^2, respectively.

Table 4.1: Floristic and stand characteristics of riparian forests throughout Benin

Regions	Sites	Relevés	Species Richness (SR) per site	Species Richness (SR) per ha	Trees density/ha	Basal area (BA/ha)
Guinean	Samiondji	**36**	**306**	**249**	**726**	**41.7±17.4**
Sudano - Guinean	Pénéssoulou	40	450	343	544	38.9±15.3
	Idadjo-Bétérou	40	183-195	129-195	748-785	45.6±15.8
	Okpara	56	-	-	315	-
	Streams at Toui- Kilibo	62	-	-	257	-
	All Sudano-Guinean sites	**198**	**556**	**129-343**	**257-785**	**42.6±15.8**
Sudanian	RFs on plateau	43	435	182-278	538-627	35.6±16.5
	RFs at hill foot	27	467	358	732	42.7±9.9
	All Sudanian sites	**70**	**591**	**182-358**	**538-732**	**40±20.6**
All RFs sites in Benin		**304**	**1003**	**129-358**	**253-785**	**41.5±17.9**

SR = Species richness per site (SR/site) or per ha (SR/ha); BA/ha = Basal area per ha in m^2; Trees = stems with dbh ≥ 10 cm; RFs = Riparian forests.

4.3.2. Diversity of riparian forest flora in Benin

From 373 floristic relevés altogether 1003 species (about 1/3 of the estimated number of species in the Benin flora) from 120 families and 513 genera were recorded. The ten (sub) families richest in species are the Fabaceae-Papilionoideae, Poaceae, Rubiaceae, Euphorbiaceae, Cyperaceae, Asteraceae, Acanthaceae, Fabaceae-Caesalpinioideae, Moraceae and Malvaceae. In all, 224 tree species (i.e. dbh ≥ 10 cm) were identified. Tree species with the highest abundance are *Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Dialium guineense, Berlinia grandiflora, Cynometra megalophylla, Elaeis guineensis, Diospyros mespiliformis, Uapaca togoensis* (see Table 4.2). The list of plant species collected in several riparian forests sites is presented at the end of this dissertation. This flora contains species from various forest types (dense semi-deciduous, dry, open), savannas and various degraded woodlands and fallow communities. Species such as *Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Culcasia scandens* and *Morelia senegalensis* are seen at all latitudes along waterways.

On the other hand, some species are confined to certain regions showing that RFs present niches to conserve dense forest species in various landscapes. In the humid Guinean region of Southern Benin and along larger waterways (rivers), typical species are *Cynometra megalophylla, Salacia pallescens, Parinari congensis, Drypetes floribunda, Cassipourea congoensis,* and *Garcinia livingstonei*. Along small waterways (streams), mainly in the Sudanian region of North Benin, typical RF species are *Raphia sudanica, Khaya* *senegalensis, Uapaca togoensis, Vitex doniana, Oxytenanthera abyssinica, Berlinia grandiflora, Brenadia salicina, Garcinia ovalifolia, Pentadesma butyracea* and *Chrysobalanus atacoriensis*.

Table 4.2: Riparian forests tree species dominance: number of individuals and basal area

no.	**Species**	**Absolute abundance**	**Abundance (%)**	**Total BA** (m²)	**BA(%)**
1	*Pterocarpus santalinoides*	1194	14.86	1038	12.8
2	*Cola laurifolia*	631	7.86	707	8.7
3	*Syzygium guineense*	499	6.21	585.2	7.2
4	*Dialium guineense*	271	3.37	264.6	3.25
5	*Berlinia grandiflora*	249	3.1	502.7	6.18
6	*Cynometra megalophylla*	248	3.08	460.7	5.66
7	*Elaeis guineensis*	222	2.76	240.7	2.96
8	*Diospyros mespiliformis*	204	2.54	463.2	5.7
9	*Uapaca togoensis*	201	2.50	237.4	2.92
	Total of the 9 most abundant tree species	3719	**46.3**	4499.52	**55.3**
	Total of the remaining (215) tree species	4311	**53.6**	3630.82	**44.6**
	Overall total for 224 tree species	8030	**100**	8130.34	**100**

BA= Basal Area in m²

Many species from forest, regrowth vegetation or pioneer species in the Guinean region and Sudano-Guinean zone of Southern and Central Benin (e.g. *Elaeis guineensis, Dracaena arborea, Dialium guineense, Holarrhena floribunda*) are found in streamside vegetations in the savanna region of North Benin. Also, certain pioneer or secondary forest species (e.g. *Leea guineensis, Rauvolfia vomitoria, Phyllanthus muellerianus, Anthocleista nobilis, Cleistopholis patens, Spathodea campanulata, Ceiba pentandra, Milicia excelsa* and *Ricinodendron heudelotii*) of the tropics (cf. Whitmore 1990) are usually seen in RFs in Benin. Other species (e.g. *Khaya senegalensis, Afzelia africana, Milicia excelsa* and *Antiaris toxicaria*) that have completely disappeared on plateaus in densely populated areas are found in RFs at higher latitudes or far from settlements. We also find some either endemic or valuable species almost exclusively in RFs. *Thunbergia atacorensis* (Acanthaceae) is one of the rare endemic species in Benin mainly found in RFs at hills feet. Among valuable species, *Dissotis anthennima* is known for its importance in medicine, *Pentadesma butyracea* and *Xylopia aethiopica* as major Non Timber Forest Products in West Africa.

Summing up, RFs in Benin are characterised, on the one hand by a flood-dependent flora widely distributed all over the country, on the other hand by many forest (pioneer and typical semi-deciduous) and savanna species.

4.3.3. Riparian forest sites diversity

The Shannon index varies from 2.43 to 5.4 bits respectively along the Ouémé river at Samiondji (South Benin) and along streams in Toui-Kilibo reserve forest (Central Benin). The overall RFs diversity is 5.8 bits, and the Equitability index of Pielou is 0.74 (Table 4.3). RFs along streams (Toui-Kilibo, Pénéssoulou, Sudanian RFs on plateau and at hill feet) have higher diversities than those along rivers (Okpara, Ouémé, Pendjari and Sota): $t = 31.57$; $df = 7502$; $p < 0.001$.

Table 4.3: Plant species diversity in several riparian forests sites in Benin

REGION	Sites	Plots (n)	Tree species richness (SRt)	Abundance (N)	Shannon index (H')	Evenness (E)
Guinean	Samiondji (Sa)	36	27	1307	2.43	0.51
Sudano Guinean	Pénéssoulou (Pe)	40	99	1086	5.17	0.78
	Idadjo-Bétérou (ID-BE)	40	64	1537	3.91	0.65
	Okpara River (Okp)	56	59	883	4.91	0.84
	Streams at Toui-Kilibo (Str TK)	62	78	1003	5.4	0.86
Sudanian	Sudanian RF on plateau (Sud Plat)	43	84	1226	4.97	0.78
	Sudanian RF at hill foot (Sud Hill)	27	65	988	4.27	0.71
	Rivers (large waterways)	156	111	4291	4.44	0.65
	Streams (small waterways)	148	144	3739	5.87	0.82
Riparian forests of BENIN		304	224	8030	5.81	0.74

n = Plots; SRt = Tree species richness per site; N = Abundance; H' = Shannon index; E = Equitability index of Pielou.

The comparison of RF sites diversities (Table 4.4), based on the t-test adapted to Shannon index, gave the ranking:
Streams at Toui-Kilibo (Str TK) > Pénéssoulou (PE) > Sudanian RF on plateau (Sud plat) > Okpara River (Okp) > Sudanian RF at Hills feet (Sud Hills) > Idadjo-Bétérou (ID-BE) > Samiondji (SA).

Table 4.4: Comparison of the diversity of riparian forest sites

SITES	Pénéssoulou	Idadjo/Bétérou	Okpara River	Streams at Toui-Kilibo forest	Sudanian RF on plateau	Sudanian RF at Hill feet
Samiondji (SA)	PE>SA (***)	ID-BE>SA (***)	Okp>SA (***)	Str TK>SA (***)	Sud plat>SA (***)	Sud Hills>SA (***)
Pénéssoulou (PE)	-	PE>ID-BE (***)	PE>Okp (***)	Str TK>PE (***)	PE>Sud plat (**)	PE>Sud Hills (***)
Idadjo-Bétérou (ID-BE)	-	-	Okp>ID-BE (***)	Str TK>ID-BE (***)	Sud plat>ID-BE (***)	Sud Hills>ID-BE (***)
Okpara River (Okp)	-	-	-	Str TK>Okp (***)	Sud plat : Okp (NS)	Okp>Sud Hills (***)
Streams at Toui-Kilibo (Str TK)	-	-	-	-	Str TK>Sud plat (***)	Str TK>Sud Hills (***)
Sudanian RF on Plateau (Sud plat)	-	-	-	-	-	Sud plat>Sud Hills (***)

NS = Not statistically significant at p=0.05, i.e. similar in terms of tree species diversity; (>) More diverse than; ** Significance at 0.01; *** Significance at < 0.001; Details of the calculations are shown in Table 4.5 in the Annex.

4.3.4. Species and families abundance models

Species abundance model, which describes the distribution of species richness frequency, shows that not all species are equally abundant (Figure 4.2). 45 % of the tree species have less than 4 individuals. Tree species with 1 or 2 individuals are very common (left part of the curve) while those with larger number of individuals (>10) are uncommon (right part forming a tail). The best abundance distribution model for RF tree species data set is the log series: $\chi^2_{\text{calculated}} = 12.15 < \chi^2_{\text{table}} = 15.5$ at $p = 0.05$ df = 8. There is no significant difference, at $p = 0.05$, between the observed and expected distributions of tree species abundance as predicted by the log series model.

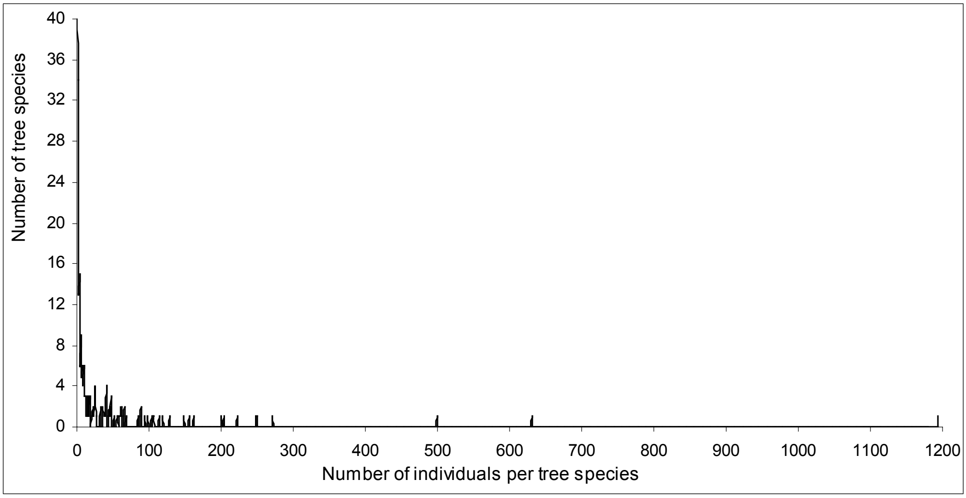

Figure 4.2: Tree species abundance distribution of riparian forests tree species in Benin

Also, the distribution of family richness frequency shows that obviously not all families have equal numbers of species (Figure 4.3). Out of 120 families, 33 (i.e. 27.5%) are represented by 616 species (about 62% of the total RF flora) and 55% families have each less than 3 species. Families with 1 or 2 species are very common (left part of the curve), while families with large number of species (i.e. > 10) are fairly uncommon (right part forming a tail). The fitting of models shows that a log series is the best fit for the family richness: $\chi^2_{\text{calculated}} = 5.7 < \chi^2_{\text{table}} = 11.07$ at $p = 0.05$ df = 5. We conclude that there is no significant difference, at $p = 0.05$, between the observed and expected distributions of family richness as predicted by the log series model.

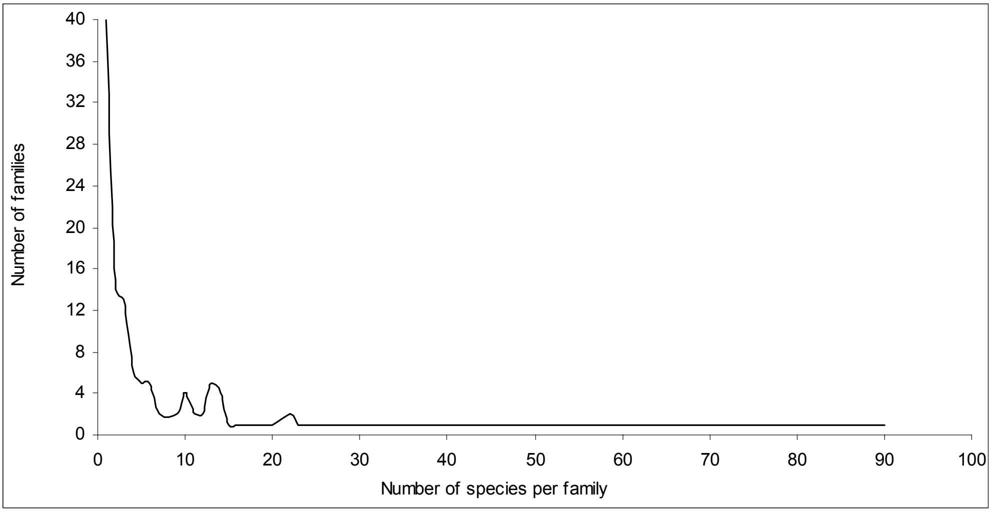

Figure 4.3: Family richness abundance distribution of riparian forests in Benin

4.4. DISCUSSION

4.4.1. Flora of riparian forests

In our large-sized data set, we enumerated more species than for the RFs in South Togo (West of Benin Republic), where Kokou *et al.* (2002) found 499 species grouped into 41 families and 108 genera. Many species (e.g. *Pterocarpus santalinoides, Cola laurifolia, Cynometra megalophylla, Manilkara multinervis* and *Parinari congensis*) typical of RFs in Benin are dominant and characteristics of RFs in Southern Côte d'Ivoire (see Devineau, 1975; 1976). Many common species in RFs are found to be encroachments of upland forests. *Elaeis guineensis*, for example is a heliophytic and pioneer species abundant in all West and central African forests (Sowunmi, 1999; Maley & Chepstow-Lusty, 2001). In the Benin context, as RFs combine plants from various ecosystems, it is likely that they are more diverse than vegetation formations consisting of only one ecosystem. Meave & Kellman (1994) already found that most riparian forest flora in a Neotropical savanna environment of Belize is not specialised to the riparian environment and there is a significant supplement of species having other habitat affinities (i.e. rain forest and non-rain forest taxa). A similar result was found in Northern Australia, where riparian strips contain vegetation dominated by diverse floristic elements unrelated to monsoon rain forests (Woinarski *et al*., 2000). For Bersier & Meyer (1994), RFs are mosaics composed of patches of different vegetation types, which cover the entire range of forest succession. Thus RFs potentially provide more different categories of food items for a variety of animals than other forest types.

Little is known about the relative rarity and threats facing most RF species in Benin. More is known from *Khaya senegalensis, Afzelia africana, Milicia excelsa* and *Antiaris toxicaria* (Eyog Matig *et al.,* 2001; Sinsin *et al*., 2002a; Eyog Matig *et al.,* 2002; Sokpon & Ouinsavi, 2002). The absence of numerous rare, endemic or disjunct plant species in the RFs of Benin, may suggest that these forests have not geographically been isolated for a very long time, instead the historical patterns of migration resulted in an accumulation of various taxa from surrounding vegetations in, and at the edge of RF corridors.

Yarpao (Atacora hilly region) and Pénéssoulou reserve forest (semi-deciduous forest region) have the highest plant richness of riparian forests, 358 and 343 species per ha respectively (see Table 4.1). Therefore we might say that protection of the dry semi-deciduous forests and the difficult accessibility of genuine RFs at hills feet have a positive impact on the conservation of plant diversity. Species richness of RFs (per ha) in Benin varied from 129 to 358. This is within common limits of certain tropical dense forests: 156 in the Taï National Park in Côte d'Ivoire (Dengueadhe, 1999), and 100-300 in South America (Loizeau, 1992). The total vascular plant list for a hectare of forests at Kade (Ghana) is nearly 300 species (Swaine *et al.,* 1987). In a 2.5 ha survey of primary forest in Dja Fauna Reserve (Cameroon) Sonké & Lejoly (1998) found 125 to 138 species. On the contrary, SR per ha of RFs in Benin is far lower than values from several neotropical rain forests (cf. Whitmore, 1990).

4.4.2. Family richness in riparian forests

There are some similarities, with regards to dominant families, between the RFs of Benin and various forest types in Benin, Africa and more generally in the tropics. Akoègninou (1984) found 93 families with the Rubiaceae, Papilionoideae, Poaceae, Euphorbiaceae and Apocynaceae as the most pluriform in several dense semi-deciduous forests in Southern Benin. In the humid zones of Southern Benin, Sokpon & Adjakidjè (1999) found 100 families with 364 species, the richest families being the Poaceae, Rubiaceae, Cyperaceae, Fabaceae, Euphorbiaceae, Moraceae and Apocynaceae. For these authors, the Leguminosae (Papilionoideae, Mimosoideae and Caesalpinioideae) are often the most species-rich family in forest formations. Likewise, the Cyperaceae are usually abundant in humid zones, while the Poaceae, the second richest family, show the effects of degradation or drier Sudanian climate.

In Burkina-Faso (North of the Republic of Benin), the Papilionaceae, Rubiaceae, Caesalpiniaceae and Poaceae were the most species-rich families in gallery forests of the Hippopotamus Pond Biosphere Reserve (Bélem & Guinko, 1998). In the Dja Fauna Reserve (Cameroon), the Euphorbiaceae, Rubiaceae, Annonaceae, Meliaceae, Caesalpiniaceae, Sapindaceae and Sapotaceae have the highest tree species richness (Lejoly *et al.,* 1996; Sonké & Lejoly, 1998). On a 2-ha dense forest at Kade (Ghana) the Leguminosae was the best represented family (Swaine *et al*., 1987). Meave & Kellman (1994) found the same result in a 1.6 ha of RF in the Mountain Pine Ridge (Belize). According to Whitmore (1990) the three tropical rain forest blocks have abundant Leguminosae (subfamily Caesalpinioideae), Annonaceae, Euphorbiaceae, Lauraceae, Myristicaceae, Rubiaceae and Sapotaceae. For Gentry (1988) three families (Rubiaceae, Annonaceae and Euphorbiaceae) are always among the ten most species-rich families on all continents.

Summing up, the Leguminosae, Euphorbiaceae, Rubiaceae and Annonaceae are the most species-rich families always found in Benin RFs and in most tropical forest formations. Meanwhile the Cyperaceae show the influence of humid sites, while the high richness of the Poaceae is indicative of open canopy, degradation of RFs as well as edge effects.

4.4.3. Tree species richness in riparian forest sites

Tree species richness per ha varied from 27 to 99 (see Table 4.1), and these values are quite similar to the mean value (52) found by Meave & Kellman (1994) in a RF of Belize. In view of the large interregional variability in tree species richness per ha, figures of RFs in Benin are comparable to values (65-77) of some dense forests in Côte d'Ivoire at Taï National Park and Yapo (Corthay, 1996; Dengueadhe, 1999). Lejoly (1994) and Lejoly *et al.* (1996) found 92 and 84 tree species per 0.5 ha respectively in Dja Fauna Reserve (Cameroon) and Ngotto forest (Central Africa Republic). Swaine *et al*. (1987) enumerated 120 tree species in a two 1-ha samples of moist semi-deciduous forest at Kade (Ghana).

On the other hand, the species richness values found in Benin are lower than those (86-122) of Dogbo, Guiroutou and Djapadji forests in Côte d'Ivoire (Dengueadhe, 1999); 69-131 for Gabon forests (Reitsma, 1988); and in some neotropical wet forests (e.g. Bajo Calima, Western Columbia), which are among the most species-rich in the world, with over 250 tree species (Faber-Langendoen & Gentry, 1991). For Whitmore (1990), tree species richness per ha of forests vary from 23 in Nigeria to 283 at Yanamomo (Peruvian Amazon), the richest forest found so far.

4.4.4. Comparison of riparian forest sites diversities

A species diversity index, which takes into account the total number of species and their relative abundance offers a good description of communities and allows comparison between them. The overall RFs diversity in Benin (5.8 bits) represents quite a high value among forest formations. This figure is similar to the one (5.4 bits) of Dja Fauna Reserve in Cameroon (Sonké & Lejoly, 1998). Meanwhile it is higher than the values given by (Sokpon *et al.,* 2001) and (Kokou *et al.,* 2002) for certain RFs in Benin and Southern Togo, respectively.

Sites along streams have higher diversity values than sites along rivers, and the reason is the lower species richness and uneven distribution of the dominant trees along rivers where

4.5% of trees are represented by 58% of total individuals, while along streams 4.8% of trees are represented by only 35.4% of the total abundance. Tree species along streams are more evenly distributed (E = 0.82) than along rivers (E = 0.65). This difference in diversities between streams (smaller waterways) and rivers (larger waterways) is confirmed by the multivariate analysis (DCA and TWINSPAN) of the RFs data set (cf. Natta *et al.*, in press, see Chapter 6).

The comparison of tree species diversity between the two RF types (along streams and rivers) is an indirect way of comparing the effect of flood frequency, duration or intensity, and importance of waterways on species richness and abundance. The absence or short periods of inundation along streams allow plants with wider ecological range (forest pioneers and savanna species) to grow. At the same time a specialised (thus less diversified) flora, which supports 4 to 6 months of submersion per year, can only grow along rivers. Therefore at this stage of the investigations on RFs, the duration of submersion or flood seems negatively correlated with tree species diversity. This result substantiates the hypothesis that frequent or long environmental stresses, such as floods along rivers, will lead to a decrease in the diversity of species (at least for tree species), and a loss of diversity will lead to the increased abundance and dominance of those species that can successfully maintain themselves on isolated or harsh sites. Hanson *et al.* (1990) described a similar phenomenon in RF patches along the Upper mid-West of Iowa river (USA). Meanwhile, as species diversity is sometimes indicative of the diversity, stability and well-being of ecological systems, and used for environmental monitoring (Magurran, 1988; Withmore, 1990; Huston, 1994), we might say that any dense and least disturbed RF is in equilibrium with the prevailing ecological conditions.

4.4.5. Species and families abundance models

Log series adequately described tree species and family richness patterns of the RFs data set. In an assessment of forest plant diversity in Nepal, Acharya (1999) found that the log series describes species abundance pattern better than the geometric series, meanwhile the fit was not so good for plots with low disturbance. Also a gradual decrease in disturbance was well explained with the progression of species abundance models from the geometric series to a log series. From a 50-ha forest plot on Barro Colorado Island (Panama), the pattern of total species abundance deviates from the log-normal in having too many rare species (Hubbell & Foster, 1986). In the Peruvian Amazon, only 15% of species had more than 2 individuals and 63 % had only one individual (Whitmore, 1990).

Log series, that are intermediate between geometric series and log normal series, often characterise communities in which species of intermediate abundance become more common. Theoretically, the geometric series provides the best fit to the observed species abundance in species-poor communities under a harsh environment, while in large species-rich or mature communities the distribution of species abundance is usually log normal. As succession proceeds, or as conditions ameliorate, species abundance patterns grade from geometric series into those of the log series (Whittaker, 1972; Magurran, 1988). Therefore RFs, under the Benin conditions, are made of moderately species-rich or mature communities in which families with intermediate species richness and tree species with intermediate abundance are fairly common.

In large assemblages (as it is for our RFs data set), empirical patterns predict log normal series. However, new insights raised by Magurran & Henderson (2003), suggest that an ecological community can be separated into two components:

1 - core (i.e. typical) species, which are persistent, abundant, and grow naturally under good/optimal ecological conditions. They are log normally distributed.

2 – occasional (i.e. non-typical) species, which occur infrequently, have low abundance and different habitat requirements. They follow a log series distribution.

4.5. CONCLUSIONS

This paper has made an attempt to assess the flora, plant species diversity, as well as species abundance models that best fit RFs in Benin. The flora of RF contains about 1/3 of all species in Benin, 120 families and 513 genera. The Leguminosae, Euphorbiaceae, Rubiaceae and Annonaceae are the most species-rich families found time and again in Benin's RFs as well as in tropical rain forests. RFs can be recognised and characterised by exclusive, frequent and species typical to certain regions. Endemism is low compared to rain forests, yet in fire-prone environment the RFs of Benin harbour plant species that prefer the wettest conditions. They are a refugee ecosystem for forest plants, and act as route or corridor for movement of certain species across the landscape.

As RFs along streams have higher tree species diversity than those along rivers, we conclude that flood frequency, duration and intensity are somehow negatively correlated with tree flora diversity. A challenge is to assess the spatio-temporal effects of flood variables on plant species diversity. This study showed that relatively large numbers of species still are maintained in small forest fragments along waterways. Although RFs are often strip-like and fragmented ecosystems, their rich and varied flora invites protection and restoration. Also this phytodiversity, should be used in selecting the most suitable plant species for the rehabilitation of degraded RF corridors, in each ecological region of the country. This will allows them to fulfil their vital ecological, socio-economic and cultural functions.

ANNEX

Table 4.5: Details of the comparison of tree species diversity between seven riparian forests sites

Comparison of riparian forest sites	H'1	H'2	df	t calculated	t-table	Significance	Hypothesis accepted	Conclusion
Pénéssoulou (40 relevés) / Samiondji (36 relevés)	5.17	2.43	2392	34.08	p=0.001; t=3.29	***	H1	PE>SA: Pénéssoulou is more diverse than Samiondji
Idadjo-Bétérou (40 relevés) / Samiondji (36 relevés)	3.91	2.43	2679	18.82	p=0.001; t=3.29	***	H1	Id-Be>SA: Idadjo-Bétérou is more diverse than Samiondji
Okpara (56 relevés) / Samiondji (36 relevés)	4.91	2.43	2186	32.36	p=0.001; t=3.29	***	H1	Okp>SA: Okpara is more diverse than Samiondji
Streams Toui-Kilibo (62 relevés) / Samiondji (36 relevés)	5.4	2.43	2211	40.48	p=0.001; t=3.29	***	H1	Tk>SA: Streams of Toui-Kilibo forest are more diverse than Samiondji
Sudanian RF on plateau (43 relevés) / Samiondji (36 relevés)	4.97	2.43	2460	32.76	p=0.001; t=3.29	***	H1	Sud Plat>SA: Sudanian RF on plateau are more diverse than Samiondji
Sudanian RF at foot of hills (27 relevés) / Samiondji (36 relevés)	4.27	2.43	2210	21.96	p=0.001; t=3.29	***	H1	Sud Hill>SA: Sudanian RF at foot of hills are more diverse than Samiondji
Idadjo-Bétérou / Pénéssoulou	3.91	5.17	2498	17.09	p=0.001; t=3.29	***	H1	PE>Id-Be: Pénéssoulou is more diverse than Idadjo-Bétérou
Okpara/Pénéssoulou	4.91	5.17	1969	3.68	p=0.001; t=3.29	***	H1	PE>Okpara: Pénéssoulou is more diverse than Okpara
Streams Toui-Kilibo(TK streams) / Pénéssoulou	5.4	5.17	2015	3.39	p=0.001; t=3.29	***	H1	TK Streams>PE: Streams at Toui-Kilibo are more diverse than Pénéssoulou
Sudanian RF on plateau / Pénéssoulou	4.97	5.17	2263	2.79	p=0.01; t=2.57	**	H1	PE>Sud Plat: RF of Pénéssoulou are more diverse than Sudanian RF on plateau
Sudanian RF at foot of hills / Pénéssoulou	4.27	5.17	1980	10.85	p=0.001; t=3.29	***	H1	PE>Sud Hill: Pénéssoulou are more diverse than Sudanian RF at foot of hills
Okpara / Idadjo-Bétérou	4.91	3.91	2318	14.34	p=0.001; t=3.29	***	H1	Idadjo-Bétérou>Okpara: Idadjo-Bétérou is more diverse than Okpara
TK streams / Idadjo-Bétérou	5.4	3.91	2538	22.58	p=0.001; t=3.29	***	H1	TK>Idadjo-Bétérou : Streams of Toui-Kilibo forest are more diverse than Idadjo-Bétérou
Sudanian RF on plateau / Idadjo-Bétérou	4.97	3.91	2747	15	p=0.001; t=3.29	***	H1	Sud RF on plateau : Sud RF on plateau are more diverse than Idadjo-Bétérou
Sudanian RF at foot of hills / Idadjo-Bétérou	4.27	3.91	2105	4.43	p=0.001; t=3.29	***	H1	TK>Idadjo-Bétérou : Streams of Toui-Kilibo forest are more diverse than Idadjo-Bétérou
TK Streams / Okpara	5.4	4.91	1826	7.78	p=0.001; t=3.29	***	H1	TK>Okpara : Streams of Toui-Kilibo forest are more diverse than Okpara
Sudanian RF on plateau / Okpara	4.97	4.91	2071	0.88	p=0.2; t=1.28	NS	H0	Sudanian RF on plateau and RF along Okpara are similar in terms of tree species diversity
Sudanian RF at foot of Hills / Okpara	4.27	4.91	1778	8.03	p=0.001; t=3.29	***	H1	Okpara>Sudanian RF at foot of Hills: Okpara is more diverse than Sudanian RF at foot of hills
Sudanian RF on plateau / TK streams	4.97	5.4	2224	6.72	p=0.001; t=3.29	***	H1	Streams TK>Sudanian RF on plateau: TK streams are more diverse than Sudanian RF on plateau
Sudanian RF at foot of Hills / TK streams	4.27	5.4	1722	14.84	p=0.001; t=3.29	***	H1	Streams TK>Sudanian RF on plateau: TK streams are more diverse than Sudanian RF on plateau
Sudanian RF on plateau / Sudanian RF at foot of Hills	4.97	4.27	1954	8.7	p=0.001; t=3.29	***	H1	Sud RF plateau>Sud RF Hills: Sud RF on plateau are more diverse than Sud RF foot of Hills

NS = Non Statistically significant at p=0.05 ; ** Significant at 0.01 ; *** Significant at < 0.001 ; H'1& H'2 = Shannon indices.

Chapter 5

STRUCTURE AND ECOLOGICAL SPECTRA OF RIPARIAN FORESTS IN BENIN

A.K. Natta

Chapter 5

STRUCTURE AND ECOLOGICAL SPECTRA OF RIPARIAN FORESTS IN BENIN

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Abstract

This paper is a preliminary investigation of the structural characteristics of riparian forests in Benin. So far such information is not available in Benin. The structure was analysed through different methods: life forms, phytogeographic types, diameter class distribution, basal area, and stem density. Riparian forests displayed a physiognomy that is highly variable in terms of vertical stratification. Riparian forests in Benin were similar to many dense tropical forests, and to the West African ones in particular, in terms of phytogeographical types (large contribution of Guineo-Congolian basin species), life forms (high abundance of therophytes and medium size trees, low percentage of mega-phanerophytes and woody lianas), diameter class distribution (reverse J type), basal area (23-59 m^2/ha) and stem density (253 to 785 trees ≥ 10 cm dbh /ha). Species dominance, in terms of abundance and basal area, was a major characteristic of riparian forests in Benin. Many stands of riparian forests are facing various levels of structural and floristic simplification, which include fundamental transformations in vegetation physiognomy, from dense pristine stands to riparian scrub, or bare land.

Key words: riparian forests, structure, life forms, phytogeographic types, diameter, basal area, stem density, species dominance, Benin.

5.1. INTRODUCTION

Pattern in vegetation structure is a four-dimensional phenomenon. It can be studied at different scales, in space and time. Generally, vegetation structure is concerned with distribution of individuals along the vertical and horizontal axes, as well as spatial arrangement of physiognomical, taxonomic, morphological and functional characteristics of the elements building the vegetation (Popma *et al*. 1988, Sterck & Bongers 2001). Various methods have been used to assess the structure of tropical forests (Whitmore 1990), among which riparian forests are a major component.

In savanna regions, several authors have documented the structural characteristics of riparian forests (abbreviated as RFs), which contrast strongly with the open forest and savanna types which otherwise dominate the landscape (Adjanohoun 1965, Monnier 1990, Woinarski *et al.* 2000). However, in the pre-forest zone of Côte d'Ivoire (West Africa), the physiognomy of riparian forests is very much similar to the one of dense semi-deciduous forest, with which they share similar features such as presence of buttresses, cauliflory, presence of numerous epiphytes and lianas (Devineau 1975, 1976, 1984).

The floristic composition and plant community diversities of riparian forests in Benin have been studied (cf. Natta & van der Maesen, see Chapter 04), but an account of the general structure is lacking. The scale of the study (19 ha of riparian forests) and sites conditions (various climatic conditions, floristic compositions and successional states), imply that the selected structural parameters should give a general picture of riparian forests in Benin. Life forms are frequently used as a means of ecological characterisation of vegetation formations or plant communities, while the geographic affinity of a flora contains information about evolution patterns of species within the region of occurrence. Also basal area, stem density and diameter class distribution are intrinsic characteristics of a given plant community, and are often used to compare vegetation types. This paper investigates the structural characteristics of riparian forests in Benin, in terms of life forms, phytogeographic types, stem density and basal area. Two research questions will be answered:

1 - What are the most prominent life forms and phytogeographic types of riparian forests, and what are the implications of their occurrence in Benin?

2 - What are the average basal area and stem density of riparian forest sites in Benin, and are these figures comparable to those from other tropical forests?

5.2. METHODS

The study was conducted from 7°10 to 12°20 N in Benin (West Africa). About 19 ha of the least disturbed forest stands along rivers and streams were surveyed in the Guinean region (Samiondji and Bètèkoukou), Sudano-Guinean zone (Toui-Kilibo, Idadjo, Bétérou and Pénéssoulou) and Sudanian region (Yarpao, Gbèssè, Pendjari Biosphere Reserve), see Figure 4.1. In total 373 rectangular plots (each of 500 m^2), were installed in several RF sites using the Braun-Blanquet phytosociological method of floristic data collection. Tree height and dbh were measured in 304 plots (i.e. dendrometric relevés, see Table 5.1). Species names follow Keay & Hepper (1954-1972), Brunel *et al.* (1984), Berhaut (1967) and Lebrun & Stork (1991-1997).

Life forms followed Raunkaier (1934), Schnell (1971) and Keay & Hepper (1954-1972). They were: Phanerophytes (Ph) subdivided into mega-phanerophyte (MPh > 30 m), meso-phanerophyte (mPh: 8 to 29 m), micro-phanerophyte (mph: 2 to 7 m) and nano-phanerophyte (nph < 2m); Therophytes (Th); Hemicrytophytes (He); Chamaephytes (Ch); Lianas (L); Geophytes (Ge); Epiphytes (Ep) and Parasites (Par).

The phytogeographic types were named after White (1986) and Keay & Hepper (1954-1972). They were:

- Species widely distributed in the tropics (Cosmopolitan-Cosmo, Pantropical-Pan, Afro-American-AA and Paleotropical-Paleo).
- Species widely distributed in Africa (Tropical Africa-TA, Pluri Regional in Africa-PRA)
- Regional species in Africa (Sudanian-S, Guinean-G, Sudano-Guinean-SG, Sudano-Zambesian-SZ, Guineo-Congolian-GC).

The family, life form and phytogeographic affinity of each plant species were added to the species list. Stem diameter at breast height (dbh) was measured for trees (i.e. dbh ≥ 10 cm). Several variables were measured in each plot and on individual trees. Plot variables were: centre co-ordinates, riparian forest width, species richness and abundance. We plotted frequency distribution curves for the life forms, phytogeographic types, diameter class, and calculated basal areas and tree densities of riparian forest sites per ha.

5.3. RESULTS

Floristic and stand characteristics of riparian forests throughout Benin

In Benin, riparian forests vary in their width along the watercourses, which they fringe. Some are no more than a few meters wide and have an open canopy, while others are much more extensive and have a closed canopy and a well-developed structure. The floristic and stand characteristics of riparian forest in Benin are presented in Table 5.1.

Table 5.1: Floristic and stand characteristics of riparian forests throughout Benin

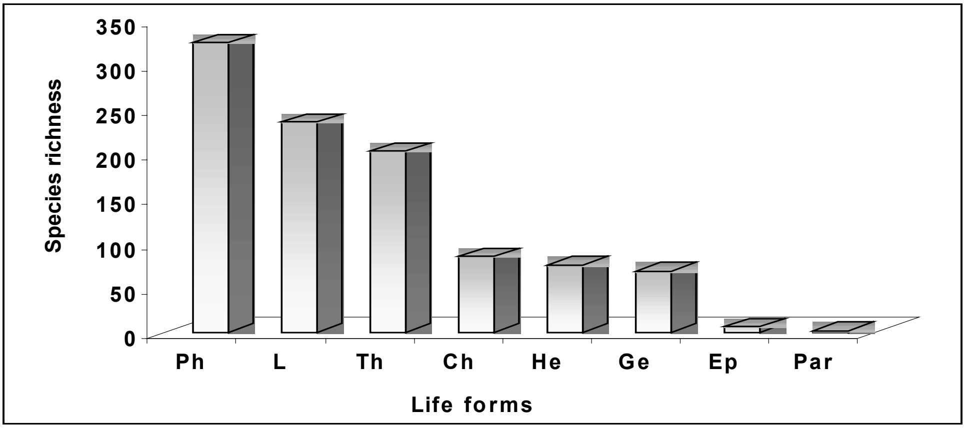
Regions	Sites	Floristic relevés (n_1)	Dendrometric relevés (n_2)	SR/site	SR/ha	SR of trees / site	Trees density/ha	Basal area (BA/ha)
Guinean	Samiondji	**38**	**36**	**306**	**249**	**27**	**726**	**41.7±17.4***
Sudano - Guinean	Pénéssoulou	41	40	450	343	99	544	38.9±15.3
	Idadjo-Bétérou	48	40	183-195	129-195	34-54	748-785	45.6±15.8
	Okpara	56	56	-	-	59	315	-
	Streams at Toui- Kilibo	78	62	-	-	78	257	-
	All Sudano-Guinean sites	**223**	**198**	**556**	**129-343**	**34-99**	**257-785**	**42.6±15.8**
Sudanian	RFs on plateau	76	43	435	182-278	36-44	538-627	35.6±16.5
	RFs at hill foot	36	27	467	358	65	732	42.7±9.9
	All Sudanian sites	**112**	**70**	**591**	**182-358**	**36-65**	**538-732**	**40±20.6**
All riparian forest sites in Benin		**373**	**304**	**1003**	**129-358**	**224**	**253-785**	**41.5±17.9**

n_1 = number of plots where floristic data were collected using the phytosociological approach; n_2 = number of plots where data were collected on individual trees; SR = Species richness per site (SR/site) or per ha (SR/ha); BA/ha = Basal area per ha in m^2; Trees = stems with dbh ≥ 10 cm; (*) ± Standard Deviation; (-) data not available.

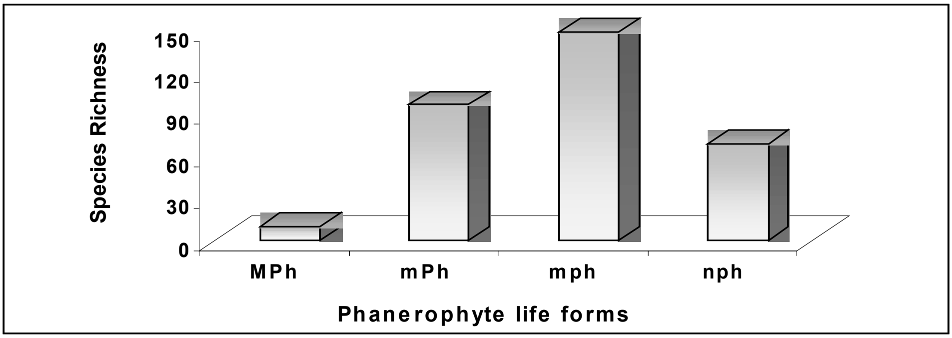
Life forms variability and frequency distribution

Phanerophytes (Ph), lianas (L) and therophytes (Th) are the richest life forms (Figure 5.1a). Field data confirm that trees are on average 14 to 18 m tall, with occasional heights of 20 to 25 m. If present, layers (i.e. vertical distribution of tree crowns) occur at variable heights, and are stand dependent. In the least disturbed stands, the top layer of uneven and discontinuous crowns is composed of a few emergent trees such as *Ceiba pentandra, Parinari congensis* and *Cynometra megalophylla*. Within phanerophytes, medium size trees (meso and micro-phanerophytes) are more frequent (75.6 %) than mega-phanerophytes (3 %) (Figure 5.1b). Also, liana richness in the Benin RFs is high (236 species, i.e. 23.6% of the overall RF species). Meanwhile, woody lianas (LMPh and LmPh, see Figure 5.1c) are only represented by 21 species (i.e. 8.9 % of the liana richness and 2 % of the total RF flora).

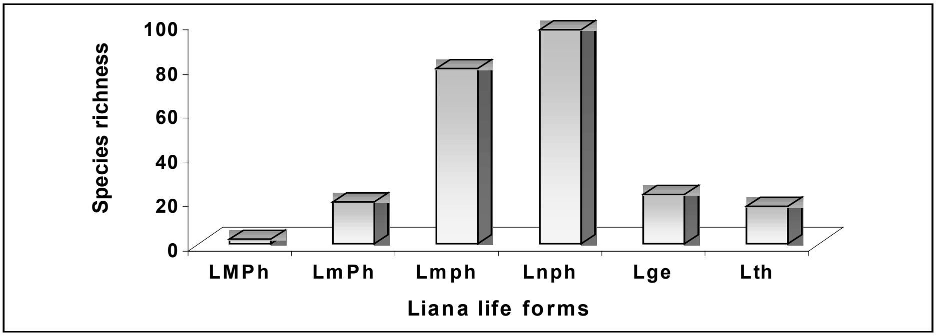
Among the six epiphyte species (0.6% of RF richness), the most frequent are the stem-tuber epiphytes *Calyptrochilum christyanum* and *C. emarginatum*. Less frequent is the humus-collecting epiphytic fern with clustered roots, *Platycerium angolense*.



(a): Overall life forms frequency distribution. Ph = Phanerophytes; L = Lianas; Th = Therophytes; Ch = Chamephytes; He = Hemicryptophytes; Ge = Geophytes; Ep = Epiphytes; Par = Parasites.



(b): Phanerophytes life forms frequency distribution. MPh = Mega-phanerophytes; mPh = meso-phanerophytes; mph = micro-phanerophytes; nph = nano-phanerophytes.



(c): Liana life forms frequency distribution in riparian forests. LMPh = Megaphanerophyte lianas; LmPh=mesophanerophyte lianas; Lmph=microphanerophyte lianas; Lnph=nanophanerophyte lianas.

Figure 5.1: Life form frequency distribution in riparian forests

Phytogeographical affinity of riparian forest species

Beside the large contribution of species from the Guineo-Congolian basin (33 % for Guineo-Congolian and Guinean types), species of wide distribution all over the tropics (Pantropical 16.7 %), and in tropical Africa (13.6 %) in particular, are the richest phytogeographic types of riparian forests in Benin (Figure 5.2).

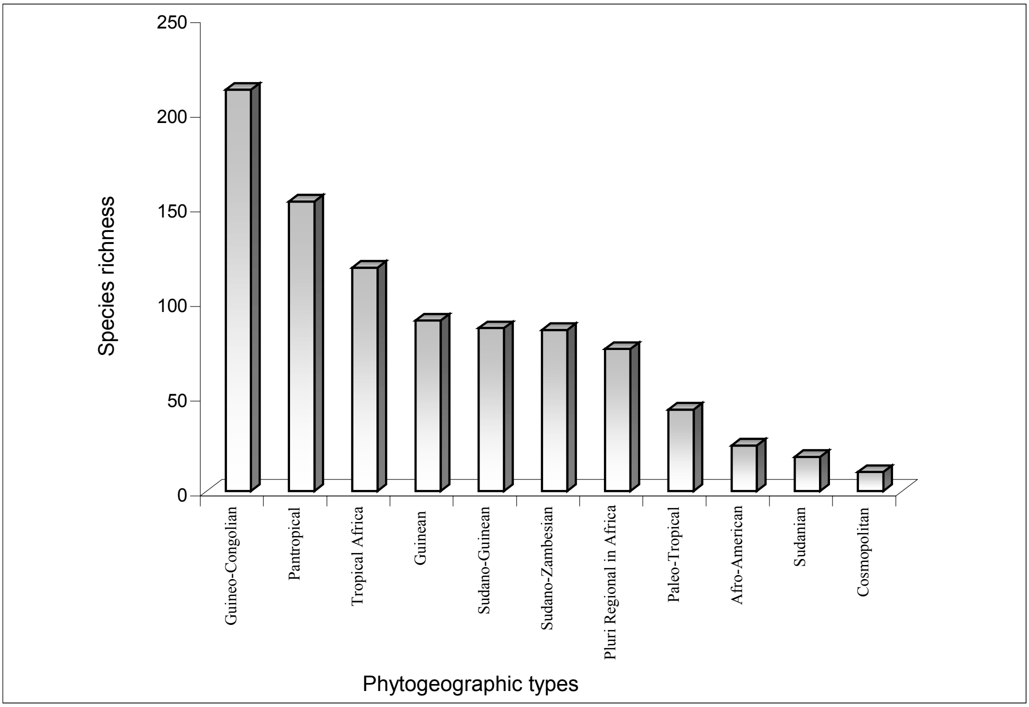


Figure 5.2: Phytogeographic types frequency distribution in riparian forests

Diameter class distribution

The size-class distribution (or stand table) of trees with a dbh ≥10 cm is drawn from 7765 stems. Stems with dbh < 50 cm are on the left part while bigger tree with dbh > 70 cm form the tail at the right part of the curve (Figure 5.3). Here higher abundance is found in the smaller size classes with a more or less logarithmic decline in numbers with increasing size. 76.4% of stems have less than 30 cm dbh.

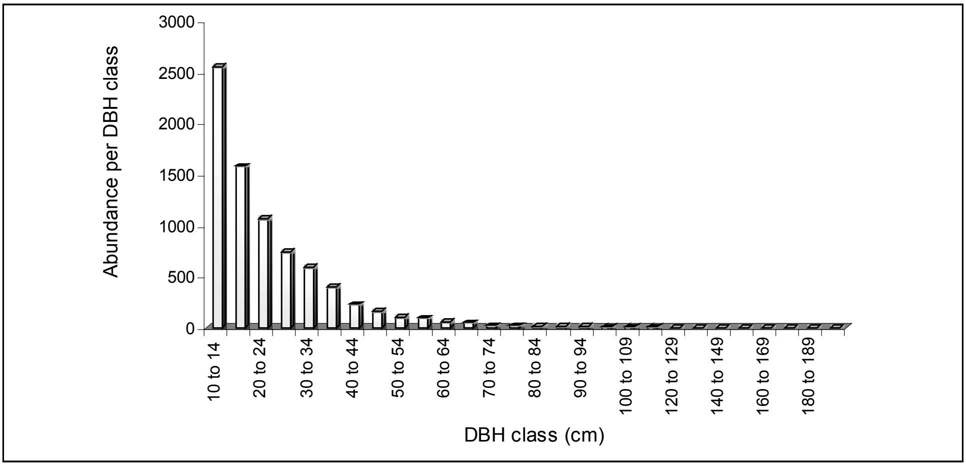


Figure 5.3: Diameter class distribution for riparian forest trees (dbh ≥ 10 cm) in Benin

Species dominance in riparian forests

Nine (i.e. 4%) tree species out of 224 contribute 46.3 % of the total abundance and 55.3 % of the total basal area. They are *Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Dialium guineense, Berlinia grandiflora, Cynometra megalophylla, Elaeis guineensis, Diospyros mespiliformis* and *Uapaca togoensis*.

5.4. DISCUSSION

Life forms variability

The life forms found in riparian forests are similar to many riparian forest sites in tropical Africa, in general and the savanna zones in particular. Akoègninou (1984) found similar ranking of life forms types in several dense semi-deciduous forests of Southern Benin. In gallery forests of the Hippopotamus Pond Biosphere Reserve (Burkina-Faso), phanerophytes and therophytes accounted for 64.8 % and 13.6 % of the total species richness respectively (Bélem & Guinko 1998). Phanerophytes are known to be the major life form in forest ecosystems, but in Benin's RFs the overall percentage is lower (56 %) than in other forest formations (e.g. 80-90 % given by Mangenot (1955) for dense tropical forests). Also at Lamto (South Côte d'Ivoire), Devineau (1984) found that RFs have more medium-size trees (meso- and micro-phanerophytes) than large ones (i.e. mega-phanerophytes). Along the Tana river (Kenya), riparian forests have a disturbed physiognomy characterised by a low mean height (14.4 m) (Medley 1992). In contrast, in tropical rain forests canopy tree heights fluctuate between 30 to 35 m and emergent trees may reach heights above 40 m (Popma *et al.* 1988, Whitmore 1990).

In Southern Togo, Kokou *et al.* (2002) found that gallery forests supported the greatest liana richness with 150 species (i.e. 30.8 % of the overall gallery forest richness), and the highest Shannon diversity index. In riparian forests along the Tana river (Kenya), 27% of the woody species are lianas (Medley 1992). Akoègninou (1984) found 150 liana species (i.e. 26.1% of the plant richness) in dense semi-deciduous forests in Southern Benin. In several rain forests in Côte d'Ivoire, the density of lianas was negatively correlated with the age of logged areas, and it ultimately reaches the maximum value of undisturbed patches (Kouamé & Traoré 2001). Lianas (woody climbers) and vines (herbaceous climbers) are an intrinsic and important component of tropical forests (Hall & Swaine 1981, Hegarty & Caballé 1991, Kokou *et al.* 2002) and are considered a major component for forest reconstitution (Kouamé & Traoré 2001, Parren 2003). Degradation (e.g. selective tree cutting or pruning, tree fall), lateral lighting as well as the multiplication of edge effects and ecotones through fragmentation, are favourable conditions for high abundance of lianas in RF.

The high abundance of vines and climbing shrubs (Lmph, Lnph, Lge and Lth, see Figure 5.1c) over woody lianas (LMPh) in RFs is indicative of relatively low forests having an irregular canopy (Medley 1992). On the other hand, the high species richness of therophytes (Figure 5.1a) indicates that many RFs in Benin are either degraded or influenced by neighbouring open plant communities. Like woody lianas, epiphytes reach their fullest development in humid tropical forests (Braun-Blanquet 1972).

Phytogeographical affinity of riparian forest species

Guinean species (Guineo-Congolian and typical Guinean) are abundant in dense semi-deciduous forests in Southern Benin (Akoègninou 1984), and in riparian forests at Bantè (Central Benin) (Akoègninou *et al.* 2001). In several gallery forests at Lamto (South Côte d'Ivoire), Devineau (1975) found 70 to 75% of Guineo-Congolian species against 15% of Sudano-Zambesian distribution. In gallery forests of the Hippopotamus Pond Biosphere Reserve (Burkina-Faso), Guineo-Congolian and Sudano-Zambesian species accounted for 61.7% and 38.3% of the total plant richness respectively (Bélem & Guinko 1998). This justifies the classification of RFs among humid vegetations. The floristic affinity towards the Guineo-Congolian rain forests is indicative for supply of water. The continuous and adequate availability of ground water and shallow water table, which originate from waterways, allow for the establishment and long-term existence of these species.

The geographical affinities (Guineo-Congolian, Pantropical and Sudanian species) of RFs from the West-African savanna regions support three conclusions: (a) The presence of numerous pan-african species with heavy seeds and fruits (e.g. *Diospyros mespiliformis*, *Oncoba spinosa*) suggest that the dense or evergreen forests in Africa were once continuous (Medley 1992); (b) the high contribution of Guineo-Congolian basin species substantiates the thesis of an early period of continuous forest block in West and Central Africa (see also Akoègninou 1984, Tossou 2002); (c) on the other hand, the incursion of savanna taxa and Sudano-Guinean transitional zone species (11.3 and 9.4 %, respectively) in RFs indicates the lower water balance along waterways in the dry season, particularly in North Benin.

Diameter class distribution

Similar results in diameter class distribution were found in RFs of Belize (Meave & Kellman 1994), where about 78% of trees were in the smallest dbh class (10-20 cm). Following these authors we might characterise RFs in Benin as low-biomass community with many small-stemmed trees, compared to the high-biomass continuous upland tropical rain forests.

The decreasing curve has a reverse-J (or J-shaped, see Figure 5.3) distribution typical of natural forest regenerating from seed. It suggests a stable size and age class distribution (Swaine *et al.* 1987). This shape is characteristic of climax species (Whitmore 1990). For Faber-Langendoen & Gentry (1991) this distribution type describes a mature stand, with many small individuals and few large ones. We hypothesise that the most abundant species among the flood-tolerant species of RFs are certainly at a stage of equilibrium with the climatic and edaphic conditions.

Basal area and stem density of riparian forests

The overall mean basal area (± S.D.) of RFs in Benin, obtained from 7765 stems (dbh ≥10 cm), was 41.5 ± 17.9 m^2 ha^{-1} and the mean density 586 ± 192 stems ha^{-1} (see Table 5.1). Sokpon *et al.* (2001) found a similar range for stem density ha^{-1} (312 to 665) for some edaphic forests in Benin with basal area ranging from 24.8 to 41 m^2 ha^{-1}. Goudiaby (1998) found a density of 507 trees/ha in a gallery forest of South East Senegal. Along the Tana river (Kenya), riparian forests have a low tree density and coverage, 409 stems ha^{-1} and 23.1 m^2/ha respectively (Medley 1992). The mean tree density of a 1.6 ha RF at the Mountain Pine Ridge (Belize) was 766 ± 241 stems ha^{-1} (Meave & Kellman 1994) that exceeds the values from Benin, obviously the mean basal area (21.9 ± 8.8 m^2 ha^{-1}) in Belize is far lower.

Values of basal area of RFs in Benin (23-59 m^2/ha) are similar to those of some West African upland dense forests (Taï, Dogbo, Guiroutou, Djapadji) in Côte d'Ivoire with 25-59 m^2/ha (Dengueadhe 1999) and humid forests in Ghana (25.5 to 33 m^2/ha) (Hall & Swaine 1976, Swaine *et al.* 1987). In Gabonese dense forests, Hladik (1982) and Reitsma (1988) found 35 and 35.7-42.9 m^2/ha respectively. In Cameroon, Sonké & Lejoly (1998) found a mean value of 30.5 m^2/ha in Dja fauna reserve and Gartlan *et al.* (1986) found 27.6 m^2/ha in the Korup forest reserve. At Parana high forest (Paraguay) the mean basal area is 39.6 m^2/ha (Stutz De Ortega 1987), while trees in the Los Tuxtlas rain forest plot (Mexico) had an average basal area of 34.9 m^2/ha (Bongers *et al.* 1988). For Gentry (1988) values range from 35 to 45 m^2/ha in Neotropical and Asian forests. Basal area figures found in Benin fit well with those given by Mori & Boom (1987) for tropical forests (21.3 - 53 m^2/ha).

Tree densities of RFs in Benin are similar to those in Taï, Dogbo, Guiroutou, Djapadji and Yapo upland forests in Côte d'Ivoire with 376–649 stems/ha (Corthay 1996, Dengueadhe 1999); while Swaine *et al.* (1987) obtained 552 ± 13 trees/ha in a 2-ha moist semi-deciduous forest at Kade (Ghana). In the Dja fauna reserve (Cameroon), Lejoly *et al.* (1996) and Sonké & Lejoly (1998) found respectively 603 and 461 trees/ha. The mean tree density was 471 ha^{-1} in the Korup reserve forest, Cameroon (Gartlan *et al.* 1986).

Forest structure at the Los Tuxtlas rain forest (Mexico) was characterised by a low density, i.e. 346 trees/ha (Bongers *et al.* 1988). Whitmore (1990) found a density of 580 stems/ha in Peru. For Neotropical forests the values ranged from 167 to 1947 trees/ha (Gentry 1982). Studies of many riparian forest fragments from Belize and Venezuela have shown that they contain tree species densities comparable to continuous forests, and a non-specialised tree flora comprised of species characteristic of continuous forest (Meave *et al.* 1991).

Species dominance in riparian forests

The phenomenon of species dominance, in which one or a few species contribute much to the total abundance and basal area, is not new in riparian systems as well as tropical forests in general. Along the Tana river (Kenya), riparian forests were characterised by a high species importance attributable to a few trees (Medley 1992). In a RF of Belize, Meave & Kellman (1994) found that the seven most abundant species (2.4% of the total species richness) account for 1/3 of the total number of stems. According to Wolter (1993) cited by Sonké & Lejoly (1998), dominant species can comprise up to 58 % of the total individuals and 75 % of basal area.

Tropical forests dominated by a few species have been considered to result from edaphic conditions unfavourable for a large majority of species (Richards 1952, Hartshorn 1988) such as poor nutrient status, presence of some minerals in toxic concentrations, and temporary or permanent flooding (Martijena & Bullock 1994, Martijena 1998). The latter factor seems more important in the present case, and this indicates the superior adaptation of such dominant tree species to a regime with vertical and lateral harsh disturbance. Therefore these species can be termed 'edaphic and climatic climax species' of RFs in the prevailing ecological conditions of Benin. They are keystone species and intrinsic components in the functioning of complex and self-organising RF systems. Moreover, they are essential for ecosystem resilience (i.e. resistance to disturbance and speed to return to a stable equilibrium) (Folke *et al.* 1996).

Process of riparian forests degradation

The impact of natural events and human activities on the structure and functioning of riparian areas in Benin include changes in the hydrology of waterways, alteration of the geomorphic structure of riparian areas, and the removal of riparian vegetation. From field observations, we have recognised three major non-successive phases of riparian forests degradation:
a) *Structural simplification* of dense and undisturbed stands, which is caused either by selective removal of big stems, destruction of the understorey (e.g. due to domestic livestock grazing or fire in the savanna region), or localised landslides that induce canopy opening and gaps at lower heights.
b) *Floristic richness depletion*, which involves constant and abusive harvest (e.g. systematic cutting, collection of all fruits or seeds of certain valuable plants), reduction in stands size (too frequent fires, shifting cultivation, dam or bridge construction), etc.
c) *Complete disappearance* consecutive to severe or irreversible transformation of the vegetation to other land and water-use (e.g. farm, dam, road, bridge construction, housing, etc.).

5.5. CONCLUSIONS

Riparian forests in Benin display a physiognomy (i.e. canopy height and vertical stratification) that is highly variable, though the understorey is generally dense. Tree size (stem diameter and height) is generally small. Most RF sites in Benin are degraded, highly influenced by adjacent more open ecosystems (edge effect) and characterised by open canopies. This is shown by a high amount of grasses (particularly annual species), a relatively low percentage of phanerophytes (particularly mega-phanerophytes and woody lianas as compared to tropical dense forests), and a high abundance of medium size and small trees. Therefore they can be termed as relatively low hygrophile forests with irregular canopy.

The most prominent phytogeographic types of riparian flora range from the Guineo-Congolian ones to species of wide distribution all over the tropics, and in tropical Africa. This substantiates the hypotheses of an early period of continuous dense forest block in West and Central Africa, and the influence of edge effects.

In terms of diameter class distribution, basal area and stem density RFs in Benin are very similar to many tropical dense forests and in particular to the West African ones. The phenomenon of species dominance, whereby few species contribute much to the total abundance and basal area, is also a major characteristic of RFs in Benin. Many riparian forests stands are facing various levels of structural and floristic simplification. This includes fundamental transformations in vegetation physiognomy, from dense pristine riparian forests to riparian scrub, or bare land. Action should be taken to overcome these threats to biodiversity by maintaining the existing legal protection and/or durable exploitation.

Chapter 6

A PHYTOSOCIOLOGICAL STUDY OF RIPARIAN FORESTS IN BENIN (WEST AFRICA)

In press, *Belgian Journal of Botany*

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Chapter 6

A PHYTOSOCIOLOGICAL STUDY OF RIPARIAN FORESTS IN BENIN (WEST AFRICA)*

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Abstract. - Floristic ordination and classification of riparian forests in Benin were derived from a comprehensive floristic inventory. TWINSPAN classification and DCA analysis of a data set of 818 plant species and 180 relevés yielded 12 plant communities. Importance of waterways, relief, topography, latitude and longitude were the five major environmental gradients that best differentiated riparian plant communities. A syntaxonomic classification of the identified riparian forests plant communities is presented. Riparian forests in Benin belong to the *Mitragynetea* Schmitz 1963, which is the phytosociological class of hygrophile fresh water forests of tropical Africa. Based on similarities of ecological conditions and floristic composition, we classified the 12 plant communities into 3 orders: *Alchornetalia cordifoliae* Lebrun 1947, *Lanneo-Pseudospondietalia* Lebrun & Gilbert 1954 and *Pterygotetalia* Lebrun & Gilbert 1954.

Key words: Riparian forests, classification, ordination, syntaxonomy, Benin.

6.1. INTRODUCTION

The recognition and definition of natural groupings of plant species in vegetation formations have always been a challenging field of study for many researchers. Phytosociology is concerned with the detection and characterisation of distinct plant assemblages as social units (groups of similar relevés), which repeat themselves over space (BRAUN-BLANQUET 1972, KENT & COKER 1992). Some authors have shown the applicability of the phytosociological approach in forests of the humid tropics (HOMMEL 1990). Plant communities provide a far better means of analysing the relation between vegetation and climate, edaphic, topographic and human factors (LAWSON *et al.* 1970, GARTLAN *et al.* 1986, RUSSEL-SMITH 1991) than the physiognomic approach does (HOMMEL 1990).

Multivariate methods for vegetation classification and ordination have been applied to tropical West African forest types (SWAINE & HALL 1976, GARTLAN *et al.* 1986, SOKPON 1995, KOKOU 1998). These methods have shown to be useful in extracting meaningful gradients and vegetation types or plant communities in tropical humid forests, which seems too complex for satisfactory analysis by more traditional methods (SWAINE & HALL 1976). In Benin, apart from the work of SOKPON *et al.* (2001), no attempt was made so far in the field of the phytosociology of riparian vegetation in general, and in particular riparian forests (hereafter abbreviated as RFs).

Control over internal structure of riparian ecosystems, in particular vegetation, has been attributed to fluvial dynamics, frequent perturbations (e.g. flooding) and soil moisture (MEDLEY 1992, THOMAS 1996, PIEGAY 1997, LEINARD *et al.* 1999), all of which are processes related to topography (HANSON *et al.* 1990).

In this paper we report the results of a multivariate analysis of RF based on comprehensive floristic data collected throughout Benin, a country located at the discontinuity of the tropical West African rain forest block. The aim of the paper is to assess whether meaningful ecological factors and environmental gradients can be derived from numerical analysis of RF samples and to provide a floristic classification (*i.e.* a typology of RF plant communities). A related aim is to document the environmental relations of the identified plant communities and their characteristic species.

6.2. MATERIAL & METHODS

6.2.1. Study area

All types of ecological regions of Benin, excluding the coast, beaches, coastal lagoons, lakes and marshlands, were surveyed. The study area (Figure 6.1) covered the latitudes 7°10 to 12°20 N. Representative sites along rivers and streams were surveyed in the Guinean region (Samiondji and Bétékoukou), the Sudano-Guinean zone (Toui-Kilibo, Ouèssè, Bétérou, Onklou-Daringa and Bassila-Pénéssoulou) and the Sudanian region (Ouaké, Affon, Natitingou, Koussoukouingou, Toukountouna, Pendjari Biosphere Reserve, Kandi, Ségbana and Malanville).

6.2.2. Phytosociological relevés in riparian forests

Floristic data were collected in 12 riparian forests sites (Table 6.1) using the BRAUN-BLANQUET (1972) method for vegetation analysis. Rectangular plots, each of 500 m^2, with variable length and width, were preferred for practical reasons to fit with any shape of the waterway and the structural uniformity (physiognomy of the RF). When all terrestrial plants in all stages are included, many authors found smaller plot sizes (500 to 1000 m^2) acceptable to allow the classification of forest plot data by means of tabular comparison (HOMMEL 1990). Field plots (50m by 10m) were established in fragmented forests in Southern Togo (KOKOU *et al.* 2002). Rectangular plots of 500 or 1000 m^2 were used to collect floristic data in several edaphic forests in Benin (SOKPON *et al.* 2001). In the strip-like forest fragments that are RF, homogeneous plots of 500 m^2, with varying length and width, seem to be of a reasonable size for the numerical ordination and classification of phytosociological relevés (see also Chapter 8).

At each site plots were established, in homogeneous stands, at about 100 m from each other, from a random starting point. In each plot all vascular plants were recorded and specimens taken for the herbarium. As we are dealing with a particular vegetation formation defined by certain hydrographic, soil and topographic characters, relevés taken into account in the present paper were selected from a larger data set with the greatest possible uniformity or homogeneity in regard to their physiognomy, species composition, and dominant species. Plots highly disturbed or less than 10 m wide, and outlier relevés were removed from the original 232 plots. This yielded 180 relevés and 818 plant species. These relevés are taken as the most representative of the ecological conditions occurring in the studied sites.

Plant nomenclature follows KEAY & Hepper (1954-1972), BRUNEL *et al.* (1984), BERHAUT (1967) and LEBRUN & STORK (1991-1997). The conventional six-part abundance-dominance scale of BRAUN-BLANQUET (1972) is adopted in the present work. This scale was applied for each species within each of the three strata: Dominant (height > 10 m), Medium (height between 3 and 10m) and Understorey (< 3 m high) species.

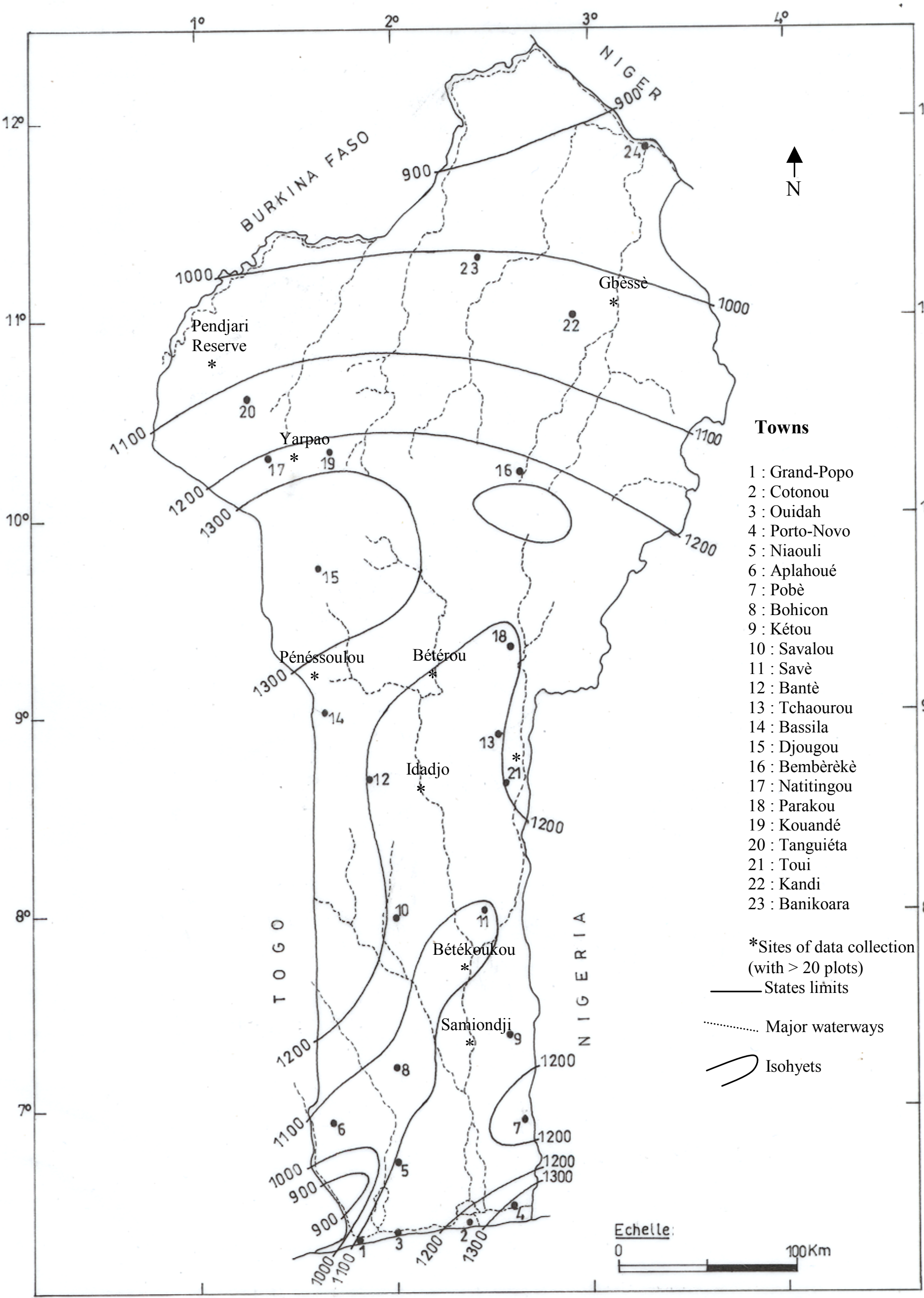


FIG. 6.1.- Study sites where data were collected in riparian forests in Benin

Table 6.1: Floristic and stand characteristics of riparian forests throughout Benin

Climatic region	Sites	Type of riparian forests	Relevés (n) *	Species richness/ha	Trees density/ha	Basal area (BA/ha)
Guinean	Samiondji (Sa)	Ouémé river	31	249	726	41.7±17.4
Sudano-Guinean	Pénéssoulou (Pe)	Streams in Pénéssoulou forest	34	343	544	38.9±15.3
	Idadjo (Id)	Ouémé river	17	129	748	35.8±10.7
	Bétérou (Be)	Ouémé river	30	195	785	41.6±15.8
Sudanian	Sota (So)	Sota river	8	-	540	33.1±7.9
	Yarpao (Ya)	Streams at hills feet	22	358	732	42.7±9.9
	Bétérou (Be), Batia (Ba)	Streams on plateau with inundations	10	-	602	40.5±8.9
	Bétérou (Be), Toucountouna (Tc), Gbèssè (Gb), Péhunco (Ph)	Streams on plateau seldom inundated	16	-	531	25.9±4.6
	Porga (Po), Konkombri (Ko)	Pendjari river	12	-	571	33.1±17.5
Total			180	129-358	253-785	41.5±17.9

* n = number of phytosociological relevés; Trees = stems with dbh ≥ 10 cm.

6.2.3. Data analysis

For data analysis of the 818 plant species and the 180 representative RF samples, both ordination and numerical classification methods were used. No species of the representative relevés was omitted in the analysis. Detrended Correspondence Analysis (DCA) (Hill & Gauch 1980, ter Braak 1995, ter Braak & Smilauer 1998) was used as indirect gradient method to detect the underlying ecological gradients/factors within the RF relevés set. The definition of plant communities was achieved through Two-Way Indicator Species (TWINSPAN) (Hill 1979). Dendrograms were obtained with STATISTICA® 5.1 (1998) using Euclidean distance as distance measure and Ward's minimum variance as aggregation method.

The classification of the individualised plant communities followed the work of Lebrun (1947), Leonard (1952), Schnell (1952), Lebrun & Gilbert (1954), Schmitz (1963, 1971, 1988), and Sokpon *et al.* (2001).

6.3. RESULTS

Environmental gradients/factors of riparian forests samples partition

The stand characteristics of the surveyed riparian forests are presented in Table 6.1. Detrended Canonical Analysis (DCA) of 180 relevés and 818 plant species (Figure 6.2) showed a major indirect floristic factor (axis 1) correlated with the type or importance of waterways: small (streams) or large (rivers). There are three groups of plant communities: RF plant communities of the Pénéssoulou forest (group 1), along streams all over the country (group 2) and along rivers (group 3). This result is in accordance with the TWINSPAN classification output. The TWINSPAN output table (three A0 format sheets) is available on request from the authors. Each one of the 3 groups is further analysed in a partial analysis.

Group 1: Riparian Forests (RF) of Pénéssoulou protected forest

The partial DCA analysis of 34 samples and 282 plant species showed a floristic gradient (axis 1) of two plant communities correlated with topography (Figure 6.3). This result is in accordance with the dendrogram (Figure 6.4). The denomination of each plant community is derived from two characteristic species, which are also the most indicative of the ecological conditions, topography in this case. They are:

1 **-** Plant community of *Isolona thonneri* and *Callichilia barteri* (10 relevés) along streams in the centre of Pénéssoulou protected forest. This plant community is located at the lowest parts of the forest along streams with frequent inundation.

2 - Plant community of *Motandra guineensis* and *Pararistolochia goldieana* (24 relevés) along streams at the East and West parts of Pénéssoulou reserve forest. This community is located in drained sites (*i.e.* seldom inundated).

Group 2: Riparian forests along streams all over the country

DCA of 48 relevés and 284 plant species (Figure 6.5) showed a major floristic factor (axis 1) correlated with land form variation, namely relief (RF at hill foot *versus* RF on plateau) and topography (RF on plateau regularly inundated *versus* RF on plateau seldom inundated). In general, this result is in accordance with the TWINSPAN output and the dendrogram (Figure 6.6). Four plant communities are discriminated from the ordination and classification analysis:

3 - Plant community of *Chrysobalanus icaco* subsp. *atacoriensis* and *Pentadesma butyracea* along streams at hill feet in the Atacora mountain chain (22 relevés).

4 - Plant community of *Alchornea cordifolia* and *Ficus trichopoda* along streams on regularly inundated plateaus all over the country (10 relevés).

5 - Plant community of *Berlinia grandiflora* and *Khaya senegalensis* along streams on drained plateaus (*i.e.* seldom inundated), mainly in the Sudanian region of the country (8 relevés).

6 - Plant community of *Raphia sudanica* and *Oxytenanthera abyssinica* along streams on drained plateaus, mainly in the Sudanian region (8 relevés).

Group 3: Riparian forests along rivers all over the country

DCA of 98 relevés and 291 plant species (Figure 6.7) showed a major gradient correlated with latitude (Axis 1: Guinean region of South *versus* Sudano-Guinean and Sudanian regions in the Central and North Benin) and longitude (Axis 2: extreme West *versus* Centre and East Benin). 3 sub-groups of relevés are shown:

(a) - Bétérou, Idadjo and Sota in the Centre;
(b) - Porga and Konkombri in the North-West and
(c) - Samiondji in the South of the country.

Each subgroup is further analysed in a partial DCA ordination and a classification.

Only the DCA of sub-group (a), (Figure 6.8) showed a floristic gradient correlated with latitude (Axis 1): Centre of the Sudano-Guinean zone (Idadjo), North of the Sudano-Guinean zone (Bétérou), and Sudanian region (Sota) at Ségbana latitude. These results are in accordance with the dendrogram (Figure 6.9) and TWINSPAN classification (Figure 6.10). Therefore five plant communities are discriminated in RF along rivers:

7 - Plant community of *Cynometra megalophylla* and *Parinari congensis* along the Ouémé river in the Guinean region of Southern Benin (31 relevés).

8 - Plant community of *Capparis thonningii* and *Crateva adansonii* along the Ouémé river in the Sudano-Guinean region of Central Benin (30 relevés).

9 - Plant community of *Lepisanthes senegalensis* and *Drypetes floribunda* along the Ouémé river in the Sudano-Guinean region of Central Benin (17 relevés).

10 - Plant community of *Uapaca heudelotii* and *Irvingia smithii* along the Sota river in the North-East of the country (8 relevés).

11 - Plant community of *Garcinia livingstonei* and *Combretum acutum* along the Pendjari river in the North-West of the country (12 relevés).

6.4. DISCUSSION

6.4.1. Environmental gradients and factors partitioning riparian forest plant communities

In total, 5 environmental gradients/factors were identified from the ordination process:
1 - Type or importance of waterways: RF along streams / RF along rivers;
2 - Relief: RF at hill feet / RF on plateau;
3 - Topography: RF on regularly inundated plateau / RF on seldom inundated plateau;
4 - Latitude: RF in the Guinean region of South-Benin / RF in the Centre of the Sudano-Guinean region (Idadjo) / RF in the North of the Sudano-Guinean region (Bétérou) / RF in the Sudanian region (Sota) at Ségbana latitude;
5 - Longitude: RF in the extreme West / RF in the Centre and East of the country.

The three sets of the RF data: Pénéssoulou, rivers and streams (see Figures 6.2, 6.10 and 6.11), somehow match the vegetation formations and phytogeographical districts of Benin. The flora of RF along rivers is much more dependent on frequent floods than the flora along streams, where the surrounding vegetation greatly influences stream side vegetation. On the other hand the Pénéssoulou region in West-Central Benin is the easternmost point of the dry semi-deciduous forest fire subtype (HALL & SWAINE 1981). This vegetation also covers Central Togo, and Central and South Ghana. In this hygrophile enclave surrounded by savannas, RFs occupy thalweg bottoms and share numerous species (e.g. *Cleistopholis patens, Pierrodendron kerstingii,* etc.) with the Pobè region, which is the wettest region of Benin in the South-East.

The first 2 DCA axes, which have the highest contribution to the total variation in the data set, were linked to environmental gradients/factors: importance of waterway, relief, topography, latitude and longitude. Depending on forest types and sites characteristics, various authors have also documented the major environmental gradients/factors that explain the grouping of floristic relevés. In an application of ordination and classification to closed-canopy forest in Ghana, rainfall was not the only factor with a large effect on forest composition. Also rock type and occasional ground fires were important in drier forests. Altitude was important in wetter forest (HALL & SWAINE 1976, SWAINE & HALL 1976). RUSSEL-SMITH (1991) identified a primary latitude-moisture gradient and a subsidiary topographic-drainage gradient as the two major environmental gradients underlying the grouping of 1219 sites and 559 rain forest taxa in Northern Australia. According to HANSON *et al.* (1990), the most important processes related to topography are flooding, soil moisture and fluvial dynamics. For various tropical forests, altitudinal zonation, rainfall variability, as well as the influence of rock type, occasional ground fires, play an important role in the typology of forest communities (NAKASHIZUKA *et al.* 1992).

The interpretation of the DCA gradients is broadly in accordance with valuable work on the phytosociology of edaphic and hygrophile vegetations of fresh water (e.g. LEBRUN & GILBERT 1954, SCHMITZ 1988, SOKPON *et al.* 2001). LEBRUN & GILBERT (1954) enumerated the ecological factors that play a role in the discrimination of edaphic forests linked to hydromorphic soils: a) variation of the water table (i.e. level and periodicity) above the soil surface and in the edaphic profile; b) the degree of alluviation; and c) the intensity of soil drainage. They further mentioned that physiographic characters of the site, the nature of water and substrate might play a role in the typology of hydromorphic vegetations, but marginal as compared to the precedent factors. Generally, the influence of flood and variation of the water table is considerable (MANDANGO & NDJELE 1986). SOKPON *et al.* (2001) found that latitude, drainage and duration of flooding were the best discriminating factors for 51 wetland forest relevés in Benin. Meanwhile, their typology did not go beyond the formation level (i.e. gallery, swamp, periodically inundated and riverine forests). A limitation of that work is that no plant communities were identified, as in the present study. Also the differentiation in such broad vegetation types, based on the floristic composition, does not always conform to the reality of the terrain.

The amount of variation explained by the DCA analysis is fairly low (14 to 21%). A reason might be the high number of relevés (180), species (818) and uncontrolled variables. GANGLO (2000), and HOUINATO (2001) found almost the same range of values for the explained variance, respectively 16 to 22% for plantations understorey in Central and Southern Benin, and 18 to 25% for savanna in Central Benin. BOCARD *et al.* (1992) pointed out that it may not be feasible to measure all the environmental variables (in the broad sense: biological interactions and external environmental factors) that are relevant in an ecological study. Given these constraints, and at this stage of the study of RFs in Benin, the underlying factors found through the interpretation of the DCA axes can nevertheless be considered as important in the structuring of these plant communities.

6.4.2. Classification of RF relevés

The apparently 'homogeneous' site characteristics of the narrow RF on continually moist, sometimes flooded and with sandy shores, hides in fact more complex fluvial processes moulded by the regional climate, relief, and human activities. This allows a variety of groupings of plant species. The floristic classification of RF relevés allows us to identify 11 constant plot assemblages, each one referring to a plant community (*i.e.* plant association). An additional riparian forest plant community (*Mimosa pigra* and *Ficus asperifolia*) regularly cited in the literature (LEBRUN & GILBERT 1954, MANDANGO 1982, MANDANGO & NDJELE 1986, SCHMITZ 1988) is widely distributed on sandy banks of rivers in tropical Africa. However it could not be clearly distinguished and classified as the 11 previous types through the DCA and TWINSPAN analysis. Therefore we can say that there are at least 12 plant communities, each having its distinct and well-developed stands, in the Benin riparian forests. This classification, based on comprehensive phytosociological relevés, is both readily interpretable and repeatable.

The two species forming the denomination of the plant community were carefully selected among the characteristic (exclusive, selective, preferential) species according to the degrees of fidelity defined by BRAUN-BLANQUET (1972). These species are among characteristic species having a high ecological indicator value. Each plant community may occur in many stations (or sites) but they all exist in only one well-defined and ecologically characteristic habitat, e.g. RF along rivers in the Guinean region of Southern Benin, RF along streams at hill feet in the North West of the country, and RF along streams on plateau in the Sudanian region.

In general, the results from DCA, TWINSPAN classification and dendrograms are similar and they appear to be complementary techniques in the partition of groups of relevés based on their floristic composition affinity.

6.4.3. Relation plant communities/environmental factors

Although some environmental factors were found to induce a certain grouping of RF samples based on presence/absence of species, the interpretation of causal relationships between the identified plant communities and these gradients should be taken with care (KENT & COKER 1992). From detailed understanding of the relationship between riparian vegetation and ecological factors, we might say that the importance of waterways, latitude, longitude, relief and topography act indirectly through climatic, geomorphologic and edaphic variables. HOMMEL (1990) already found that both physiognomy and floristic composition clearly reflect the relation between climate and vegetation.

On the one hand, the most important climatic conditions in Benin are rainfall, temperature, hygrometry, Potential Evapotranspiration (PET) and seasons duration; on the other hand, soil texture, structure and nutrient status, and bedrock type are the most important edaphic variables. The combination of these variables modulated by the relief and topography not only control the volume, velocity of water and the duration of inundation but also specific requirements of individual species in these edaphic and hygrophyle plant formations. Generally for plant communities, the effective external factors are numerous and variable, and the possible combinations so manifold. Also the overlapping is frequent and the relation of habitat to plant community is not a simple and reversible function. In consequence, a clear and unequivocal delimitation of the identified plant communities' habitats according to operative external factors appears quite unattainable (BRAUN-BLANQUET 1972).

As plant species experience the conditions provided by many environmental variables (TER BRAAK 1987), from the field data we can draw preliminary conclusions concerning the response of certain species to the combination of the ecological variables cited above. Species that seem to be influenced by climate and edaphic conditions along waterways in:
- the Guinean region and Sudano-Guinean zone: *Cynometra megalophylla, Lepisanthes senegalensis, Drypetes floribunda, Cassipourea congoensis*, *Cleistopholis patens, Napoleonaea vogelii, Pierreodendron kerstingii*;
- the Sudano-Guinean zone: *Pararistolochia goldieana, Callichilia barteri, Detarium senegalense, Motandra guineensis, Pandanus candelabrum, Leea guineensis, Khaya grandifoliola*, *Pseudospondias microcarpa*;
- the Sudano-Guinean and Southern Sudanian zones: *Pentadesma butyracea, Isolona thonneri, Raphia sudanica, Celtis toka, Garcinia ovalifolia, Ixora brachypoda, Uapaca togoensis, Ficus trichopoda*;
- the Sudanian region: *Chrysobalanus icaco* subsp. *atacoriensis, Brenadia salicina, Chionanthus niloticus, Eriocoelum kerstingii, Thunbergia atacoriensis, Oxytenanthera abyssinica, Synsepalum passargei*;
- the Northern Sudanian zone: *Irvingia smithii, Garcinia livingstonei, Combretum acutum*;
- the whole country: *Pterocarpus santalinoides, Mimosa pigra, Ficus asperifolia, Dialium guineense, Elaeis guineensis, Cola laurifolia, Berlinia grandifolia, Parinari congensis, Kigelia africana, Crateva adansonii, Morelia senegalensis, Syzygium guineensis* var. *guineensis, Alchornea cordifolia, Khaya senegalensis, Uapaca heudelotii.*

Biotic factors such as intra and inter species relationships and human induced disturbance, which play a role in the grouping and layering plant species are not explored in the present study. This preliminary information about the occurrence of individual species might be useful in drawing distribution maps of these species and the plant communities in which they reach their optimal development in Benin.

6.4.4. Syntaxonomic relationships of the 12 plant communities

We present a syntaxonomic classification of the identified plant communities under the hierarchical structure (orders and suitable alliances) of edaphic forest formations of fresh water occurring in West and Central Africa. Thus far, in Benin such a general system of RF plant communities classification is not available.

All tropical African RF belongs to the *Mitragynetea* SCHMITZ 1963, the class of hygrophile forests of fresh water (SCHMITZ 1971, 1988). As for gallery forests of the Congo basin (see LEBRUN & GILBERT 1954), RF of Benin have either a Guinean or Sudanian-Zambesian tendency. In Benin the most frequent plants of the *Mitragynetea* SCHMITZ 1963 are *Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Dialium guineense, Morelia senegalensis, Elaeis guineensis, Parinari congensis, Manilkara multinervis, Phaulopsis barteri, P. ciliata, Taccazea apiculata, Achyranthes aspera, Afzelia africana, Xylopia parviflora,* and *Antidesma venosum*.

Based on field data, similarities of ecological conditions and floristic composition, we classified the 12 RF plant communities into 3 orders that are *Alchornetalia cordifoliae* LEBRUN 1947, *Lanneo-Pseudospondietalia* LEBRUN & GILBERT 1954 and *Pterygotetalia* LEBRUN & GILBERT 1954 (Figure 6.11).

*** *Alchornetalia cordifoliae* LEBRUN 1947:**

It is the order of shrubby and pre-forest plant communities following herbaceous semi-aquatic formations along larger waterways (Ouémé, Sota rivers), with relatively important alluvial deposits. This order also occurs in larger valleys along streams with a long period of inundation. The most frequent species are *Mimosa pigra, Ficus asperifolia, Alchornea cordifolia, Ficus* spp., etc. Within this order we can distinguish 3 alliances each containing one plant community:

1 – *Mimosion pigrae* MANDANGO 1982, alliance with a Guinean tendency although it can be found in the Sudano-Zambesian region (LEBRUN & GILBERT 1954). The *Mimosa pigra* and *Ficus asperifolia* plant community is classified in this alliance. It occurs as dense shrubby but isolated stands always found on sandy bars close to the lowest level of the water along rivers. Therefore, every year it is flooded for 3 to 4 months. MANDANGO & NDJELE (1986) defined it as an association in the Congo basin.

2 – *Alchorneion cordatae* LEBRUN 1947, alliance of shrubby and pioneer plant communities of fresh water. The *Alchornea cordifolia* and *Ficus trichopoda* plant community is the only that can be classified in this alliance. In fact this community is widely distributed over the country in sites where the substrate is either constantly humid or periodically inundated or muddy with clayey soil. Several authors (e.g. LÉONARD 1952, KALANDA 1981, LEJOLY & MANDANGO 1982, MANDANGO & NDJELE 1986) have described a variety of plant communities with *Alchornea cordifolia* as characteristic species.

3 – *Uapacion heudelotii* LEBRUN & GILBERT 1954. This alliance harbours the plant community of *Uapaca heudelotii* and *Irvingia smithii* that was already defined as association by LÉONARD (1947) and KALANDA (1981). It is widely distributed throughout tropical Africa from Congo to Senegal (SCHMITZ 1988). Meanwhile in Benin the two characteristic species are only seen associated in the North, showing the association's Northern Sudanian tendency.

*** *Lanneo-Pseudospondietalia* LEBRUN & GILBERT 1954:**

This order groups all riverine forest with a seasonally alternation of heavy inundation and short period of drainage. It is typical to the Guinean region (e.g. Samiondji latitude), meanwhile penetrates the Sudano-Guinean zone (Ouèssè, Bétérou and Pénéssoulou latitudes). The most frequent species of this order are *Napoleonaea vogelii, Cassipourea congoensis, Salacia pallescens*, *Synsepalum brevipes*, *Cleistopholis patens, Pseudospondias microcarpa, Pierreodendron kerstingii, Spathodea campanulata, Trilepiseum madagascariense, Parquetina nigrescens*. The associated plant communities are:

a) - In the Guinean region of Southern Benin at Samiondji latitude: *Cynometra megalophylla* and *Parinari congensis* along the Ouémé river.

b) - In the Sudano-Guinean region of Central Benin at Ouèssè and Bétérou latitudes: *Lepisanthes senegalensis* and *Drypetes floribunda*; *Capparis thonningii* and *Crateva adansonii* along the Ouémé river.

c) - In the Pénéssoulou protected forest: *Isolona thonneri* and *Callichilia barteri; Motandra guineensis* and *Pararistolochia goldieana.*

*** *Pterygotetalia* LEBRUN & GILBERT 1954:**

This order groups all riparian forests with a Sudanian-Zambesian tendency occurring in valleys or on drained plateau with short periods of inundation (few days during the rainy season) and long periods of dryness. For LEBRUN & GILBERT (1954), this order is not only edaphic but also physiographic as steep banks of hills can hem in streams. The most frequent species are *Berlinia grandiflora, Khaya senegalensis, Raphia sudanica, Oxytenanthera abyssinica, Uapaca togoensis, Diospyros mespiliformis, Vitex doniana, Strychnos nigritana, Oxyanthus unilocularis, Chionanthus niloticus, Garcinia ovalifolia,* etc. This order includes:

a) - gallery forests of Central and North Benin on drained plateau (*Berlinia grandiflora* and *Khaya senegalensis*; *Raphia sudanica* and *Oxytenanthera abyssinica* plant communities),

b) - gallery forests at hill feet (*Chrysobalanus icaco* subsp. *atacoriensis* and *Pentadesma butyracea* plant community), and

c) - gallery forests along the Pendjari streams and its tributaries in the North-West of the country (*Garcinia livingstonei* and *Combretum acutum* plant community).

Sites descriptions, floristic composition, physiognomy, ecological spectra and structural characteristics and phytosociological tables for each plant community will be discussed in separate papers (Natta *et al*., in preparation, for association of *Garcinia livingstonei* and *Combretum acutum*).

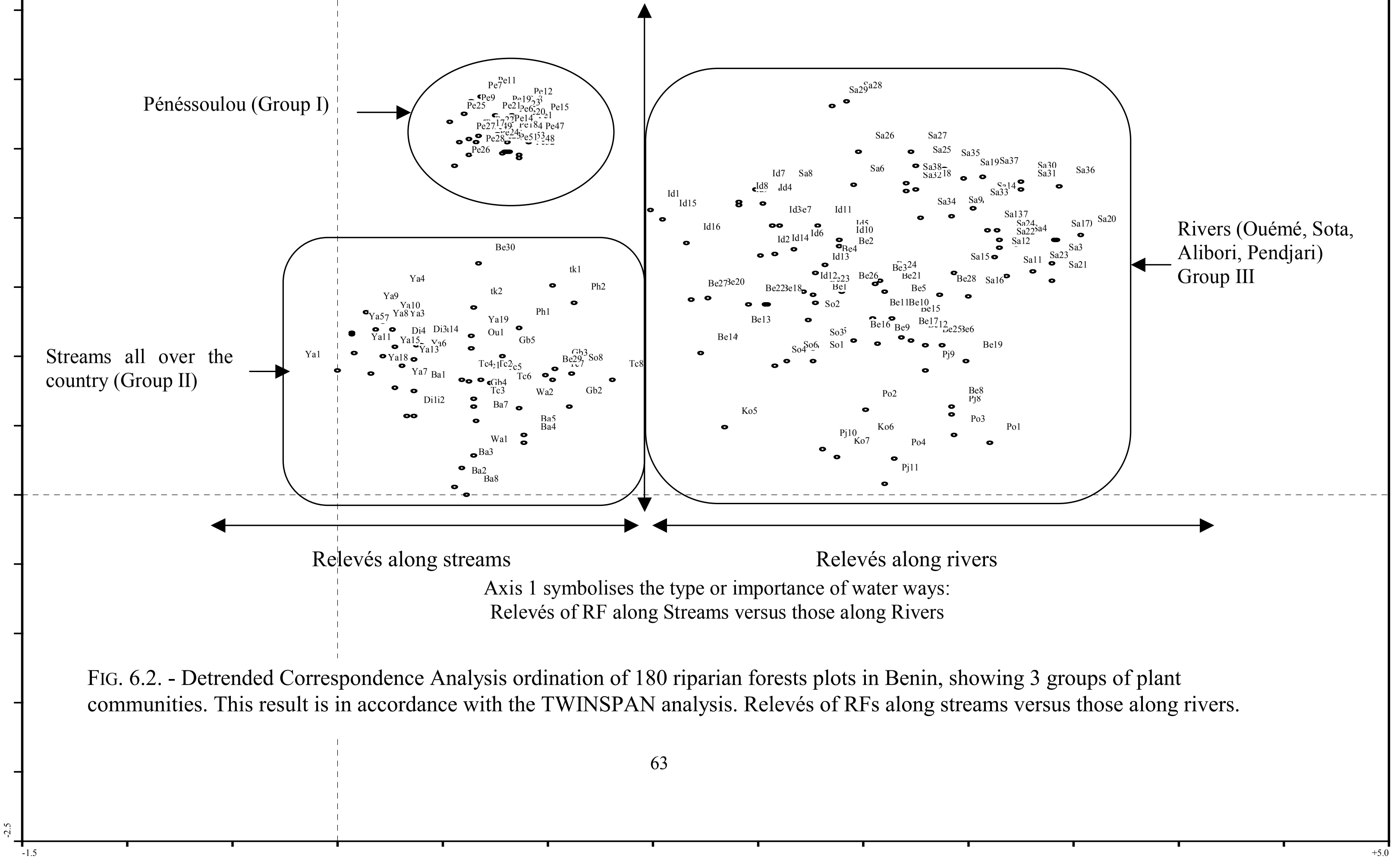
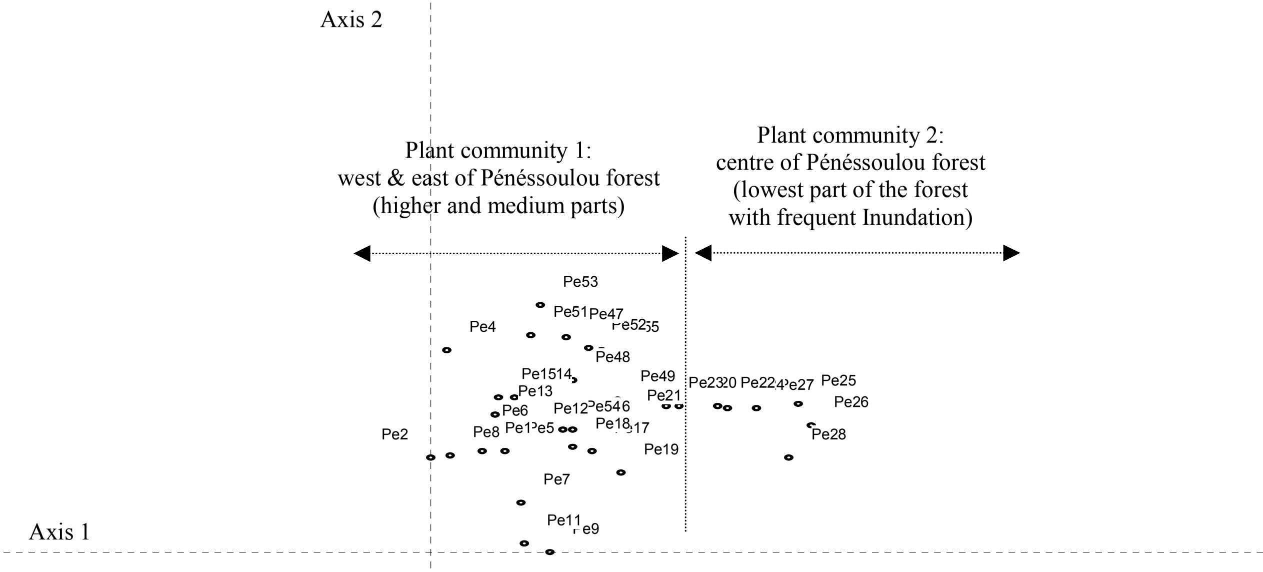


FIG. 6.2. - Detrended Correspondence Analysis ordination of 180 riparian forests plots in Benin, showing 3 groups of plant communities. This result is in accordance with the TWINSPAN analysis. Relevés of RFs along streams versus those along rivers.



Axis 1 symbolises the topography: bottom versus medium & centre of valleys

FIG. 6.3. - DCA ordination of 34 plots of Group I (RF of Pénéssoulou reserve forest; see Fig. 6.2.) showing 2 plant communities correlated with topography. (……………) subdivisions obtained with TWINSPAN.

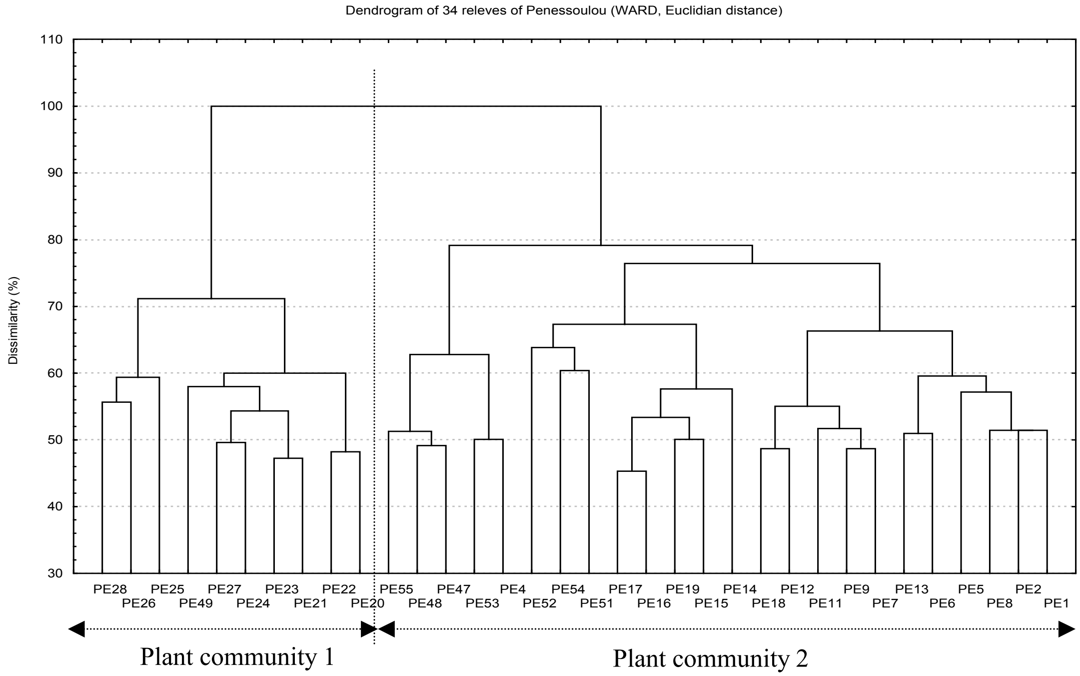


FIG. 6.4. - Dendrogram of 34 plots in the Pénéssoulou reserve forest showing 2 plant communities. (……) subdivisions obtained with TWINSPAN.

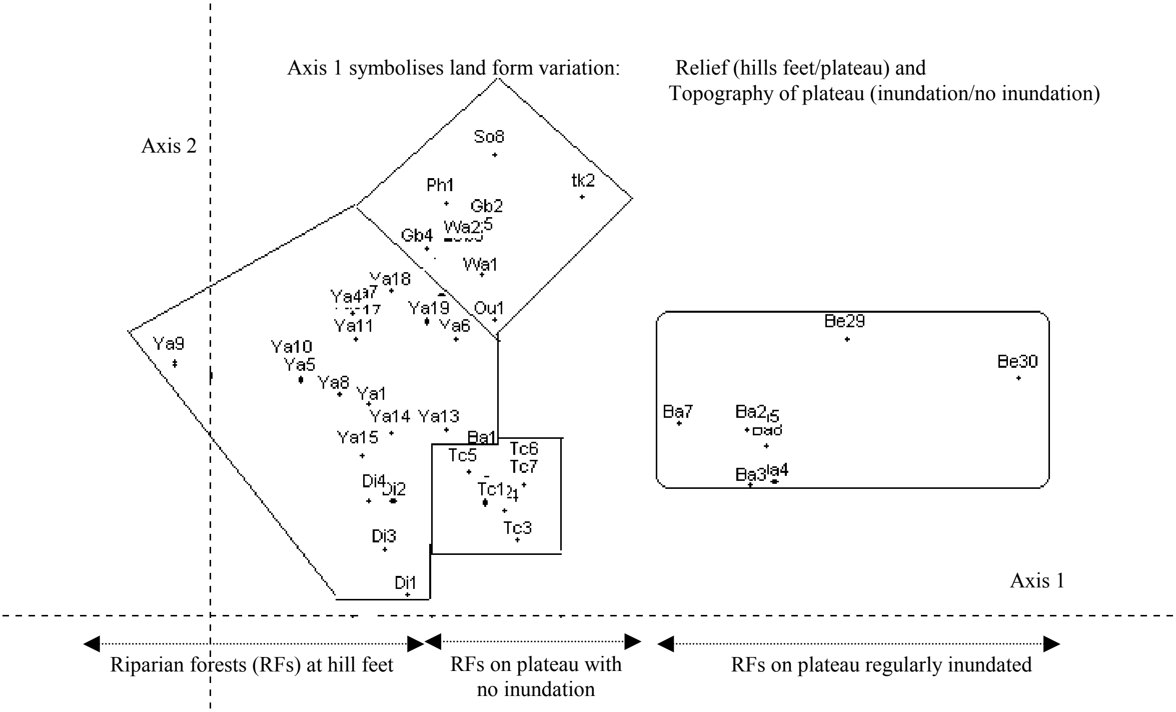


FIG. 6.5. - DCA ordination of 48 plots of RF along streams (see Group II in Fig. 6.2) showing 4 plant communities. (——) divisions obtained with TWINSPAN.

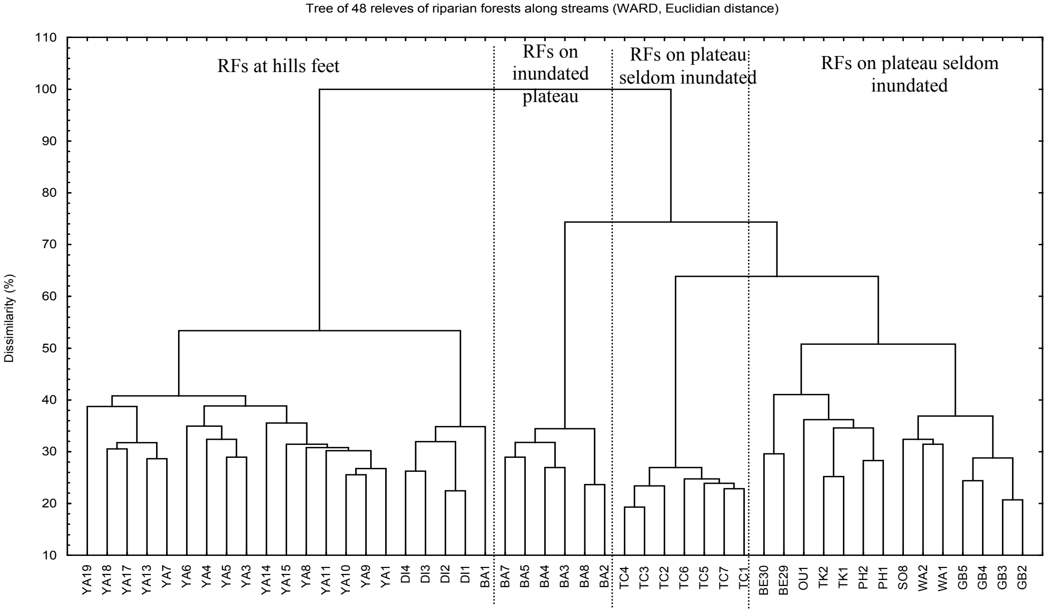

Tree of 48 releves of riparian forests along streams (WARD, Euclidian distance)

FIG. 6.6. - Dendrogram of 48 plots of RF along streams showing 4 plant communities. (············) subdivisions from TWINSPAN.

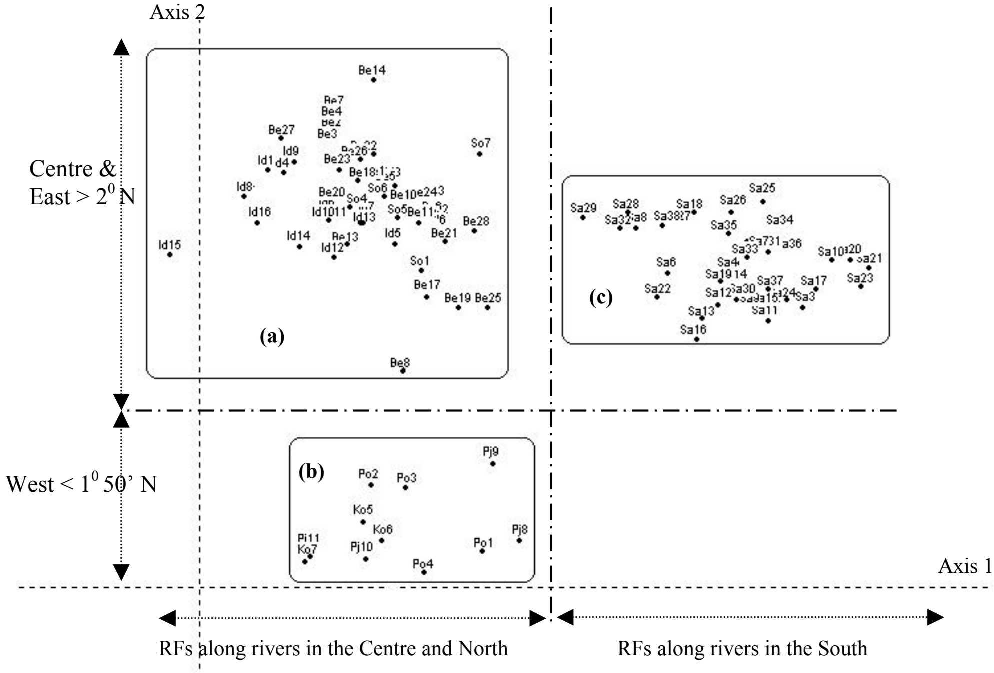


FIG. 6.7. - DCA ordination of 98 plots of RF along rivers all over the country (see Group III in Fig. 6.2) showing 3 sub-groups according to Latitude (axis 1) and Longitude (axis 2).

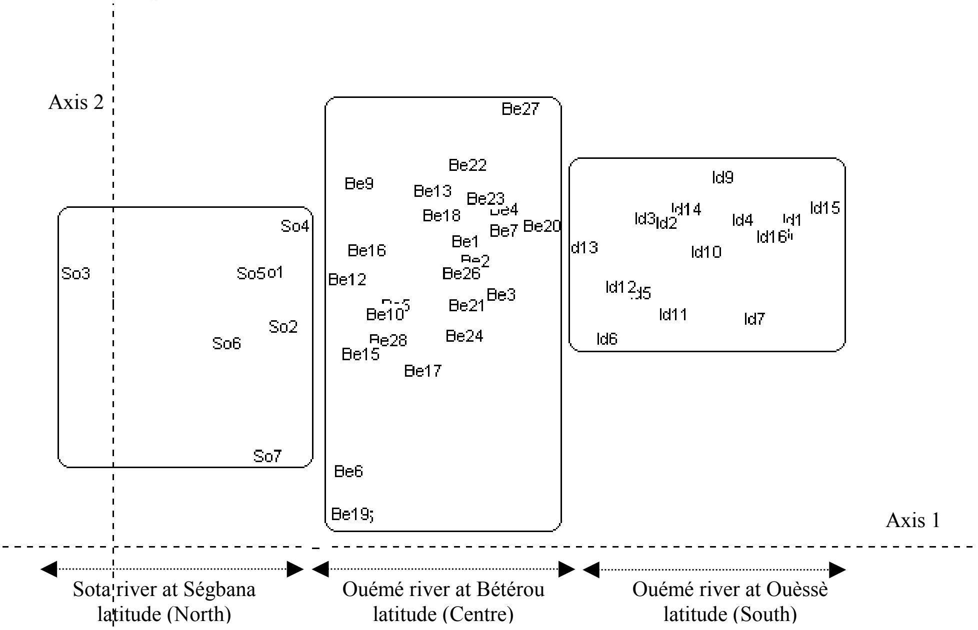


FIG. 6.8. - Partial DCA ordination of sub-group (a) of Fig. 6.7. (*i.e.* 55 plots of RF along rivers at Ouèssè, Bétérou and Ségbana) showing 3 plant communities according to Latitude (axis 1).

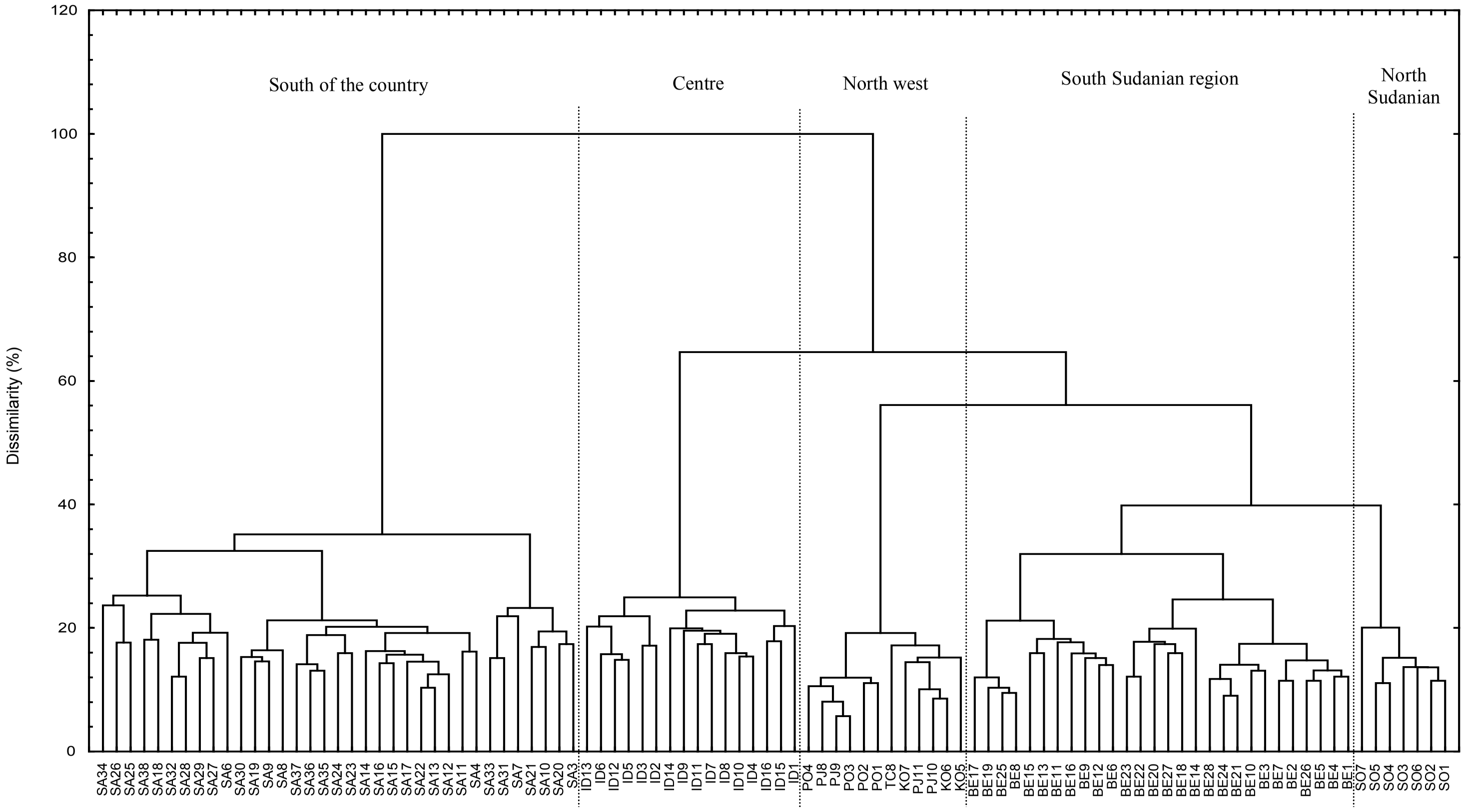
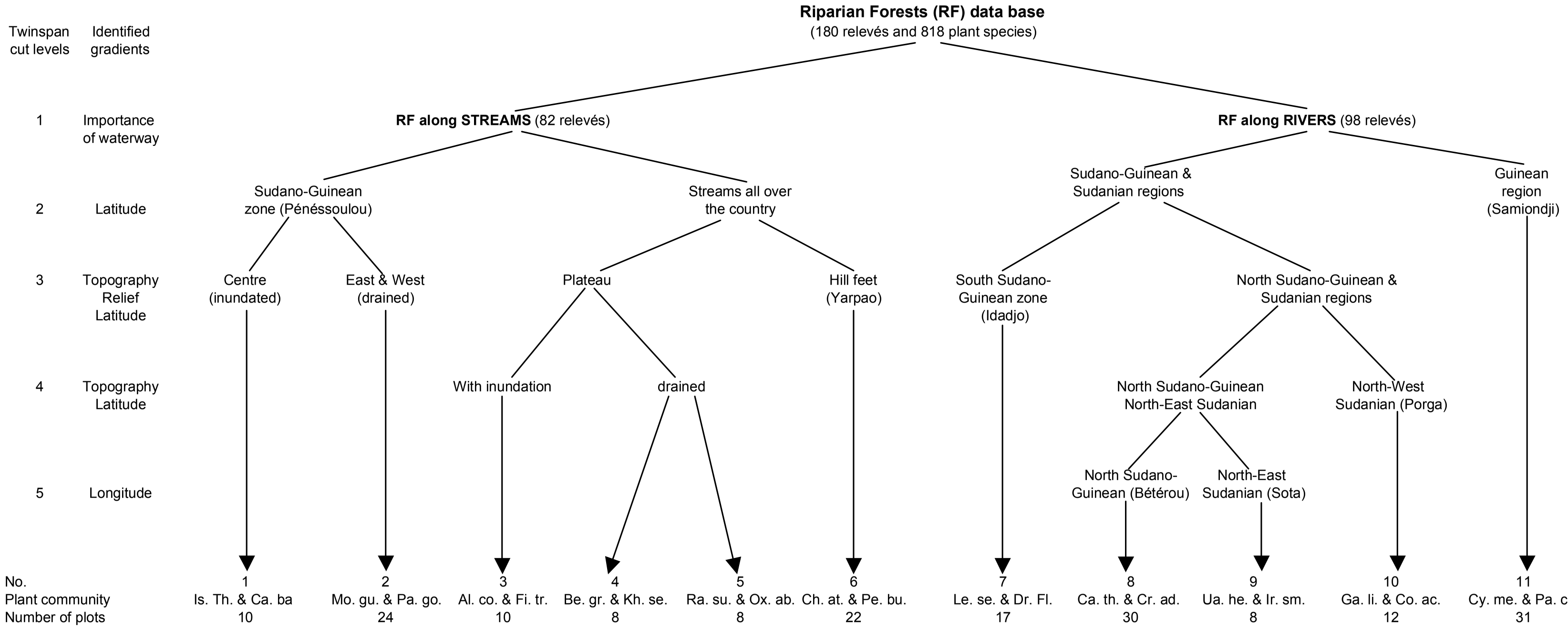


FIG. 6.9. - Dendrogram of 98 relevés of riparian forests along rivers in Benin, showing 5 plant communities. (……………) divisions from TWINSPAN

Name of riparian forest sites in Figs 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8 and 6.9:
Guinean region: Samiondji = Sa; Sudano-Guinean zone: Pénéssoulou = Pe; Bétérou = Be; Idadjo = Id; Toui-Kilibo = Tk; Sudanian region: Yarpao = Ya; Péhunco = Ph; Dimari = Di; Ouaké = Ou; Gbèssè = Gb; Sota = So; Warrana = Wa; Toucountouna = Tc; Batia = Ba; Pendjari = Pj; Porga = Po; Konkombri = Ko.



1 - Is. Th. & Ca. ba. = Plant community of Isolona thonneri and Callichilia barteri along streams in the centre of Pénéssoulou reserve forest.
2 - Mo. gu. & Pa. go. = Plant community of Motandra guineensis and Pararistolochia goldieana along streams at the East and West parts of Pénéssoulou reserve forest.
3 - Al. co. & Fi. tr. = Plant community of Alchornea cordifolia and Ficus trichopoda along streams on plateau regularly inundated all over the country.
4 - Be. gr. & Kh. se. = Plant community of Berlinia grandiflora and Khaya senegalensis along streams on drained plateau, mainly in the Sudanian region of the country.
5 - Ra. su. & Ox. ab. = Plant community of Raphia sudanica and Oxytenanthera abyssinica along streams on drained plateau, mainly in the Sudanian region of the country.
6 - Ch. at. & Pe. bu. = Plant community of Chrysobalanus icaco subsp. atacoriensis and Pentadesma butyracea along streams at hill feet in the Atacora mountain chain.
7 - Le. se. & Dr. Fl. = Plant community of Lepisanthes senegalensis and Drypetes floribunda along the Ouémé river in the Sudano-Guinean zone of Centre Benin.
8 - Ca. th. & Cr. ad. = Plant community of Capparis thonningii and Crateva adansonii along the Ouémé river in the Sudano-Guinean zone of Centre Benin.
9 - Ua. he. & Ir. sm. = Plant community of Uapaca heudelotii and Irvingia smithii along the Sota river in the North-East of the country.
10 - Ga. li. & Co. ac. = Plant community of Garcinia livingstonei and Combretum acutum along the Pendjari stream in the North-West of the country.
11 - Cy. me. & Pa. co. = Plant community of Cynometra megalophylla and Parinari congensis along the Ouémé river in the Guinean region of Southern Benin.
12 - An additonal plant community, Mi.pi & Fi.as. = *Mimosa pigra* and *Ficus asperifolia,* from the literature exist but could not be discriminated through the numerical classification proccess.

Fig. 6.10. - TWINSPAN classification hierarchy and relationship of the initial 180 relevés to 11 plant communities

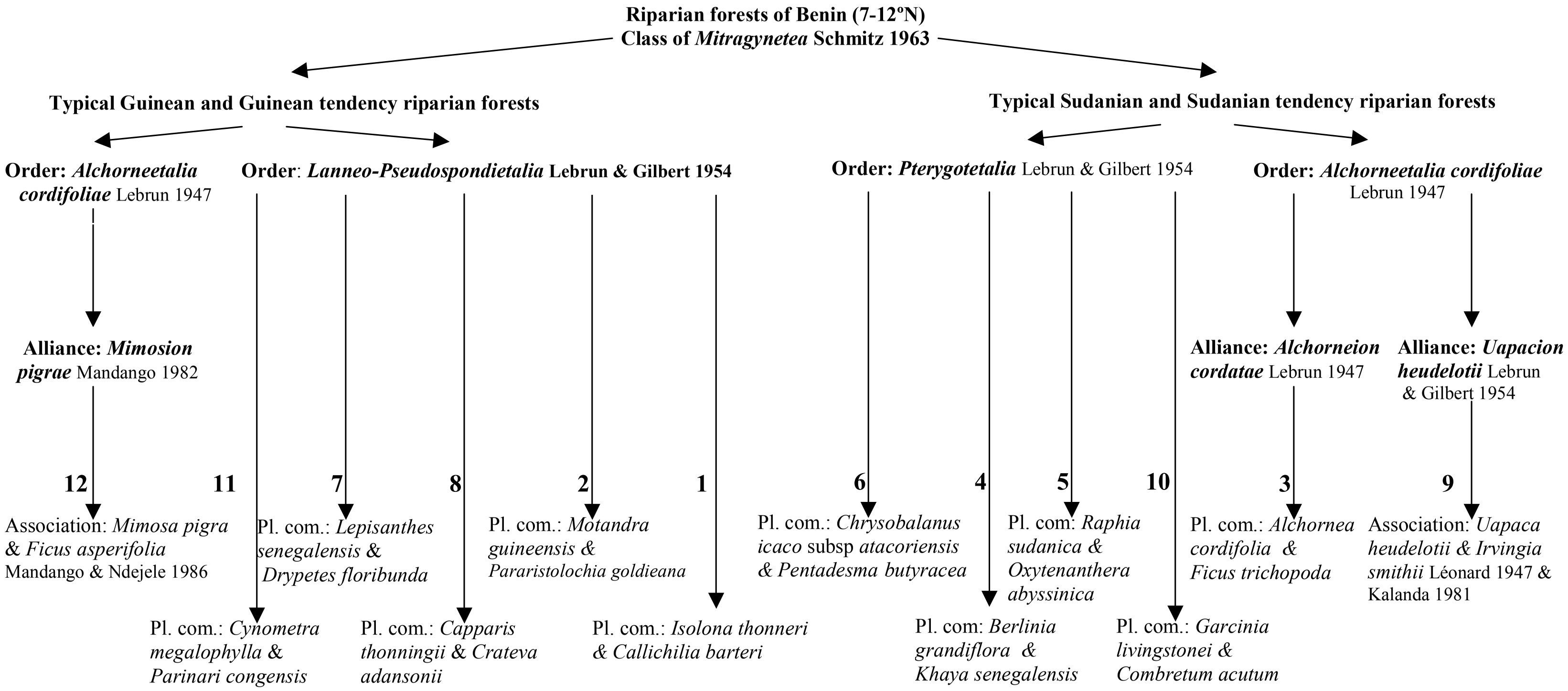


FIG. 6.11.- Synthesis of the 12 Riparian forests plant communities identified in Benin and their synsystematic relationships. Pl. com.= Plant community. Numbers 1 to 12 refer to FIG. 6.10.

Chapter 7

SPATIAL DISTRIBUTION AND ECOLOGICAL FACTORS DETERMINING THE OCCURRENCE OF *PENTADESMA BUTYRACEA* SABINE (CLUSIACEAE) IN BENIN

Submitted to *Acta Oecologica*

Notulae Florae Beninensis 6

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Chapter 7

SPATIAL DISTRIBUTION AND ECOLOGICAL FACTORS DETERMINING THE OCCURRENCE OF *PENTADESMA BUTYRACEA* SABINE (CLUSIACEAE) IN BENIN (*)

Notulae Florae Beninensis 6

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(*) Submitted to *Acta Oecologica*

ABSTRACT

Sample surveys were conducted in all ten ecological districts recognised in Benin (West Africa) to assess the spatial distribution and ecological factors determining the occurrence of *Pentadesma butyracea,* a multipurpose tree species found exclusively in some gallery forests. Natural stands of the species occur in two regions at Bassila (Pira to Bodi) and in the Atacora mountain chain (Perma to Tandafa). Isolated trees are found around Agbassa village (between Ouèssè and Alafiarou in Central Benin) and as far as the latitude of Gbèssè village (Ségbana district) in the North East of the country. The presence of *Pentadesma* in the Bassila region was linked to the presence of dry semi-deciduous forests in the Sudano-Guinean region of Central Benin. In the Sudanian region only riparian forests, with permanent water at hills foot, provide a water balance of sufficient level: the most important causal factor for the persistence of this species in a relatively dry and fire-prone landscape.

Key words: *Pentadesma butyracea*, Non Timber Forest Products, indicator species, gallery forest, Benin.

7.1. INTRODUCTION

Every country needs to undertake monographical research on biological diversity with special care to the multipurpose values of keystone or indicator ecosystems and species (UNCED 1992). Conservation agencies and scientists have recognised the requirement for spatial knowledge of biodiversity for purposes of planning, management and conservation evaluation (Acharya 1999).

Pentadesma butyracea, tallow tree (Clusiaceae), is known to be a common species of dense evergreen forest (Aubreville 1959, Vivien & Faure 1985, Hawthorne 1996), and natural stands are found in Africa from Sierra-Leone to the Democratic Republic of Congo (Bamps 1971, Ouattara 1999). Therefore its presence in Benin, located at the discontinuity (the Dahomey gap) of the belt of closed tropical rain forest from Elmina (near Cape Coast, Ghana) to Porto-Novo, is an important issue for Beninese phytogeography. In Benin savanna is the dominant ecosystem, and there is an increasing interest in the study and conservation of *Pentadesma butyracea,* a multipurpose species found exclusively in some gallery forests (i.e. riparian forests) (Houngbedji 1997, Sinadouwirou 2000). The species is well known for its edible butter produced from its nuts that resemble those of *Vitellaria paradoxa* (Adomako 1977, Guelly 1994, Baumer 1995), and the fat is used for tallow production (Whitmore 1990, Abbiw 1990, Schreckenberg 1996). The wood of *Pentadesma* butyracea is of good quality (Purba & Sumarua 1987, Rachman *et al.* 1987, Tuani *et al.* 1994). Young stems are cut and sold as vegetal toothbrush in the region of Natitingou (North West Benin). In Ghana, *Pentadesma* oil is used for candle-making and margarine, its stems serve as chewing sticks and are made into for hair combs, its roots decoction is taken as anthelmintic and its bark combats diarrhoea and dysentery (Abbiw 1990).

Meanwhile, a few authors have studied (e.g. Gunasekera *et al.* 1977, Tuani *et al.* 1994) the chemical, cosmetic and pharmacological properties of its butter, leaves, bark and roots. The ecology of *Pentadesma butyracea* upon which it is useful to base conservation and management activities (e.g. reforestation of gallery forests, agroforestry and valorisation of its various uses) is yet to be fully investigated. So far no information has been available on the spatial distribution of *Pentadesma butyracea* under the less favourable climatic conditions of Benin, as compared with the two West-African rain forest blocks. This paper maps the current distribution of the species and assesses the ecological factors of its presence and development in Benin.

7.2. MATERIAL AND METHODS

7.2.1. Study area

Riparian forests were surveyed in the ten ecological districts of Benin (Adjanohoun *et al.* 1989, Houinato *et al.* 2000). Benin is located at the discontinuity of the tropical rain forest zone in West Africa, the *'Dahomey Gap*', which is the product of topographic, oceanographic, climatic and human interactions (Jenik 1994). This gap includes essentially the drier types of the Guineo-Congolian forest belt in South-Eastern Ghana, Southern Togo and parts of South-Eastern Benin (Ern 1988). As a result, there are no evergreen tropical forests or rain forests in the country. Centuries of intense human activity accompanied by a drying climate resulted in the loss of most of Benin closed forests long ago. Small patches of moist forest remain today only on moist soils or as numerous sacred groves and riparian forests.

The important hydrographic network allows the presence of many riparian forests widely distributed all over the country. The hydrographic network includes the Atlantic Ocean watershed with the Ouémé, Couffo and Mono Rivers and their tributaries and the Niger River, which is the end point of the Sota, Alibori and Mékrou Rivers. In the North West of Benin, the Pendjari River starts in the Atacora Mountains and ends in the Volta River in Ghana. In the Southern part there is an important complex of coastal lagoons, lakes and swamps. Table 7.1 summarises the climatic and edaphic characteristics of the two main areas of occurrence (Bassila and Natitingou) of *Pentadesma butyracea* in Benin.

7.2.2. Data collection in riparian forests

Several riparian forests were surveyed using the Braun-Blanquet method for vegetation analysis based on phytosociological relevés. 500 m^2 plots were installed in different sites in the Guinean region (Samiondji and Bétécoucou), the Sudano-Guinean region (Toui-Kilibo, Ouèssè, Agbassa, Alafiarou, Bétérou, Daringa, Onklou, Bassila and Pénéssoulou) and the Sudanian region (Ouaké, Affon, Boukombé, Toucountouna, Natitingou, Matéri, Tanguiéta and all the Pendjari Biosphere Reserve, Kouandé, Péhonko, Kérou, Banikoara, Kandi, Malanville, Karimama, Ségbana). For other parts of the country, a review of scientific work on the flora of Benin and the National Herbarium was made to check the presence of the species. Additional information was gathered as well from local people about the presence of this species on their land.

Table 7.1: Climatic and edaphic characteristics of the two main regions (Bassila and Natitingou) of occurrence of *Pentadesma butyracea* in Benin

Major factors (1)	Region of Bantè-Bassila (Sudano-Guinean)	Region of Natitingou (Sudanian)
Climate type	Sudano-Guinean climate (transitional zone between the Guineo-Congolian and the Sudanian climate characterised by progressive fusion of the two peaks of rainfall typical of the Guineo-Congolian climate)	Typical Sudanian climate
Seasons	2 seasons: *rainy season: mid-April to end-October (6 months) *dry season: End-October to mid-April (6 months)	2 seasons: *rainy season: May to mid-October (5 months) *dry season: mid-October to April (7 months)
Humid season (P>½PET)	from April to October	from May to October
Period of humidity excess (P>PET)	from June to September	from June to September
Annual rainfall (mm)	1100 – 1300	1000 –1100
Average temperature (°C)	26 – 32	28 - 38
Relative humidity (%)	15 (dry season) to 99 (rainy season)	16 (dry season) to 98 (rainy season)
Mean annual insolation (hours)	2420	2660
Average annual potential evapotranspiration (mm)	1536	1510
Edaphic conditions at stream banks	Hydromorph and deep soils of lowlands, or along streams surrounded by plateau. Clayed-sandy or silt-clayed texture with shallow water table Often presence of sand bars	Hydromorph soils at hill feet, or along streams surrounded by plateaus, or stony stream banks. silt-clayed texture

(1) Climatic data observed over the last 40 years (1956-1995); P = Rainfall (mm); PET = Potential Evapo-Transpiration

In total 373 plots were installed all over the country and their coordinates taken by GPS. The presence of *Pentadesma butyracea* was checked and measurements taken from individual trees (dbh ≥ 5 cm, height, crown width, and distance to river or stream edge). The presence of the species was also checked outside plots when walking along rivers and streams. All *Pentadesma butyracea* trees detected outside plots were measured and their coordinates taken. Special care was made to detect the regeneration (dbh < 5 cm).

Co-ordinates of plot centres where the species is found and coordinates of trees (≥ 10 cm) allow mapping the distribution of the species all over the country using the ArcView GIS 3.2 software.

7.3. RESULTS AND DISCUSSIONS

7.3.1. *Pentadesma butyracea* is a core species of some gallery forests in Benin

Pentadesma butyracea grows in multi-species stands and is always found along some streams with more or less permanent water all year round. It is characterised by a barochore distribution of its diaspores. This species has not yet been seen along larger waterways such as the Ouémé, Zou, Sota, Alibori and Niger Rivers. We might say that the species somehow compensates the hydric deficit of the Sudanian region and Sudano-Guinean zone while avoiding long periods of floods (4 to 6 months) that characterises most riparian forests along rivers in Benin. *Pentadesma butyracea* has a high indicative value of gallery forests, as it is always tied to water. Moreover the distribution of the individual trees show that they are always found close to stream beds inside the gallery forests, near trees such as *Pterocarpus santalinoides, Syzygium guineense* var. *guineense* and *Berlinia grandiflora*. *Pentadesma* only occurs at gallery forest edges when the vegetation is degraded. Thus it can be termed as a core gallery forest species in Benin.

Although it is an evergreen tree, it is frequent along waterways in the pre-forest, Sudano-Guinean and savanna zones of Central Côte d'Ivoire (Ouattara 1999). It has a gregarious distribution pattern shown by clusters of individuals in several segments of the streams (Sinadouwirou 2000). In Benin typical stands are found in the Pénéssoulou protected forest and along the Yarpao stream (Natitingou district).

7.3.2. Distribution of *Pentadesma butyracea* in Benin

Based on recorded presence of the species, there are four separate areas of occurrence of *Pentadesma butyracea* in Benin (Figure 7.1). The first and second areas of occurrence are located in the Sudano-Guinean zone of Central Benin (Bassila region and around Agbassa village, mid-way between Idadjo and Alafiarou villages in Cental Benin). The third area of occurrence is in the Sudanian region of North West Benin (Natitingou region), while the fourth one is a small area near Gbèssè village far in the North East (Ségbana district). The Southern limit is around 8°15' N in the district of Bantè. The Northern limit is the axis Tanougou-Séri (10°45' N) and Gbèssè village (11° N). The Western limit follows the Togo border (around 1°22' E at Pénéssoulou latitude), while the Eastern limit extends to (3°16'E). So far the species has not been seen elsewhere, but isolated trees might be found along streams in potential zone of occurrence that connect the four mentioned areas.

The distribution of *Pentadesma butyracea* in Benin, based on intensive data collection, is a subset, of its larger-scale African distribution map (Bamps 1971). The species occurs in corresponding ecological areas: the mountains and plains of North and Central Togo (Zepernick & Timler 1984). In Ghana, the species is found in wet evergreen forests (Swaine & Hall 1976).

While the Atacora mountain chain and the dry semi-deciduous forest (fire sub-type) of Bassila region common to Benin, Togo and Ghana do harbour stands of *Pentadesma butyracea*, the absence of the species in Southern Benin (below 8^o N) is questionable.

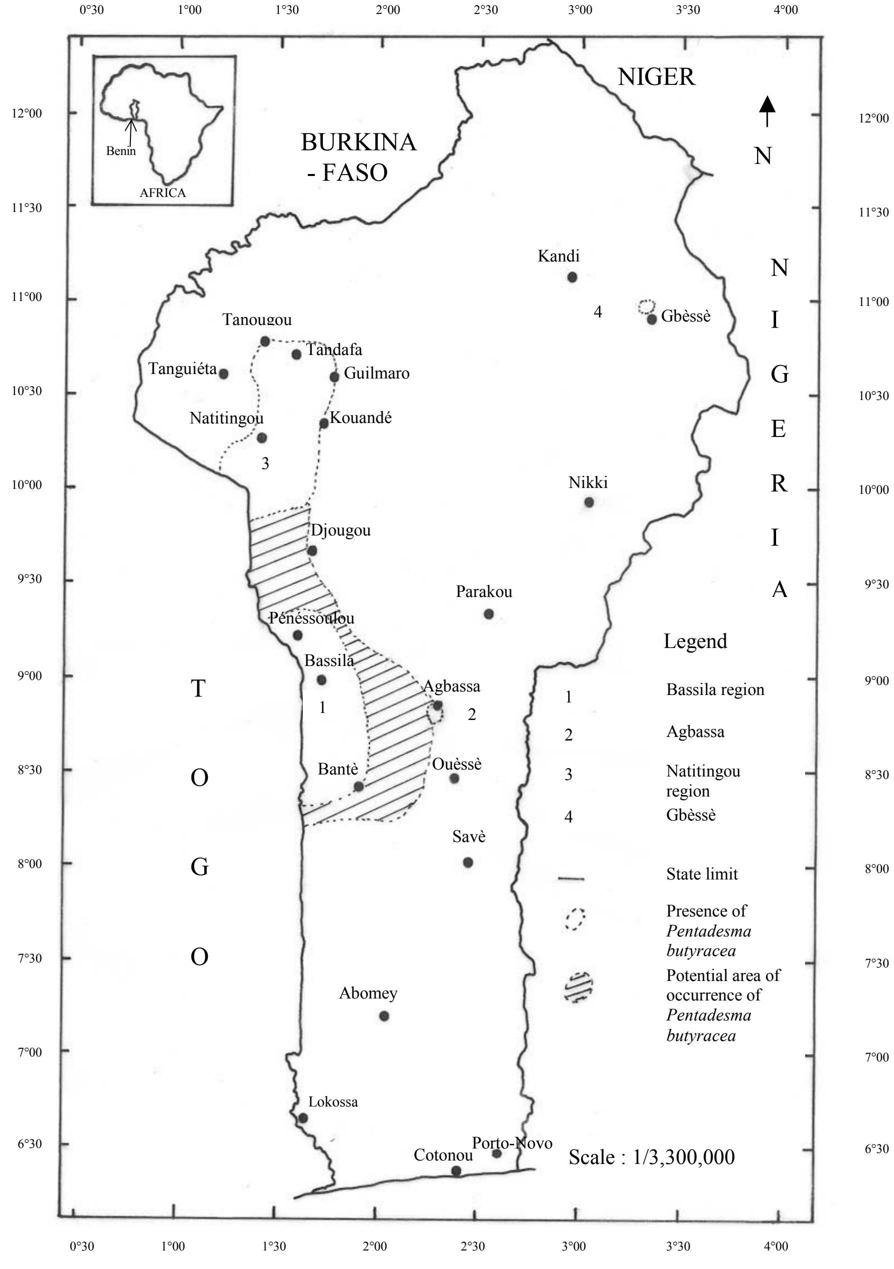

Figure 7.1: Distribution map of *Pentadesma butyracea* in Benin

One might expect the presence of *Pentadesma* in the Pobè region, the wettest region of Benin in terms of rainfall (1300 to 1400 mm per year) and relative humidity. In fact this region is dominated by remnant dense semi-deciduous forests that are contiguous to the relatively ”dry” forest of South-Western Nigeria (Onochie 1979). According to Swaine & Hall (1976) *Pentadesma butyracea* occurs usually in wet evergreen forest with at least >1750 mm mean annual rainfall. It is obvious that *Pentadesma* occurs in Benin in a less suitable climate environment than elsewhere. Therefore we cannot expect large stands in fire-prone and drier landscapes. Centuries of intense land clearance, vegetation fragmentation through fire, destruction of riparian forests, selective tree cutting, over-collection of nuts, as well as a drying climate have probably contributed to the fragmentation and isolation of distribution areas of *Pentadesma butyracea*. It is likely that the current non-contiguous areas of occurrence of this species are remnant and refugee zones in Benin that need to be protected and managed for their conservation.

7.3.3. Causal factors of the presence and persistence of *Pentadesma butyracea* in Benin

Several authors have documented the influence of abiotic and biotic factors on the presence and spatial repartition of plants. For natural stands, climatic and edaphic conditions are the most important factors, meanwhile intense disturbance may determine a particular distribution pattern or cause complete disappearance of a species.

* **Expanse of the dry semi-deciduous forest**: the probable cause of the presence of *Pentadesma butyracea* in the region of Bassila.

The region of Bassila is the easternmost point of the dry semi-deciduous forest, fire subtype (Hall & Swaine 1981). This hygrophile enclave surrounded by savannas stretches out to Togo (Southern part of Togo mountains) and to the South and Centre of Ghana, where the species is present (Bamps 1971, Zepernick & Timler 1984). From this entry point *Pentadesma butyracea* probably spread to the East around the Alafiarou village and South around Bantè district.

Another viewpoint is that the species has always been there in the past and due to certain factors (e.g. human-induced degradation or drying climate) the current occurrence area in the Sudano-Guinean zone of Central Benin is remnant of a previously larger one.

* **High water balance:** the most important causal factor for the persistence of *Pentadesma butyracea* in the Sudanian region of Natitingou.

The Sudanian region of Natitingou (North West of Benin), is dominated by the Atacora mountains chain continuing into the mountains of Northern Togo; mountains at the foot of which *Pentadesma butyracea* is present (Zepernick & Timler 1984). The niches for *Pentadesma* in this region are gallery forests at the foot of hills, because they provide an ample water supply: a combination of medium rainfall and evapotranspiration, high relative humidity, lower temperatures, resurgence of water at the foot of hills, presence of water in streams all year round. Here the relief and topography counterbalance the less suitable climatic conditions.

According to Ouattara (1999), in Côte d’Ivoire *Pentadesma butyracea* disappears when annual rainfall falls below 1000 mm. Therefore the viability of natural stands of the species depends on the existence of high to medium quality habitats, such as the gallery forests in the Bassila and Natitingou region. On the other hand the presence of a few individuals as far as at the latitude of Kandi-Ségbana (with an average annual rainfall of 900 to 1000 mm) shows the adaptation of the species to sub-optimal habitats in terms of annual rainfall and relative humidity. Under natural conditions, this matches the thesis that the long-term survival of populations can be strongly affected by the spatial and temporal distribution of both suitable and unsuitable habitat patches (Pulliam *et al.* 1992, Carrol *et al.* 1996). Gallery forests of the Sudano-Guinean zone and Sudanian region Benin, therefore act as refugee ecosystem for *Pentadesma butyracea*.

In general, little is known about the geographical patterns of genetic diversity for most tropical forests species (Aide & Rivera 1998); and about *Pentadesma butyracea* populations in West Africa in particular. The distribution of genetic diversity within and among the four non-contiguous populations in Benin, and those in Togo and Ghana will give insight in the origin and evolution of this species in Benin.

As *Pentadesma butyracea* in Benin is exclusively present in gallery forests, some hypotheses on the ecological importance of these hygrophile and edaphic forest formations are substantiated.

** Gallery forests act as refugee ecosystem for forest tree species in a fire prone environment*

In many seasonally dry regions, but also in formerly forested areas, gallery forests have the character of a refuge for plants and animals (Porembski 2001). The extent and impact of fire in a system of gallery forests were evaluated in the Mountain Pine Ridge savanna of Belize, (Kellman & Tackaberry 1993, Kellman *et al.* 1994) and such systems represent plausible refugia for forest species in fire-prone landscapes. In Benin, it is obvious that *Pentadesma butyracea* cannot survive but inside the wettest ecosystem that exists in the majority of fire-influenced landscapes.

** Gallery forests harbour the tree species requiring moist habitats in the landscape*

Fresh-water bodies, surface-emergent aquifers and soil moisture in excess in gallery forests are the underlying factors that support mesic vegetation distinctive in structure and/or floristics from that of the contiguous more xeric uplands (Warner 1979). Due to their elevated moisture regime (compared to the surroundings), they enable the establishment and persistence of plant species, which under zonal conditions are bound to wet forest types, often evergreen rain forest (Porembski 2001). Tropical riparian forest fragments are known for their potential, albeit limited, to maintain large numbers of species and may act as safe sites for tropical rain forest species (Kellman *et al.* 1994, Meave & Kellman 1994). Likewise gallery forests are the most suitable vegetation for plant species adapted to a moist climatic regime (Medley 1992). Therefore, *Pentadesma* finds suitable ecological niches in gallery forests that border streams in savanna dominated landscape.

** Gallery forests act as route for movement of certain species across the landscape*

Riparian forests are important as routes for movement of plants and terrestrial animals across the landscape (Forman & Godron 1986). They play an important role as migration channels, which provide opportunities for genetic exchange between geographically isolated populations (Porembski 2001). This seems to be the case with *Pentadesma butyracea* in gallery forest corridors at hills feet along the Atacora mountain chain and in the semi-deciduous forest stretching from Ghana to Benin.

7.3.4. Major causes of gallery forests degradation in Benin and their consequences on natural stands of *Pentadesma butyracea*

Natural stands of *Pentadesma butyracea* are disappearing along with the destruction of gallery forests in Benin.

** Destruction of gallery forests*

Rapid changes in land use in Benin have led to the destruction and fragmentation of riparian forests. Riparian forests provide fertile soil for cultivation and provide an opportunity for irrigation (Natta 2000). Riparian forests form a highly endangered ecosystem, and their destruction could have severe consequences for the genetic exchange between disjunct vegetation stands (Natta *et al*. 2002). In the Sudano-Guinean region of Côte d'Ivoire, agro-pastoral management is the underlying factor of the disappearance of the species from its natural habitat (Ouattara 1999). As a core species of gallery forest, destruction of gallery forest implies disappearance of *Pentadesma butyracea* individuals.

** Harvest of Pentadesma nuts*

The regeneration of *Pentadesma* is already very difficult under natural conditions as seeds have a short germinative power (Ouattara 1999). Therefore the collection of all or most nuts of this species from the wild by local people is a major threat to its survival in Benin.

** Cutting of young stems for sale as vegetal teeth brushes*

As in Ghana (see Abbiw 1990), young stems of *Pentadesma* are used as chewing sticks in the North West of Benin. Therefore, the growth of young stems is seriously affected and many cannot reach the stage of fructification, particularly in the Natitingou region.

** Selective tree cutting of the largest stems for timber*

The good wood quality and the facility of working induce people to harvest the biggest stems for the local wood industry.

** Disturbance due to fire*

Uncontrolled bush fires often affect badly the regeneration of *Pentadesma butyracea* in the dry season. Effects are more visible in isolated patches or narrow gallery forests than in fair-sized forests.

7.4. CONCLUSION

Pentadesma butyracea is found in Benin in four non-contiguous areas. Its distribution is principally influenced by the presence of numerous gallery forests in the semi-deciduous forest of Bassila region and at the foot of hills in the Atacora mountain chain that continue in Togo and Ghana. These four current areas appear to be remnant and refugee zones of *Pentadesma butyracea*, and the assessment of their genetic diversity will provide new insight on this enigma. In the meantime, these remnant populations need to be protected and managed with and by local people.

Chapter 8

FOREST STRUCTURAL PARAMETERS AND FLORISTIC COMPOSITION SPATIAL VARIATION AND MODELLING ACROSS RIVERS IN BENIN

A.K. Natta

Chapter 8

FOREST STRUCTURAL PARAMETERS AND FLORISTIC COMPOSITION SPATIAL VARIATION AND MODELLING ACROSS RIVERS IN BENIN

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ABSTRACT

Forest structural parameters, floristic composition and spatial distribution of tree species were assessed across several rivers in Benin through multivariate analysis, distribution curves and model fitting. The variation of tree stems from riverside up to 100 m away reveals an uneven distribution of abundance, while tree height and basal area variations at riverside do not show any clear pattern. Results from the numerical analysis show differences in the floristic composition at riverside, across riparian forests and neighbouring plant communities. The gradual change in species composition and relative abundance, which corresponds to a gradual environmental change, indicates that tree species have different affinities to water and humidity from the river. Typical riparian forest tree species are *Syzygium guineense, Pterocarpus santalinoides, Parinari congensis, Cola laurifolia, Napoleonaea vogelii, Cynometra megalophylla, Drypetes floribunda* and *Manilkara multinervis*. This research not only confirms empirical knowledge about the ecology of certain riparian forest and surrounding vegetations plant species, but also makes a distinction between river front, the central portion and edge species of riparian forests. Criteria (e.g. average distance range and best fit models) are also provided for the most common tree species along river. These results suggest that riparian forests little disturbed by men can be partitioned in three different habitats among tree species, along the horizontal gradient of wetness. Meanwhile due to lack of sufficient data we cannot yet draw conclusions about the distribution behaviour of all tree species encountered along the riverside. An implication for plant species diversity assessment in riparian forest is that sampling design (i.e. plot size, shape and layout in the terrain) should take into account the three major parts of the floristic composition at riverside (river front, central portion and edge). Therefore rectangular plots with varying width and length, and covering the whole riparian forest cross section are the most suitable sampling units for savanna regions.

Keys words: Riparian forest, adjacent vegetation, structure, floristic composition, spatial distribution, modelling, Benin.

8.1. INTRODUCTION

The riparian zone, functionally defined as a three dimensional zone of direct interaction between aquatic and terrestrial environments, has boundaries that extend laterally from the channel to the limits of flooding and vertically into the vegetative canopy (Swanson & Lienkamper 1982, Gregory *et al.* 1991). Riparian forests are at the same time so important as a collection of natural resources and so limited in individual size that they both merit and require higher resolution inventory procedures than those deployed for other larger ecosystems such as savanna and upland forests (Natta *et al.* 2002). In both predominantly forested areas and savanna regions, they sustain a type of vegetation that is distinct from the surrounding area in species composition and vegetation structure. Their location between river and adjacent landscape contribute to their ecotone character (Brinson & Verhoeven 1999). Due to their elevated moisture regime, they enable the establishment of plant species which under zonal conditions are bound to wet forest types (Porembski 2001).

The study of West-African riparian forests has hitherto been neglected and the published studies dealt mainly with their structural and floristic characteristics and dynamics (Devineau 1975, Bonkoungou 1984, Bélem & Guinko 1998, Goudiaby 1998, Lykke & Goudiaby 1999, Natta 2000, Natta *et al.* in preparation). Few publications have been devoted to the spatial variation of species and forest structural parameters across riparian forests (Porembski 2001, Natta & Porembski, in press, see chapter 9). Classification and ordination of riparian forests floristic data in Benin resulted in three major groups of plant communities: riparian forest along rivers, along streams and the one of Pénéssoulou protected forest (Sudano-Guinean zone of Central Benin) (Natta *et al.* in press, see Chapter 6).

This paper deals with the spatial variation of forest structural parameters and floristic composition across rivers. The objective is to investigate the floristic composition variation and assess the spatial distribution of tree species at riverside, across riparian forests and adjacent vegetation formations. We also explore the effect of distance from water on the composition and structure of tree species, so as to detect riverside, interior and edge species of riparian forests. The research questions were:

- Do structural parameters (i.e. abundance, height and basal area) vary across riparian forests and neighbouring plant communities at riverside?
- Is there any relationship between riparian forest width and tree species richness?
- Does the floristic composition vary across riparian forests and neighbouring plant communities?
- Is there any recognisable spatial distribution of tree species, across riparian forests and neighbouring plant communities, and how can it be modelled?

This contribution aims to provide insights into the ecology of certain tree species at riversides in West African riparian systems and provide recommendations for sampling designs.

8.2. Material and Methods

To assess the floristic composition variation and capture distribution patterns of tree species, a cross section or crown cover intersection method was applied. This method consists of a 100 m long transect, which runs through the riparian forest and beyond its edge through the adjacent (*i.e.* neighbouring) plant communities. At every point, a tape was laid on the ground, perpendicular to the river direction, beyond the riparian forest edge. The position of each tree stem (dbh ≥ 10 cm) is measured from the river bed to the base of each tree having its crown intercepting the tape. This method was applied every 100 m from a random starting point, perpendicularly to river direction, so as to cover at least all the riparian forest and the ecotone (*i.e.* transitional) zone with adjacent vegetation. Five riparian forest sites were surveyed from 7º20 to 11º30 N in Benin, along the Ouémé, Alibori, Sota and Pendjari rivers. One riverside was surveyed at each site. In total 56 transects were done.

We measured the distance from the river, dbh, height and crown width of each stem. Riparian forest width, ecotone zone and the type of adjacent vegetation formation were recorded as well. The position of trees permitted to compile floristic lists at different distance intervals (e.g. every 1 m, 2m, etc.) from the river bed up to 100 m. The floristic composition of each distance class has been taken taken as a relevé. The variability and similarity of the floristic composition from the river bed were assessed through Detrended Correspondence Analysis (DCA) (Hill & Gauch 1980, ter Braak & Smilauer 1998) and Two-Way Indicator Species Analysis (TWINSPAN) (Hill 1979). Clusters are obtained with Statistica® (1998) using Euclidean distance as distance measure and Ward's minimum variance as aggregation method. The numerical analysis will detect any gradual change of the floristic composition in relation with the distance to river bed. Break lines, if detected, within this gradual floristic change will indicate types of natural grouping of species linked to landscape units at riverside. The upper limits of the detected distance intervals will be taken as threshold values to classify each tree species among these natural groupings. We tested the presence of riverside species (RS), species of riparian forest middle (MS), riparian forest edge species (ES), and adjacent ecosystem species (AES), through a t-test, which compared the distribution of stem positions to each class threshold value.

The distribution pattern of each tree species, in the direction perpendicular to river, is obtained in plotting the relative abundance of stems (Y) versus their distance to river (X). Scatter plots are drawn and several models fitted. The best model, in terms of the coefficient of correlation (R^2), significance of overall regression equation (F value) and regression coefficients (t-tests) was selected. The illustration of such typology (see Figure 8.1), which substantiates the presence of a riparian vegetation width effect (or patch width effect, Forman & Godron 1986), is summarised as follow:

a - Riverside species (RS) are those close to river bed and only present in riparian forests. This group includes species that have constantly decreasing number of individuals within riparian forest, from the river.

b - Species of the middle of riparian forest (MS) have a more or less bell shape abundance distribution centred at the middle (i.e. central portion) of riparian forest.

c - Riparian forest edge species (ES) have their highest abundance at the external end of riparian forests.

d - Adjacent ecosystem species (AES) are generally not seen inside riparian forests and belong to mature neighbouring natural vegetation formations. Under the study area conditions this group includes species typical of savanna woodland, and open, dry or dense semi-deciduous upland forests.

The response of plant species expressed in individual plant growth, frequency or cover to the varying conditions along an ecological gradient often takes the form of bell-shaped curves (van Groenewoud 1975). Meanwhile, the theoretical species distribution curves presented in Figure 8.1 are consistent with field evidence. In effect, along larger waterways (i.e. rivers) with more or less extensive flood plain the riparian vegetation is usually distinct from that of surrounding uplands. Moreover within riparian forests, the abundance of certain tree species decreases dramatically a short distance from the river while other shows the reverse trend (Ericsson & Schimpf 1986, MacDougall & Kellman 1992, Stromberg *et al.* 1996, Natta 2000, Porembski 2001, Natta & Porembski, in press see chapter 9).

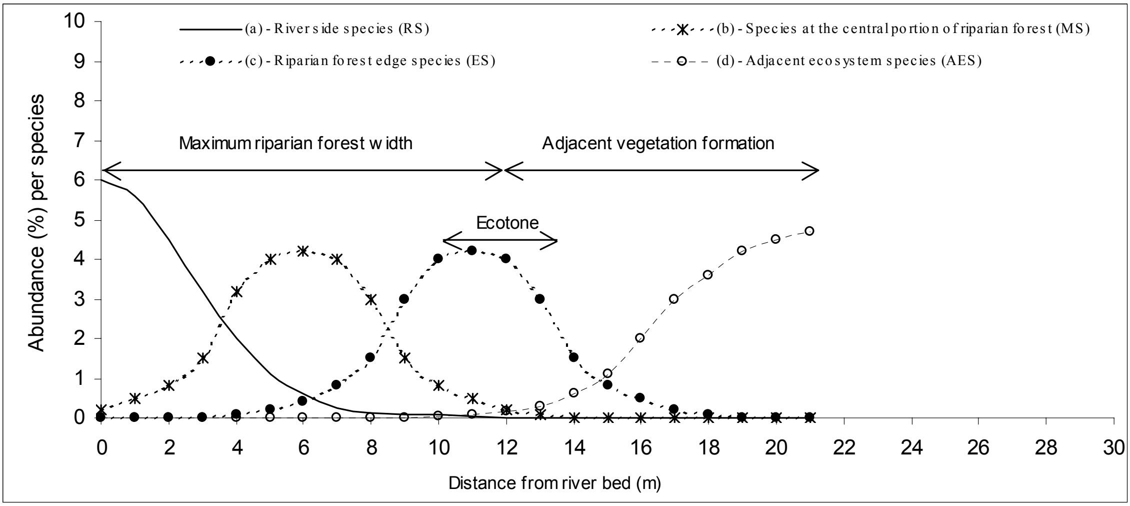


Figure 8.1: Simplified theoretical distribution curves of tree species at riverside, across riparian forests and neighbouring vegetation formations (riparian vegetation width effect)

8.3. RESULTS

8.3.1. Characteristics of the cross sections at each site

We present here results of the least disturbed transects along the Ouémé, Sota, and Pendjari rivers. Table 8.1 summarises the characteristics of the cross sections at riverside at each site. Some 106 tree species were identified from 56 cross sections through riparian forests and adjacent plant communities. The average width of undisturbed riparian forest (35.31 ± 7.97 m) includes three units generally found at riverside: the riverside close to river bed, the middle and edge of riparian forest.

Table 8.1: Characteristics of the studied sites

Sites	Rivers	No. of transects	No. of individuals	No. of tree species	Mean (± SD) RF width (m)
Samiondji (Guinean region)	Ouémé	21	496	44	29.14 ± 9.63
Idadjo (Sudano-Guinean zone)	Ouémé	16	426	48	41.12 ± 19.5
Bétérou (Sudano-Guinean zone)	Ouémé	11	420	55	38.27 ± 8.96
Sota & Porga (Sudanian region)	Sota & Porga	08	228	39	27.25 ± 9.60
Total of all rivers		56	1571	106	35.3 ± 7.97

SD = Standard Deviation; RF = Riparian forest

8.3.2. Variation of the number of stems, tree height and basal area at riverside

The abundance of tree species stems over a width of 100 m is unequally distributed (Figure 8.2), and is best explained by an exponential function. There is a constant decrease of tree individuals in dense riparian forests (up to 50 m from the river). After 50 m, in the adjacent plant communities, the further decrease is less pronounced. Eventually a slight increase of stem abundance is seen from 90 to 100 m. On the contrary, tree height (Figure 8.3) and basal area (Figure 8.4) variations at riverside do not show any clear patterns, and the coefficients of determination (R^2) were very low. This shows the weak relationships between these variables. Meanwhile the first distance class (0 - 2 m), that has the highest abundance (see figure 8.2) and lowest average height (see figure 8.3), gives the highest basal area value (see figure 8.4).

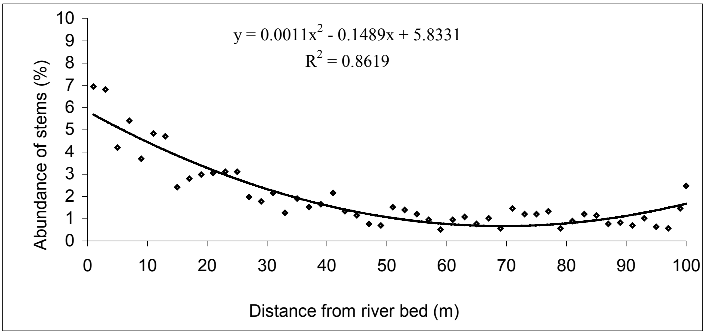


Figure 8.2: Distribution of tree stems across the riverside

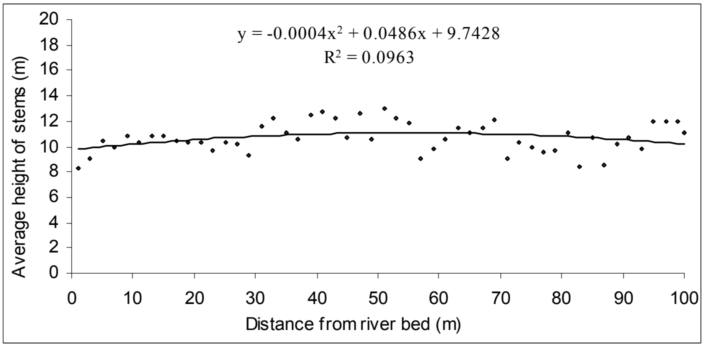


Figure 8.3: Variation of the average tree height across the riverside

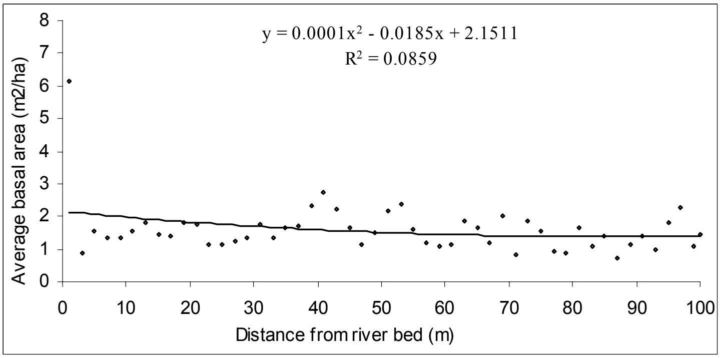


Figure 8.4: Variation of the average basal area of trees across the riverside

8.3.3. Relationship between tree species richness and riparian forest width

Tree species richness and riparian forest width are positively correlated (Figure 8.5), but R^2 is very low (0.21 for linear and polynomial curves). Therefore we expect more tree species to accumulate more or less linearly as riparian forest width increases.

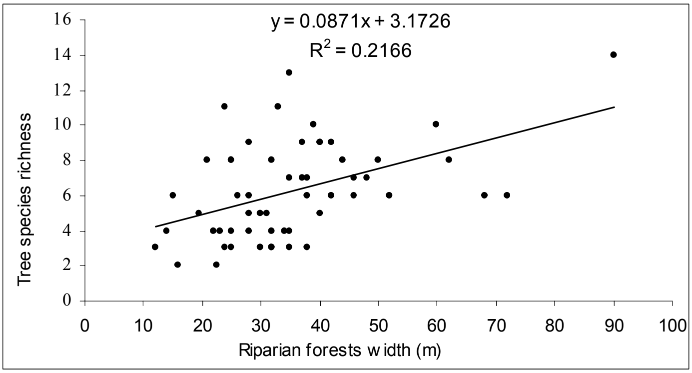


Figure 8.5: Relationship between tree species richness and riparian forest width along rivers

8.3.4. Floristic composition variation at riverside

Variation of tree species richness and floristic relevés distribution from the river bed up to 100 m are assessed. Tree richness seems to decrease with increasing distance from the river, but the fit is not good (see Figure 8.6).

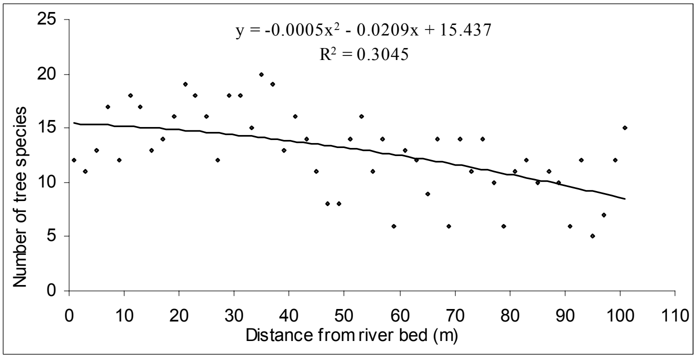


Figure 8.6: Distribution of tree species richness at riverside

The DCA and TWINSPAN analyses (see Figures 8.7 and 8.8, respectively) show a clear pattern in the floristic relevés distribution. The gradual change in the floristic composition is illustrated by the succession of the relevés from the river to about 60 m, this includes the whole riparian forest width, the transitional zone and parts of the neighbouring vegetations. Beyond 60 m the floristic composition seems to exhibit no variation. The first DCA axis (Figure 8.7) is correlated with distance from the river bed. It symbolises the variation of the floristic composition at riverside, across riparian forest and adjacent vegetations.

The gradual change in species composition at riverside is also clearly shown by the TWINSPAN output (available on request from the authors), and is summarised in Figure 8.8. It shows the existence of an ecotone between 30 and 57 m, which separates the dense riparian forests and the adjacent plant communities. The interpretation of the DCA (Figure 8.7), TWINSPAN (Figure 8.8) outputs, the average RF width (27.34 to 43.28 m), and the knowledge about the ecology of each species occurring at river edges, suggest three break lines (or intervals) within riparian forests:

- [0 - 16] m from the river bed: for species mostly found close to the river bed;
- [17 - 29] m from the river bed: for species mostly found in the centre (i.e. middle portion) of the riparian forest;
- [30 - 57] m from the river bed: for species in the transitional zone with adjacent plant communities.

These results confirm the theoretical subdivision of species composition, at least for tree species, into riverside, middle and edge species of riparian forest, and species typical of adjacent vegetations (see Figure 8.1). Table 8.2 is derived from Figures 8.7 and 8.8. It summarises the floristic variation at riverside and the natural grouping of tree species within riparian forests. The distance intervals that are obtained from the TWINSPAN output indicate that the floristic composition of undisturbed riparian forests (i.e. on average 27.34 to 43.28 m wide), include those species always found close to the river bed, in the middle and edge of riparian forest respectively.

Table 8.2: Floristic composition variation across riparian forests and adjacent vegetations

Distance interval (1)	0 to 16 m	17 to 29 m	30 to 57 m	58 to 101 m
Landscape units	Riverside close to river bed	Middle of riparian forest	Edge of riparian forest and ecotone zone	Adjacent vegetation formations
Pattern of species	RS	MS	ES	AES
Threshold distances	16 m	17 and 29 m	30 and 57 m	More than 57 m
Most faithful tree species in each landscape unit	*Syzygium guineense,* *Pterocarpus santalinoides,* *Parinari congensis,* *Cola laurifolia,* *Napoleonaea vogelii*	*Cynometra megalophylla,* *Drypetes floribunda,* *Manilkara multinervis*	*Dialium guineense,* *Diospyros mespiliformis,* *Elaeis guineensis,* *Cola gigantea,* *Ceiba pentandra*	*Albizia ferruginea,* *Combretum collinum,* *Lonchocarpus sericeus,* *Millettia thonningii* *Anogeissus leiocarpus*

(1) Distance intervals are obtained from TWINSPAN analysis (see Figure 8.8); RS = Riverside Species; MS = Middle of riparian forest Species; ES = Ecotone zone Species; and AES = Adjacent Ecosystem Species.

The position of tree individuals from river compared to threshold values of each riparian forest portion (see Table 8.2) allow the detection of distribution patterns, and the investigation of the issue of core and edge species in riparian forests. For each tree species, the t-test compared the positions of all stems from river bed to riparian forest portions threshold distances: 16 m for river front (or riverside); 17 and 29 m for species always in the middle of riparian forest; 30 and 57 m for ecotone zone species; and more than 57 m for adjacent plant communities species. Table 8.3 (annex) summarises the outputs from t-tests.

Therefore the following typology and definitions are given for tree species found at riverside in the Benin context:

- Riverside tree species (RS) are those that always occur between 0 and 16 m from the river (i.e. river front species);
- Tree species in the middle of riparian forest (MS) are those that occur always between 17 and 29 m from the river (i.e. central portion of the riparian forest);

- Tree species, that always occur between 30 and 57 m, are either riparian forest edge species or ecotone species (ES); and
- Tree species typical of adjacent plant communities (AES) are those that always occur outside riparian forests.
- We also define typical RF tree species along rivers as those always occurring between 0 and 35.3 m away from the river bed.

This typology is only valid for rivers in Benin. The typology related to small waterways (i.e. streams) is not investigated in the present chapter.

The abundance distribution models for 18 tree species are shown in Figures 8.9; 8.10; 8.11 and 8.12 (see Annex). We present here results for tree species having at least 20 individuals recorded at riversides across riparian forests. In general the distribution curves follow the theoretical trends of Figure 8.1 for each species type.

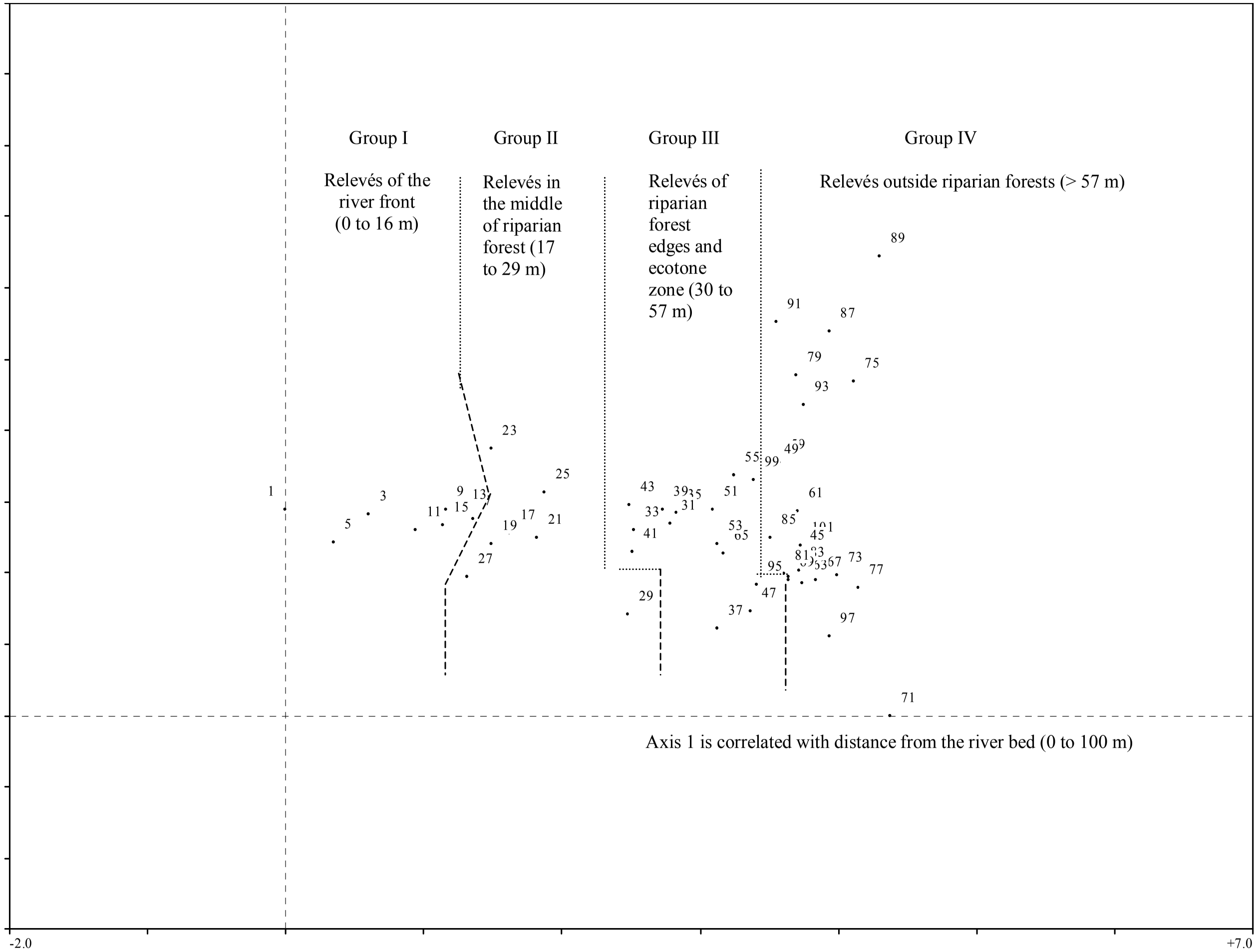
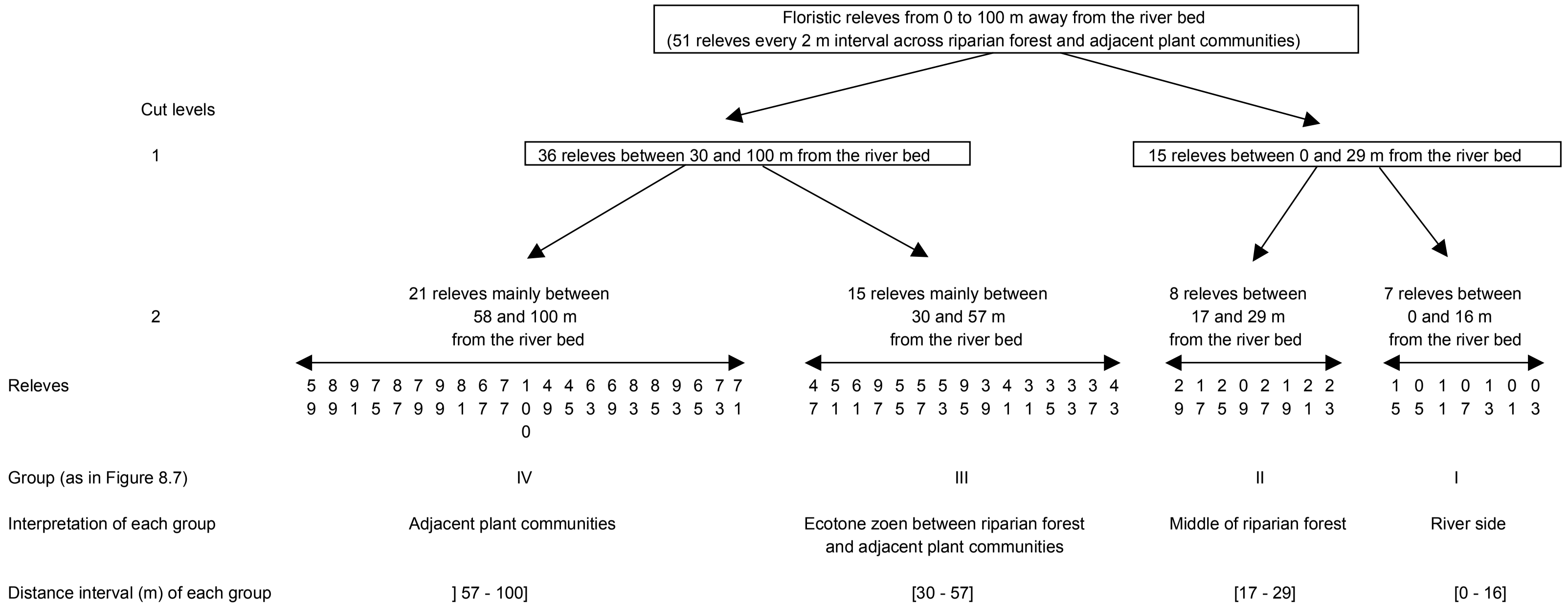


Figure 8.7: Detrended Correspondence Analysis (i.e. ordination) of the floristic composition of tree species at riverside. It shows a gradual variation of tree species composition at riverside. (……………) subdivisions and distance intervals are obtained from TWINSPAN (see Figure 8.8) and show the partition for riparian flora in three groups (river front, middle and forest edge).



NB: Numbers 1, 3, …, 99 represent floristic releves at [0-2[, [2-4[, ….,[98-100[m distance range

Figure 8.8 : TWINSPAN analysis of 51 releves across riparian forests and adjacent plant communities. It shows 4 groups of releves correlated with distance from the river bed: (I) at river side, (II) middle of riparian forest, (III) ecotone zone, and (IV) adjacent plant communities.

8.4. DISCUSSION

8.4.1. Partitioning riparian forests in three: river front, middle and forest edge

The DCA, TWINSPAN and Clusters analysis outputs, and frequency distribution curves showed interesting features regarding plant species ecology at riverside under the study area conditions, and probably for the whole Dahomey Gap region. The horizontal structure of species exhibit complex patterns across the studied rivers, and the underlying factors are still poorly understood. Rivers and riverbanks constitute very complex environmental gradients, with few (if any) factors having an overriding influence on species richness and composition. Probably, the relative importance of any factor varies greatly over the geographic scale chosen (Nilsson *et al.* 1989). Also, the predicted covariation in species composition and diversity, and the heterogeneity of environmental factors, which is consistent with the intermediate disturbance hypothesis, are documented from several riparian systems (Minshall *et al.* 1985, Tabacchi *et al.* 1990, Kellman & Tackaberry 1993). It is generally assumed that interior and edge areas are affected by patch size and shape (Forman & Godron 1986) and a gradient of environmental variables (e.g. moisture, light) will influence the distribution and frequency of tree and shrub species within and across riparian forests (Porembski 2001).

Apart from a few emergent species (e.g. *Ceiba pentandra, Cola gigantea, Parinari congensis* and *Manilkara multinervis*) the average tree height is often less than 18 m. The more or less distinct forest layers, each receiving progressively less light, are not always seen across riparian forests and adjacent plant communities. This is in accordance with the climax formations of Benin that are open, dry, or dense semi-deciduous forests with a relatively low height. Generally, riparian forests display a physiognomy that is highly variable, though the understorey is generally dense. Therefore they can be termed as relatively low edaphic and hygrophile forests with irregular canopy (Natta *et al.* in press, chapter 9), compared to upland tropical rain forests where canopy tree heights fluctuate between 30 to 45 m, and emergent trees may reach heights above 50 m (Popma *et al.* 1988, Whitmore 1990).

Our results reveal that when vegetation formations are undisturbed at the riverside, the floristic composition varies gradually across riparian forest and surrounding plant communities (see Figures 8.7 & 8.8). For Forman & Godron (1986) a gradual change is present where the major controlling environmental factors vary evenly (linearly) with distance. This suggests that, over short distance, water availability, humidity and flood frequency (July to December), as well as soil and micro-climatic variables may vary and differently affect both groups of species and individual species at the riverside. Across a Lake Superior tributary in Minnesota (USA), tree composition was correlated with stream gradient, and at least two effects of floods, oxygen depletion in the root zone and soil modification, could influence riparian vegetation (Ericsson & Schimpf 1986). In riparian ecosystems of South-Western USA, ordinations analyses provided evidence that riparian forests are structured along gradients relating to moisture, salinity, disturbance from fire, and community maturity (Busch & Smith 1995).

Certain tree species have a greater fidelity for riparian habitats along rivers. The decreasing affinity of tree species (see Figures 8.9; 8.10 and Table 8.3) to water availability from river to riparian forest edges is as follow: *Syzygium guineense, Pterocarpus santalinoides, Parinari congensis, Cola laurifolia, Napoleonaea vogelii, Drypetes floribunda, Cynometra megalophylla, Manilkara multinervis* and *Dialium guineense*. *Pterocarpus santalinoides, Parinari congensis, Cola laurifolia* and *Manilkara multinervis* were found to be the most frequent species along the Ouémé, Mono, Couffo, Alibori, Sota and Mékrou rivers in Benin (Sokpon *et al.* 2001). However, these authors have not made any distinction or ranking among riparian forest species. Typical riparian forest species are those always present at river front and in central portions of riparian forests, (i.e. the first eight species in Table 8.2). Therefore they are well adapted to high soil moisture and periodic flooding. Meanwhile, the effects of water-related factors across rivers in Benin are not fully elaborated.

Apart from the variation in floristic composition with water-related variables, attention has been focused upon the extent of edaphic and micro-climatic effects in riparian fragments flora because of the large perimeter to area ratio that these patches characteristically possess. In Nigeria, Nye (1954) found that the composition of riverain forest species in the immediate neighbouring of streams varies with the soils of the catena. In Belize, understorey light intensity was highest at riparian forest edge, but rapidly decreased towards the forest interior, where light levels were comparable to other tropical rain forest understoreys. Also the distribution of six species across riparian forest indicates that the light-correlated spatial patterning of seedlings persists to adulthood (MacDougall & Kellman 1992). These results suggest that the light regime in riparian forests has sufficient variation to support several regeneration and adult strategies, despite their small patch sizes.

8.4.2. Transition zone between riparian forests and neighbouring plant communities

In the study area, the boundary or ecotone between riparian forest and surrounding savanna or forest is on average between 30 and 57 m from the river bed. Under low human disturbance, this overlap zone is more characterised by a gradual change in species composition (Figure 8.7) than a change of structural parameters (i.e. stem density, average height, and basal area; see Figures 8.2, 8.3, and 8.4 respectively), and species richness (see Figure 8.6). The most frequent tree species in this interval, with regards to their abundance, are *Dialium guineense, Diospyros mespiliformis, Elaeis guineensis, Cola gigantea* and *Ceiba pentandra*. Interestingly, statistical analysis shows that these five species are not typical to riparian forest found along rivers (see Table 8.3 in Annex). Our results match with empirical knowledge from various floras (e.g. Keay & Hepper 1954-1972, Brunel *et al.* 1984, Berhaut 1967). *Dialium guineense* and *Diospyros mespiliformis* reach their optimal growth inside dense deciduous upland forests. *Elaeis guineensis,* a heliophytic and pioneering species, is naturally abundant in all West and Central African forests (Sowunmi 1999, Maley & Chepstow-Lusty 2001). Also, *Ceiba pentandra* is a late secondary pioneer species widely distributed in the tropics (Whitmore 1990, Meave & Kellman 1994), while *Cola gigantea*, typical of the Guineo-Congolian basin, is among the largest tree species of dense semi-deciduous forests.

Another issue revealed by species lateral distribution patterns (Figures 8.9 to 8.12 in Annex) is that the ecotone zone is composed mainly of species from both sides (i.e. riparian forest and adjacent savanna or upland forest). Numerous authors (e.g. Williamson 1975, Simberloff & Gotelli 1984, van der Maarel 1990, Kent & Coker 1992) have shown how one vegetation type grades into another through a transitional or ecotone zone, which concentrates a certain percentage of the two sides' species. A sharper ecotone often occurs where the amount of an environmental factor changes abruptly. In the West-African savanna region, abrupt borders seem to be controlled by an interplay of large herbivores, fires (mostly lit by humans), deforestation, shifting cultivation and edaphic factors (Porembski 2001). Between 8°30 and 9° N in Central Benin and North East Côte d'Ivoire, the gallery forest/savanna contact is made through a belt either of light demanding species (e.g. *Anogeissus leiocarpus, Mitragyna inermis, Alchornea cordifolia*) or species from dense semi-deciduous and open forest (*Pouteria alnifolia, Ceiba pentandra, Albizia* spp. and *Antiaris toxicaria*) (Poilecot *et al.* 1991, Natta & Porembski, see chapter 9). At the Mountain Pine Ridge savanna site in Belize (Central America), the transition zone between riparian forest and savanna is narrow and often dominated by a tall light-loving grass (*Tripsacum latifolium*) that grows in dense swards up to the edge of the forest (MacDougall & Kellman 1992). Fringing (i.e. edge specialist) species, such as species of savanna affinity, may act as a resilient buffer preventing fire intrusion into the riparian forest interior thus conserving species at the riparian habitat core (Meave & Kellman 1994). Forman & Godron (1986) hypothesise that the interdigitation zone is an area both of high total species diversity, since two vegetation types are in close contact, and of low diversity of interior species. Our own data on tree species at riversides could not yet confirm or reject this hypothesis.

Beyond the ecotone zone, in adjacent plant communities, the five most frequent tree species are either of large distribution in the Guineo-Congolian basin, Sudano-Guinean, or Sudano-Zambesian regions, but reach their optimal growth in upland forest or savanna woodland. *Albizia ferruginea* is a common semi-deciduous forest tree. *Lonchocarpus sericeus* and *Millettia thonningii* are deciduous tree species usually seen in fringing and semi-deciduous forest near water. *Anogeissus leiocarpus* extends from the driest savanna to the borders of the forest zone, usually in moist situations but also in relatively dry situations, while *Combretum collinum* is a common savanna tree (Keay *et al.* 1964, Keay & Hepper 1954-1972).

8.4.3. Modelling tree species distribution across rivers

Tree stems are not evenly distributed across riparian forests in Benin. The decrease of the number of individuals at the riverside to 50 m away (Figure 8.2) suggests a decrease in tree species density within riparian forests. This is linked to the biology and adaptation of typical riparian forest tree species to recurrent floods and shallow water table. Such natural selection and adaptation are revealed by the fact that all river front species (i.e. *Syzygium guineense, Pterocarpus santalinoides, Cola laurifolia* and *Cynometra megalophylla*) are multi-stemmed species.

Provided sufficient data, it is eventually possible to get best fitting models for the lateral distribution patterns of plant species at the riverside. Modelling deals with the construction of a manageable system, which is simpler than the reality that is modelled, but which nevertheless shares interesting features and behaviour with the real systems (Tongeren & Prentice 1986). In general polynomial and linear functions are the best-fit models, and low values of R^2 should be linked to complex relationships of tree species to environmental variables under natural conditions. These results accredit the thesis of the presence of a riparian vegetation width effect for tree species, which is a pattern where species distributions are related to the width of vegetation formations at riverside. Nevertheless, the effects of riparian forest width, and disturbance on the width, species composition and community structure along waterway types (i.e. streams and rivers) need further investigation in Benin.

8.4.4. Plot size and shape for plant diversity assessment in riparian forests

The variation of tree species composition at riverside according to environmental factors has several implications upon sampling designs, designated at assessing riparian plant diversity. The primary criteria of site selection should be appearance (i.e. physiognomy), species composition and dominant species encountered at riverside. According to the research objectives, random or systematic sampling designs are suitable in continuous and dense vegetation belts by waterways. On the contrary, stations for data collection have to be purposely selected in dense riparian forest stands to avoid bare land or degraded plots. Also, sites designated for drawing species-area curve of riparian forests should be carefully selected in stands uniform with regards to physiognomy and species composition, and avoid ecotone zones where edge species are frequent. Including the transitional (i.e. ecotone) zone at a riverside could cause the curve to rise with increasing plot size.

When all terrestrial plants in all stages are included, plot sizes of 500 to 1000 m^2 are acceptable for classification of forest relevés (Hommel 1990). Field plots (50 m by 10 m) were established in forests fragment forests in Southern Togo (Kokou *et al.* 2002). In Benin, rectangular plots of 500 or 1000 m^2 were used to collect floristic data in several edaphic forests (Sokpon *et al.* 2001). In Central Benin, a 500 m^2 plot size was taken as the minimal plot size of riparian forest (Natta 2000). From the results presented above, circular and square plots may not always cover the whole riparian forest width (i.e. in average 27 to 43 m wide). Circular plots in particular in riparian forests, are characterised by an unequal probability of sampling species, because our results show that species and stems are not evenly, nor randomly distributed in riparian forests (see also Ericsson & Schimpf 1986, MacDougall & Kellman 1992, Stromberg *et al.* 1996, Natta 2000, Porembski 2001, Natta & Porembski, in press). Therefore circular plots will tend to oversample stems and species of the central portion of riparian forests compared to those at the river front and riparian forest edge. They also do not guarantee a total coverage of the riparian forest width at every stand. In homogeneous strip-like riparian forest fragments, rectangular plots, with varying length and width, fit with any shape of the waterway (see also Begon *et al.* 1986, Goudiaby 1998).

8.4.5. Optimal riparian forest width to be protected under Benin conditions

Riparian forest width varies from river to river, and along a single river system. This has several vital functional implications. The Benin forest law (no. 93-009 of July the 2nd of 1993), does not allow clearance of wood and shrubs within 25 m from both sides of any water course and stretch of smooth water (article 28). This limit was not set up based on scientific data. From field observations, Natta *et al.* (2002) suggested a limit of 100 m. Can we answer the important question: How wide should riparian forest corridors be to fulfil their vital ecological functions? A prudent approach for riparian biodiversity conservation is to preserve not only the full range of river front, interior and edges species of riparian forests (*i.e.* at least 57 m from the river bed), but also parts of the adjacent upland forest or savanna as buffer zone. Moreover dense and continuous canopy at the riverside can extend to more than 100 m (e.g. Samiondji, Idadjo, Pénéssoulou, Yarpao, etc). This could guide legislators to update the optimal threshold distance to be protected at each riverside at 100 m (*i.e.* four time the actual distance).

Overseas studies have shown the importance of the issue of optimal distance to be protected at both waterway sides. In South East Brazil, the optimal width that allows RFs to fulfil its multifunctional roles (e.g. sediment retention and improvement of water quality) was found to be 52 m, which was actually wider and more efficient than to the official legal recommendation of 30 m (Sparovek *et al.* 2002). In South East Australia, Dignan & Bren (2003) found that the fixed minimum non-disturbance width of 20 m along all permanent streams does not provide maintenance of the light regime that could protect riparian forests values, instead they suggest forested buffers 70 to 100 m wide.

8.5. CONCLUSION

The present study investigates the structure, floristic composition variation, and spatial distribution of tree species across riparian forests and their adjacent plant communities at riverside. Horizontal and vertical structures of tree species exhibit complex patterns at riversides. On the one hand, tree stems are characterised by an uneven distribution across riparian forests, on the other hand height and basal area variations at riverside do not show any clear patterns. The numerical analysis confirms a gradual variation of the floristic composition at riverside, across riparian forests and neighbouring plant communities. This floristic and abundance gradient may correspond to a change of water-related, as well as soil and microclimate variables. This research not only confirms empirical knowledge about the ecology of certain riparian forest and surrounding vegetations plant species, but also makes a distinction between river front, central portion and edge species of riparian forests. Criteria (e.g. average distance range and models) are provided for the most common tree species along rivers. These results suggest a partitioning of riparian forests in three habitats among tree species along the horizontal gradient.

In the present paper we could only draw conclusions about the distribution pattern of 18 tree species out of 106 encountered at the riverside. Investigations on the remaining species should continue. An implication of our results for riparian forest phytodiversity assessment is that plot size, shape and layout in the terrain should take into account the river front, central portion and riparian forests edge species. Due to the non-coverage of the whole riparian forest width and unequal chance of species and stems to be sampled, circular and square plots are not suitable for structural parameters and phytodiversity assessment in riparian forests. Instead rectangular plots with varying length and width, and covering the whole cross section of riparian forest appear to be the most suitable under the study area conditions, and probably for savanna regions. The present study also provides scientific guidelines for an improvement of the forest law regarding the distance to be protected at riverside, i.e. 100 m instead of 25 m.

Annex

Table 8.3: Summary of the t-test outputs. Abundance distribution curves are plotted in Figures 8.9, 8.10 and 8.11.

Species	Abundance	Position (m) from river bed (± SD)	Compared with	t-calculated	df	Probability	Results
1-*Syzygium guineense*	72	3.66 ± 4.97	Riverside limit (16m)	21.05	142	p<0.001***	Typical riverside species
2-*Pterocarpus santalinoides*	213	7.43 ± 8.6	Riverside limit (16m)	14.53	424	p<0.001***	Typical riverside species
3-*Parinari congensis*	32	8.28 ± 5.94	Riverside limit (16m)	7.34	62	p<0.001***	Typical riverside species
4-*Cola laurifolia*	181	14.15 ± 9.8	Riverside limit (16m)	2.53	360	p = 0.0117*	Typical riverside species
5-*Napoleonaea vogelii*	25	14.27 ± 6.51	Riverside limit (16m)	1.32	48	p = 0.19 NS	Typical riverside species
6-*Drypetes floribunda*	39	22.55 ± 12	Middle limits (17-29m)	3.35	76	p = 0.0012**	Riparian forest middle species
7-*Cynometra megalophylla*	70	22.07 ± 20.12	Middle limits (17-29m)	2.87	138	p = 0.004**	Riparian forest middle species
8-*Manilkara multinervis*	25	27.39 ± 18.16	Middle limits (17-29m)	2.41	48	p = 0.019*	Riparian forest middle species
9-*Dialium guineense*	107	30.6 ± 22.59	Riparian forest limit (38m)	2.81	212	p = 0.005**	Riparian forest edge species
10-*Diospyros mespiliformis*	58	52.54 ± 35.61	Riparian forest limit (31m)	4.05	114	p < 0.001***	Ecotone zone outside riparian forest
11-*Elaeis guineensis*	21	29.93 ± 18.49	Riparian forest limit (26m)	0.75	40	p = 0.45 NS	Ecotone zone outside riparian forest
12-*Cola gigantea*	21	39.53 ± 19.18	Riparian forest limit (36m)	0.77	40	p = 0.44 NS	Ecotone zone outside riparian forest
13-*Ceiba pentandra*	35	49.39 ± 24.41	Riparian forest limit (30m)	4.04	68	p = 0.001***	Ecotone zone outside riparian forest
14-*Albizia ferruginea*	22	49.41 ± 19.93	Riparian forest limit (29m)	4.21	42	p = 0.001***	Ecotone zone outside riparian forest
15-*Combretum collinum*	23	53.17 ± 14.31	Riparian forest limit (32m)	3.87	44	p < 0.001***	Ecotone zone outside riparian forest
16-*Lonchocarpus sericeus*	32	60.93 ± 24.34	Riparian forest limit (32m)	5.81	62	p < 0.001***	Adjacent vegetation species
17-*Millettia thonningii*	40	61.36 ± 22.77	Riparian forest limit (43m)	3.99	78	p = 0.0014**	Adjacent vegetation species
18-*Anogeissus leiocarpus*	114	71.11 ± 22.96	Riparian forest limit (34m)	14.87	226	p < 0.001***	Adjacent vegetation species

SD = standard deviation; *** highly significant (p<0.001); ** significant at p=0.01; * significant at p=0.05; NS = non significant at p = 0.05

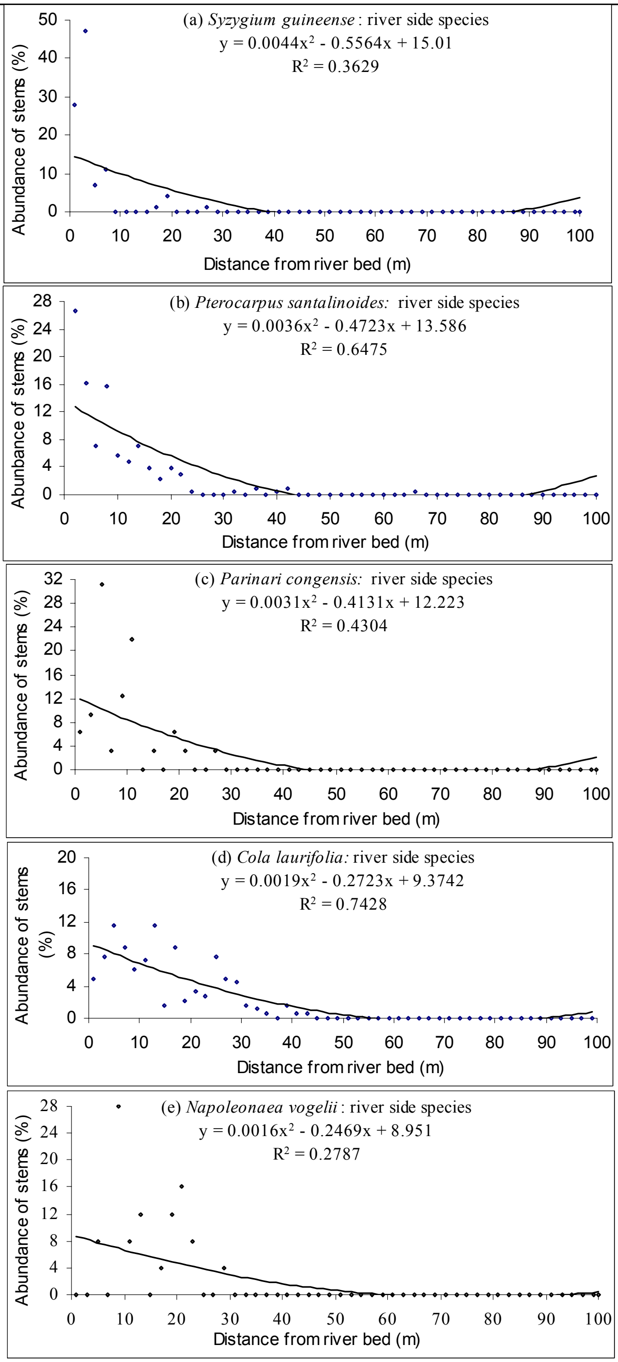


Figure 8.9: Typical riverside tree species (RS) mainly found less than 16 m from the river bed

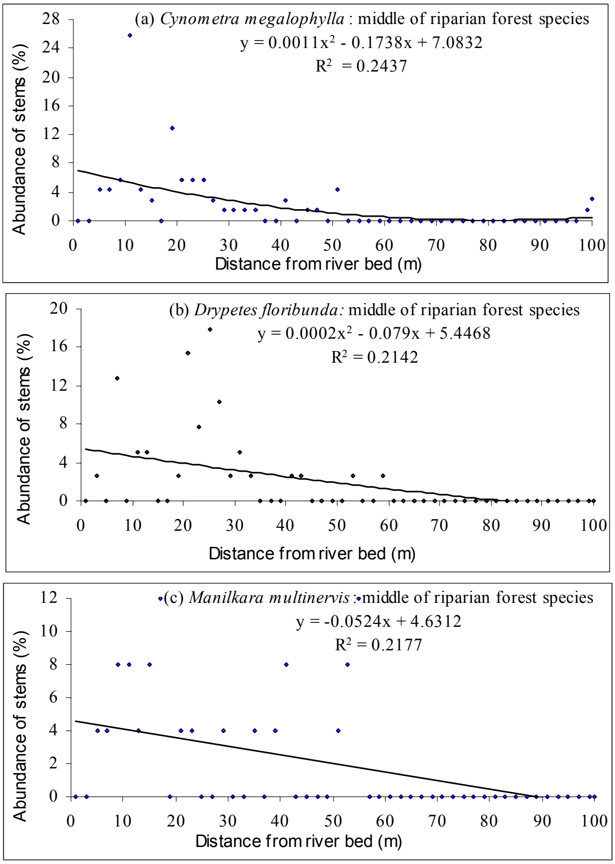


Figure 8.10: Typical species of the middle of riparian forests (MS) mainly found between 17 and 29 m away from the river bed

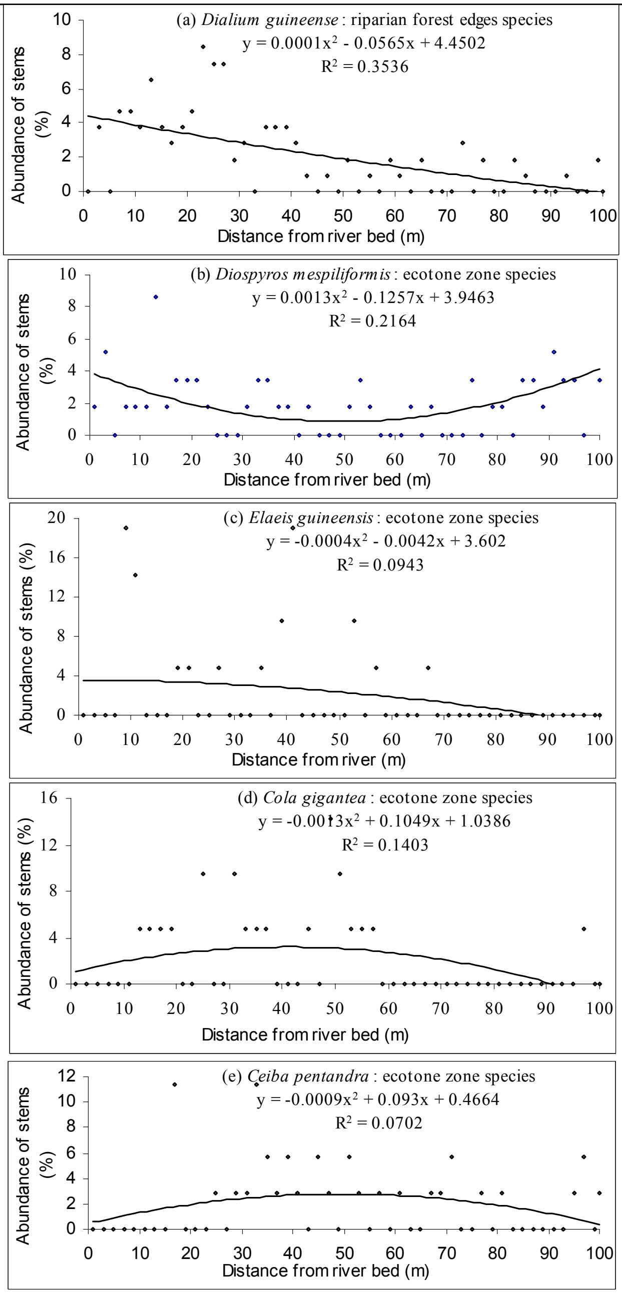


Figure 8.11: Typical species at riparian forest edges (ES) or in the ecotone zone with neighbouring plant communities (i.e. between 30 and 56 m away from river bed)

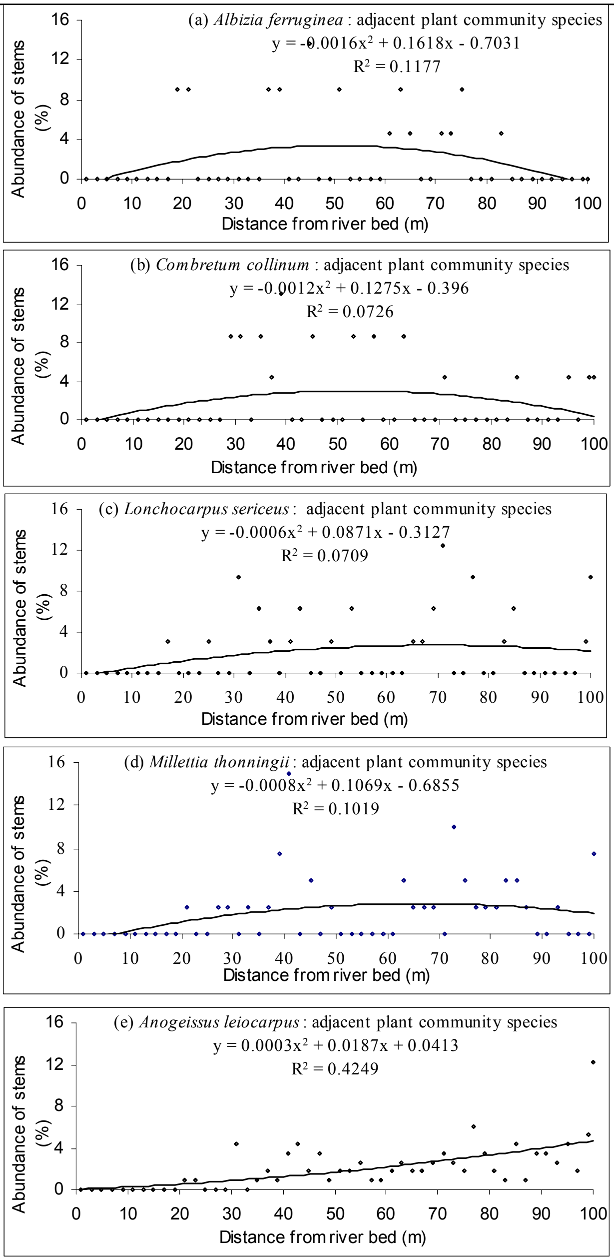


Figure 8.12: Typical species of plant communities adjacent to riparian forests (AES), and beyond the ecotone zone (*i.e.* found constantly beyond 57 m from the river bed).

Chapter 9

OUÉMÉ AND COMOÉ: FOREST-SAVANNA BORDER RELATIONSHIPS IN TWO RIPARIAN ECOSYSTEMS IN WEST AFRICA (*)

Notulae Florae Beninensis 8

In press, *Botanische Jahrbücher.*

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Chapter 9

OUÉMÉ AND COMOÉ: FOREST-SAVANNA BORDER RELATIONSHIPS IN TWO RIPARIAN ECOSYSTEMS IN WEST AFRICA (*)

Notulae Florae Beninensis 8

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(*) In press, *Botanische Jahrbücher.*

ABSTRACT

The floristic composition, species richness and structure at river edges are compared between two gallery forests/savanna ecosystems along the Ouémé (Central Benin) and Comoé (North-East Côte d'Ivoire) rivers. Although the overall physiognomy of the two gallery forest sites seems similar and they share the most prominent families, there are marked differences in terms of canopy density and height, herb layer density, number of individuals, tree richness and diversity (*H'*), and species composition. Gallery forest width, top canopy density and height were more developed along the Comoé than along the Ouémé, but the herb layer is more luxuriant at the latter site. Concerning absolute density and basal area *Cynometra megalophylla* accounted for 9 to 16 %, and 26 to 33 %, respectively in the two sites. At the two sites this species was time and again the most frequent and dominant one at both riverside and in the middle of the gallery forest.

A detailed comparison of the three gallery forest plot types (riverside, middle and savanna edge) revealed considerable differences and contrasting results concerning the dominant trees, species composition, the number of species and individuals, average height and diameter, and basal area. Species characteristic for the river front and the central portion of gallery forests were *Cynometra megalophylla, Dialium guineense, Cassipourea congoensis, Syzygium guineense* and *Parinari congensis* at both sites, with *Pterocarpus santalinoides* being particularly abundant along the Ouémé river. The savanna edge has the most distinct floristic composition with *Pouteria alnifolia* at both sites; *Antidesma venosum, Fagara zanthoxyloides* along at the Comoé site; and *Ceiba pentandra, Albizia* spp. and *Antiaris toxicaria* at the Ouémé site. The difference between the plot types concerning species diversity (*H'*) was not statistically significant. The present study shows the variability and complexity of ecological processes between and within gallery forests sites.

Key words: gallery forest, forest edge, savanna, core species, Benin, Côte d'Ivoire, West Africa.

9.1. INTRODUCTION

Gallery forest (also riparian forest) is one of the major vegetation formations, which underlines the outline of waterways in savanna or in forest-savanna mosaic ecosystems (MONNIER 1990, NATTA 2000). They sustain a type of vegetation that is distinct from the surrounding areas in species composition and vegetation structure (POREMBSKI 2001). Although linear in shape and small in area, as compared to large extents of dense forests, the role played by tropical gallery forests in fluvial processes, and animal and plant species conservation is well documented (FORMAN & GODRON 1986, DECAMPS *et al.* 1988, BAKER 1990, LEVAUX 1990, MEAVE *et al.* 1991, ROGGERI 1995, MEDLEY 1992, THOMAS 1996, PIEGAY 1997, LEINARD *et al.* 1999, VAN ETTEN 1999, NATTA *et al.* 2002).

The study of West-African gallery forests has hitherto been limited (POREMBSKI 2001). So far, most of the published work concerns floristic and structural characteristics of genuine or single gallery forests along specific waterways and the gallery forest/savanna edge relationships, both in species composition and structure, were little investigated.

The Ouémé and Comoé, which are among the largest rivers in Benin and Côte d'Ivoire respectively, with their forested banks harbour a rich birdlife and serve as major habitat for primates and other animals of many kinds. Moreover, they are important extrazonal corridors, acting as refugee ecosystem for forest tree species in a fire-prone environment, harbouring species requiring moist habitats, and allowing the migration of species far beyond their zonal distributional area. At the two sites, more than 600 km apart, a field survey shows the presence and dominance of some typical gallery forests tree species, such as *Cynometra megalophylla, Dialium guineense, Cassipourea congoensis* and *Drypetes floribunda*. The present paper aims at comparing the floristic composition and structure of two genuine gallery forest/savanna ecosystems, at the same latitude, along the most important rivers in two different West-African countries, Benin and Côte d'Ivoire. The spatial distribution of certain species inside and along the gallery forest edge is investigated as well.

9.2. MATERIAL AND METHODS

9.2.1. Study sites

The two gallery forest ecosystems (hereafter GF), which are approximately at the same latitude, are located within protected areas, the Comoé National Park and the Kouffé Mountains (Figure 9.1). They are representative of GFs occurring between 8°30 and 9° N along the Ouémé (Central Benin) and the Comoé (North East Côte d'Ivoire) rivers, which are among the largest waterways in the two countries. At this latitude, the belts of GFs are almost continuous with only a few local gaps. Apart from bush fire traces, the two sites showed no signs of human impact. Their climates are similar in many points, particularly average rainfall (1100 - 1200 mm) and a pronounced seasonality with a dry season from November to March/April and a rainy season from May to October. From January to March the dry-hot Harmattan results in daytime temperatures in excess of 40° C whilst air humidity drops below 20%. During the night temperature can fall below 20° C, and the sudden decrease is occasionally accompanied by dew. The hydrological regime of the Comoé and Ouémé rivers is of tropical transition type, characterised by a unique rise in the water level in August-September-October. At the end of the dry season, in March/April, the two rivers usually stop to flow but large water holes are still present.

The Ouémé river GFs at the latitude of Ouèssè are located at the Eastern limit of the Kouffé Mountains forest reserve that lies along the boundary between the Sudanian regional centre of endemism and the Guinea-Sudanian regional transition zone. It is moister than the protected areas of Northern Benin, so its plant and animal species are more diverse. Despite many decades of neglect, the reserve still contains dozens of small patches of GF and dense moist forest. These remnants appear undisturbed internally, and are therefore of very high biodiversity value (PGRN/IUCN 1994). GF ecosystems and the surrounding vegetation are among the least degraded in the Sudano-Guinean zone. This zone is characterised by the decrease of rain and merging of the two peaks of rainfall typical of the Guinean region of Southern Benin. The mean annual temperature is 28° C and the elevation ranges from 190 to 390 m a.s.l. Dense semi-deciduous and dry forests represent climax vegetation formations at this latitude. The maximum GF width may reach 200 to 300 m, but the dense and continuous canopy is generally less than 100 m wide.

The investigation of GF along the Comoé river focused on the South-Western part of the Comoé National Park (CNP) where semi-deciduous forest represents a large proportion the natural vegetation. Meanwhile, due to annual burning, the vegetation consists mainly of different savanna types (>85%), forests islands (4.4%) and gallery forests (2.3%) (FGU KRONBERG 1979). The climate of the Central and Southern areas of the CNP can be assigned to the 'secteur sub-soudanais', which is of tropical sub-humid type (ADJANOHOUN & AKÉ ASSI 1967, GUILLAUMET & ADJANOHOUN 1971, ELDIN 1971). Mean annual temperature is in the range of 26-27° C. March is the hottest month with a mean daily temperature of 37° C. The lowest temperature (15° C) is recorded in January. The river Comoé runs through the park for about 200 km and drains with its tributaries some 78,000 km^2 (POILECOT *et al.* 1991). Permanent and semi-permanent water occurs in many places. The width of GFs may reach up to 600 m, but at the study site, they attain a maximum width of 130 m (POREMBSKI 2001).

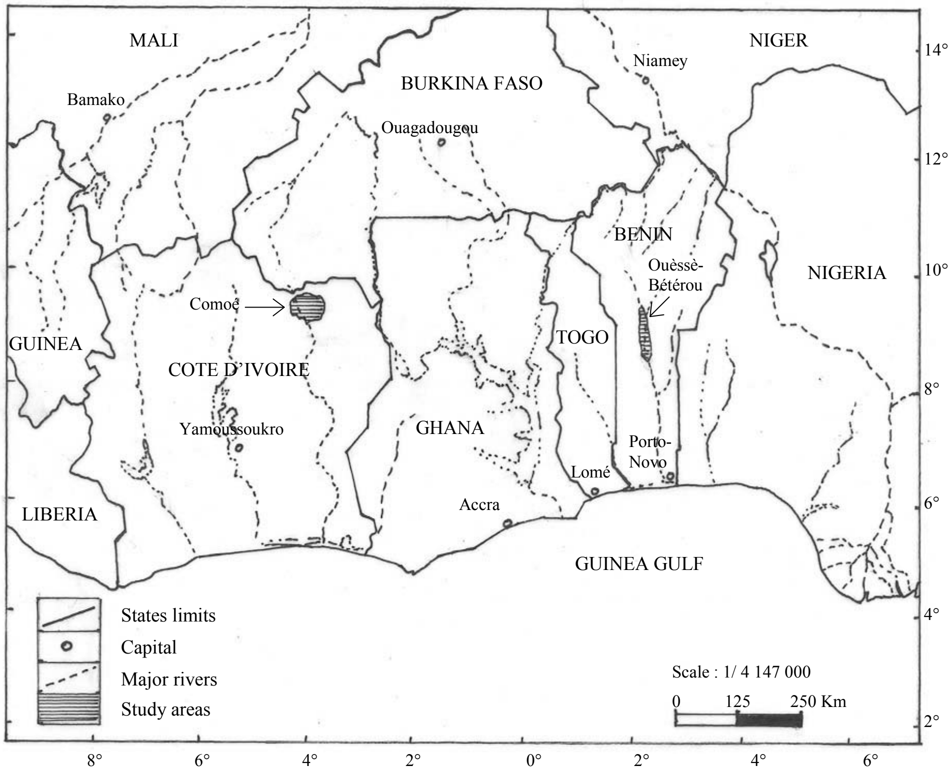

Figure 9.1: The Comoé National Park and Kouffé Mountains gallery forests sites in Côte d'Ivoire and Benin in West Africa.

9.2.2. Data collection and analysis

The investigation and comparison of the two sites are based on 9000 m^2 of GF (i.e. 4500 m^2 per site). Floristic data were collected through phytosociological survey in plots (300 m^2 to 500 m^2), laid out along a gradient from the stream-side to the border with the savanna. Three plot types were considered: riverside, middle of GF and savanna edge. Per site and at each plot type 1500 m^2 were surveyed. All trees and lianas of a diameter at breast height (dbh, at 1.3 m above the ground level) of at least 5 cm were recorded and identified. Nomenclature of the species recorded follows KEAY & HEPPER (1954-1972), BRUNEL *et al.* (1984), BERHAUT (1967), and LEBRUN & STORK (1991-1997).

Tree (i.e. dbh ≥ 5 cm) species diversity for each plot type was calculated using the Shannon-index *H'*. A t-test based on the Shannon index (*H'*) and its variance was used to test for differences in alpha-diversity (including evenness) between the plot types, and the two GF sites. This method was successfully used on riparian forests of Central Benin (NATTA 2000) and in the CNP (POREMBSKI 2001). For further details see MAGURRAN (1988). The floristic similarity of the two GF sites was assessed through the Jaccard and Sørensen coefficients.

9.3. RESULTS

9.3.1. General characterisation of the Ouémé and Comoé GF sites

GFs investigated along the Comoé and Ouémé rivers have generally a well-marked boundary with the surrounding savanna, which is regularly burnt in the dry season. Elsewhere the contact is more abrupt, with a grass layer bordering the GF. The two GF sites show no clear evidence of stratification, with the different strata transgressing into each other. Here and there, there is a continuum of the top layer canopy with adjacent dense semi-deciduous or dry forests, but ground cover of the dominant trees is always lower at GF fringe than inside.

At the Comoé river site, the herbaceous stratum at GF/savanna border is dominated by *Vetiveria fulvibarbis, Loudetia simplex*, and among the important trees there are *Anogeissus leiocarpus, Mitragyna inermis, Holarrhena floribunda, Tamarindus indica, Acacia sieberiana*. The interior of this GF is made up of species such as *Cymonetra megalophylla, Cola cordifolia, Manilkara multinervis,* and *Diospyros mespiliformis* at a height of 25-30 m. Occasionally, emergent trees such as *Ceiba pentandra*, reach a height of up to 40 m. The lower storeys consist of smaller trees (e.g. *Dialium guineense, Drypetes floribunda, Cassipourea congoensis, Diospyros abyssinica, Celtis brownii*) and shrubs (e.g. *Oxyanthus racemosus, Rinorea kibbiensis, Tapura fischeri*, etc.). Lianas are abundant, with *Cnestis ferruginea, Dioscorea* spp., *Cissus* spp., *Strophanthus* spp.*, and Strychnos* spp. Both towards the Comoé river as well as towards the savanna border, light demanding trees (e.g. *Pterocarpus santalinoides, Cassia sieberiana, Christiana africana*) can be found. A continuous herb layer is only developed in some gaps.

On the contrary, at the Ouémé site *Andropogon* spp. and *Pennisetum* spp. are among the dominant herbaceous species at GF/savanna border whilst the most important tree species are *Millettia thonningii, Anogeissus leiocarpus, Albizia* spp.*, Combretum* spp., *Pouteria alnifolia, Acacia sieberiana* and *Lonchocarpus sericeus*. The top canopy tree species inside the GF are *Cynometra megalophylla, Parinari congensis, Cola laurifolia, and Pterocarpus santalinoides* with a maximum height of 16-20 m. Here, *Dialium guineense* is among the top layer trees. The emergent tree *Cola gigantea*, reaches a maximum height of 26 m, which is much lower than those along the Comoé river. The lower storeys consist of smaller trees such as *Drypetes floribunda, Lepisanthes senegalensis, Cassipourea congoensis, Salacia pallescens, Vitex chrysocarpa* and *Morelia senegalensis*. Lianas are also abundant: *Strychnos* spp., *Loeseneriella* spp., *Alafia* spp., *Taccazea apiculata, Connarus africana, Paullinia pinnata, Lonchocarpus cyanescens, Cremaspora triflora* and *Canthium horizontale*. The herb layer consists of *Achyranthes aspera, Phaulopsis* spp., *Polygonum salicifolium, Heliotropium indicum, Ruspolia hypocrateriformis, Ruellia praetermissa,* and *Cyperus* spp., and, in contrary to the CNP, is continuous even under dense canopy.

9.3.2. Floristic diversity at the Ouémé and Comoé GF sites

The two sites share the most prominent families Leguminosae, Rubiaceae and Sapotaceae, but they have only 16 tree species, out of 88, in common. The Jaccard and Sørensen similarity coefficients are therefore very low, 13.3 and 23.5% respectively. The GFs along the Comoé have higher tree species richness and abundance than those along the Ouémé (see Table 9.1). The t-test, based on the Shannon index that combines species richness and abundance, reveals that the two sites differ highly significantly ($t = 8.48$, $df = 1305$, $p < 0.001$) in terms of tree species diversity. At the same latitude, the GFs along the Comoé are thus more diverse than those along the Ouémé. In absolute density (individuals/ha), *Cynometra megalophylla* ranks first in the two sites, followed by *Cola laurifolia* along the Ouémé and *Dialium guineense* along the Comoé.

Table 9.1: Major characteristics of gallery forests along the Ouémé and Comoé rivers.

Major characteristics	GF along the Ouémé (Central Benin)	GF along the Comoé (CNP) (North East Côte d'Ivoire)
Tree species richness	50	54
Number of individuals	624	906
Most prominent families (species number)	Leguminosae (8); Moraceae (4); Rubiaceae (4); Annonaceae (3); Sapindaceae (3) and Sapotaceae (3)	Leguminosae (8); Euphorbiaceae (7); Rubiaceae (3) and Sapotaceae (3)
Most frequent trees	*Cynometra megalophylla* (102); *Cola laurifolia* (65); *Lepisanthes senegalensis* (58); *Pterocarpus santalinoides* (56); *Drypetes floribunda* (53) and *Xylopia parviflora* (43)	*Cynometra megalophylla* (84); *Dialium guineense* (74); *Cassipourea congoensis* (63); *Ouratea affinis* (55); *Tapura fischeri* (54) and *Drypetes floribunda* (47)
Shannon index (H')	3.97	4.87 (most diverse site)
Pielou index (E)	0.70	0.85

The most frequent tree species is *Cynometra megalophylla*, which accounts for 9 to 16 % of the total abundance, and 26 to 33 % of the total basal area at the Comoé and Ouémé sites respectively (Table 9.2).

Table 9.2: Measured variables for *Cynometra megalophylla* at the Ouémé and Comoé sites.

Variables	Ouémé (Central Benin)	Comoé (North East Côte d'Ivoire)
Abundance (%)	16.3	9.3
Basal Area (%)	33.06	26.1
Mean diameter (cm)	19.53	18.6
Mean height (m)	9.48	16.2

9.3.3. Floristic and structural variability at the riverside, inside GF and at GF edge

A detailed comparison of the three GF plot types (riverside, middle of GF and savanna edge) revealed considerable differences concerning the number of individuals and dominant tree and shrub species. At the Comoé GF site, the number of individuals increased from 'riverside' (263) and 'middle' (317) to 'savanna' (326), whilst it decreased (345, 176 and 103 respectively) at the Ouémé site (see Table 9.3). 'Savanna edge', 'middle of GF' and 'riverside' were clearly differentiated when considering the most important species at the two sites and certain species showed particular preferences for specific plot types.

Table 9.3: Dominant tree species (with regards to number of individuals, dbh ≥ 5 cm) in different GF plot types at the Ouémé and Comoé sites.

(a) The Ouémé GF site at Ouèssè latitude

GF sites	Ouémé (Central Benin)		
Plot type	Riverside	Middle of GF	Savanna edge
Trees abundance	345	176	103
Number of tree species	32	26	22
Mean height (m)	7.44	7.47	8.1
Average diameter (cm)	13.5	13.32	16.37
Total basal area (m^2)	169.6	83.2	74.1
Shannon index (H')	3.9	3.8	3.5
Dominant tree species	*Cynometra megalophylla* (57)	*Cynometra megalophylla* (29)	*Drypetes floribunda* (23)
	Pterocarpus santalinoides (49)	*Lepisanthes senegalensis* (28)	*Lepisanthes senegalensis* (19)
	Cola laurifolia (48)	*Xylopia parviflora* (27)	*Cynometra megalophylla* (17)
	Syzygium guineense (36)	*Cola laurifolia* (18)	*Manilkara multinervis* (7)
	Morelia senegalensis (22)	*Drypetes floribunda* (10)	*Ceiba pentandra* (5)
	Drypetes floribunda (20)	*Dialium guineense* (9)	*Albizia ferruginea* (3)
	Vitex chrysocarpa (18)	*Manilkara multinervis* (7)	*Antiaris toxicaria* (3)
	Xylopia parviflora (15)	*Morelia senegalensis* (6)	*Dialium guineense* (3)
	Dialium guineense (11)	*Vitex chrysocarpa* (6)	*Pouteria alnifolia* (3)

(b) The Comoé GF site in the South-West of the Comoé National Park

GF sites	Comoé (North East Côte d'Ivoire)		
Plot type	Riverside	Middle of GF	Savanna edge
Trees abundance	263	317	326
Mean height (m)	8.82	9.21	8.44
Average diameter (cm)	14.2	14.7	13.3
Total basal area (m^2)	101.4	112.3	98.5
Number of tree species	27	23	34
Shannon index (H')	2.69	2.41	2.5
Dominant tree species	*Cynometra megalophylla* (25)	*Cynometra megalophylla* (48)	*Pouteria alnifolia* (25)
	Syzygium guineense (15)	*Dialium guineense* (42)	*Dialium guineense* (23)
	Parinari congensis (15)	*Cassipourea congoensis* (37)	*Antidesma venosum* (18)
	Cassipourea congoensis (14)	*Drypetes floribunda* (35)	*Tapura fischeri* (17)
	Manilkara multinervis (14)	*Tapura fisheri* (35)	*Fagara zanthoxyloides* (15)
	Drypetes floribunda (12)	*Ouratea affinis* (32)	*Lannea kerstingii* (15)
	Mallotus oppositifolius (11)	*Mallotus oppositifolius* (26)	*Alchornea cordifolia* (14)
	Dialium guineense (9)	*Holarrhena floribunda* (17)	*Anogeissus leiocarpus* (13)
	Lecaniodiscus cupanioides (9)	*Diospyros abyssinica* (17)	*Christiana africana* (13)
	Diospyros abyssinica (8)	*Lecaniodiscus cupanioides* (17)	*Diospyros mespiliformis* (13)

At the Comoé site, species characteristic for the central portion of the GF were *Cynometra megalophylla, Dialium guineense* and *Cassipourea congoensis. Cynometra* *megalophylla* was also abundant along the Comoé river front where *Syzygium guineense* and *Parinari congensis* were likewise frequent. At the Ouémé site the difference between 'river edge' and 'middle of GF' is best shown by a decrease of abundance of certain species such as *Cynometra megalophylla, Lepisanthes senegalensis, Cola laurifolia, Drypetes floribunda, Morelia senegalensis, Vitex chrysocarpa, Dialium guineense, Xylopia parviflora* and *Manilkara multinervis*. Meanwhile, *Pterocarpus santalinoides* and *Syzygium guineense* are particularly abundant along the Ouémé river. 'Savanna edge' has the most distinct floristic composition with *Pouteria alnifolia* at both sites; *Antidesma venosum, Fagara zanthoxyloides* along the Comoé river and *Ceiba pentandra, Albizia* spp. and *Antiaris toxicaria* at the Ouémé site.

Contrasting results were obtained concerning the tree species richness and diversity (*H'*) between the three plot types. For example, the number of species was highest at 'savanna edge' and 'riverside' plots respectively for both Comoé and Ouémé. On the contrary, species diversity was at a maximum in the 'riverside' plots, but minimum diversity was reached in the 'middle' plots at the Comoé site and at 'savanna edge' at the Ouémé site. However, the difference between the plot types concerning species diversity (*H'*) was not statistically significant (at $p = 0.05$) in both GF sites.

Concerning the structure variability at the three plot types, contrasting results were obtained as well. Along the Comoé, both 'middle' and 'riverside' attained higher values for tree height, diameter and basal area (m^2/ha) than 'savanna edge', where tree height was clearly lower. Likewise, maximum tree height (30 m) was found for an individual of *Ceiba pentandra* occurring in 'Central' plots. On the contrary, at the Ouémé site, 'savanna edge' plots had the highest average diameter and height. Total basal area decreased from the 'riverside' to 'savanna edge' plots. The tallest tree, *Cola gigantea* (26 m), was found at the GF/savanna boundary.

9.4. DISCUSSION

With regard to the most prominent families of the Comoé and Ouémé GFs, there are some similarities with several tropical GFs and dense forests. Leguminosae, Euphorbiaceae, Rubiaceae and Annonaceae are the most species-rich families always found in Benin riparian forests (NATTA *et al.*, in prep.). In the Dja fauna reserve (Cameroon) Euphorbiaceae, Rubiaceae, Annonaceae, Meliaceae, Caesalpiniaceae, Sapindaceae and Sapotaceae have the highest tree species richness (LEJOLY *et al.* 1996, SONKÉ & LEJOLY 1998). In a dense 2-ha forest at Kade (Ghana) Leguminosae was the best represented family (SWAINE *et al.* 1987). MEAVE & KELLMAN (1994) found similar results in a 1.6 ha of riparian forest in the Mountain Pine Ridge (Belize). They further found similarities between this riparian forest flora and the flora of neotropical continuous rain forests. The three tropical rain forest blocks are abundant in Leguminosae, Annonaceae, Euphorbiaceae, Lauraceae, Myristicaceae, Rubiaceae and Sapotaceae (WHITMORE 1990).

The floristic dissimilarity between the two West African sites is illustrated by the comparison of the Shannon indices, which combine species richness and abundance. The higher diversity of the Comoé site over the Ouémé site can be attributed to the regional flora and vegetation diversity. Benin is located in 'the Dahomey gap', a discontinuity of the West African rain forest belt, which is the product of erratic rainfall, topographic and oceanographic interactions (JENIK 1994). This gap includes essentially the drier types of the Guineo-Congolian forest belt in South-Eastern Ghana, Southern Togo and parts of Southern Benin (ERN 1988). So in Benin, savanna and agro-ecosystems are widespread, and gallery forests are always among the most dense and diverse vegetation formations (NATTA *et al.* 2002). Côte d'Ivoire is a major rain forest country in West Africa with a much more diversified vegetation and flora than Benin. Due to their elevated moisture regime (compared to adjacent regions), GFs in the South of the CNP enable the establishment and persistence of plant species from wetter zones such as evergreen rain forests from lower latitudes in Côte d'Ivoire (POREMBSKI 2001). At both sites, species characteristic for river front and central portion of GF were *Cynometra megalophylla, Dialium guineense, Cassipourea congoensis, Syzygium guineense* and *Parinari congensis*, while *Pterocarpus santalinoides* is particularly abundant along the Ouémé. For the Benin riparian forests, *Pterocarpus santalinoides* is the most common species at all latitudes (NATTA *et al*., in prep.).

The Ouémé and Comoé GFs act as outpost for certain species (e.g. *Dialium guineense, Drypetes floribunda, Diospyros abyssinica, Holarrhena floribunda, Fagara zanthoxyloides, Ceiba pentandra, Celtis* spp*., Mallotus oppositifolius, Spathodea campanulata, Elaeis guineensis*, *Albizia* spp., etc.) which occur in humid forest on plateau between 8° and 9º N or which can be found under more humid climatic conditions in the rain forest region of Southern Côte d'Ivoire. The presence of these species substantiates some hypotheses on the ecological importance of these hygrophilous and edaphically controlled forest formations. They play an important role as migration channels, which provide opportunities for genetic exchange between geographically isolated populations. In many seasonally dry regions, but also in formerly forested rain forest areas, gallery forests possess the character of a refugium for plants and animals (POREMBSKI 2001). FORMAN & GODRON (1986) have documented the importance of gallery forests as routes for movement of plants and terrestrial animals across the landscape. For MEDLEY (1992), gallery forests are the most suitable vegetation for plant species adapted to a moist climatic regime. Tropical riparian forest fragments represent plausible refugia for forest species in fire-prone landscapes, and are known for their potential, albeit limited, to act as safe sites for tropical rain forest species (KELLMAN & TACKABERRY 1993, KELLMAN *et al.* 1994, MEAVE & KELLMAN 1994, KELLMAN & MEAVE 1997).

Cynometra megalophylla, a typical riverine forest species, is the most frequent and dominant species at the riverside and in the middle of GF in the two sites. It may occur occasionally in other forest types (KEAY & HEPPER 1964, HALL & SWAINE 1981). In Benin, apart from riparian forests, this species is dominant only in a periodically flooded forest on vertisol (dark-clayey soil), the Lama forest (AGBANI 2002). Concerning absolute density and basal area *Cynometra megalophylla* accounted for 9 to 16 %, and 26 to 33 %, respectively in the two sites. In fact, the dominance of a group or a single species is not a new phenomenon within tropical forest in general, and GFs in particular. According to WOLTER (1993) cited by SONKÉ & LEJOLY (1998), dominant species can comprise up to 58 % of the total individuals and 75 % of the basal area. In Benin, 9 tree species (*Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Dialium guineense, Berlinia grandiflora, Cynometra megalophylla, Elaeis guineensis, Diospyros mespiliformis* and *Uapaca togoensis*) out of 224 contribute to 46.3 % of the total abundance and occupy 55.3 % of the total basal area. *Pterocarpus santalinoides* alone contributes to 14.8 % and 12.8 % of total abundance and basal area respectively (Natta *et al*., in prep). In a riparian forest of Belize, MEAVE & KELLMAN (1994) found that the seven most abundant species (2.4% of the species richness) account for 1/3 of the total number of stems.

At least three reasons might explain the dominance of *Cynometra megalophylla* at the two GF sites. Firstly, mono-dominance may develop if disturbance does not occur over long periods and if the regional pool of shade tolerant species is limited (HART 1990). Secondly, according to POREMBSKI (2001), this species may possess particular competitive traits in the specific abiotic conditions of a GF. Thirdly field data show that *Cynometra megalophylla* occurs along larger waterways South of 9º10' N (latitude of Bétérou in Central Benin, see NATTA *et al*., in press Chapter 6) and as far North as Ferkéssédougou (9º30' N) in Northern

Côte d'Ivoire (AKÉ ASSI, pers. comm.). This species seems to reach its optimal ecological range in the Guinean zone and in sub-humid areas along rivers. It is hypothesized that frequent or lasting environmental stresses, such as floods, result to a decrease in species diversity (at least for trees), which in turn will lead to the increased abundance and dominance of those species that can successfully maintain themselves in isolated or harsh sites. HANSON *et al.* (1990) described a similar phenomenon in GF patches along rivers in the upper mid-West of the Iowa river (USA). The dominant species along waterways are seen as keystone species and intrinsic components in the functioning of complex and self-organizing riparian ecosystems. They are generally essential for ecosystem resilience (FOLKE *et al.* 1996). The phenomenon of dominance by a few or single species should also be investigated from the viewpoint of micro-climatic and soils conditions.

The plots situated at the forest/savanna boundary were distinguished from the middle of GF and riverside by their physiognomy and structure (i.e. height, diameter, basal area of trees), floristic composition and species richness; but with contrasting trends between the two sites. Along the Ouémé river there is a constant decrease of the number of individuals, tree species, basal area and Shannon indices (H') from the "riverside' to 'middle' of GF ending at the 'savanna edge'. At the Comoé site, the number of individuals and species are highest at savanna edges whilst average tree height, diameter and basal area are highest in the 'middle of GF and at 'river edge'. Surprisingly, the difference between the three plot types concerning tree species diversity (*H'*) was not statistically significant at both sites.

At both sites, the GF/savanna contact is made through a belt of either light demanding species such as *Anogeissus leiocarpus, Mitragyna inermis, Alchornea cordifolia* (POILECOT *et al.* 1991, POREMBSKI 2001) or species from dense semi-deciduous and open forest (*Pouteria alnifolia, Ceiba pentandra, Albizia* spp. and *Antiaris toxicaria*). Light regime and flood frequency somehow play an important role for GF edge communities. From the trends detected here, the assumption that a gradient of environmental variables (e.g. moisture, light) influences the distribution and frequency of tree and shrubs species within GF hold true. More detailed data about microclimate and edaphic conditions, as well as seedling establishment, growth, light demand, and other ecological factors for typical GF and savanna boundary species, would enable to draw more definitive conclusions. The present study illustrates the complex variability of ecological processes within gallery forest and between gallery forest and the adjacent savanna.

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Chapter 10

ASSESSING THE DENSITY OF *KHAYA* SPECIES THROUGH SIMPLE RANDOM SAMPLING, STRATIFIED SAMPLING AND SYSTEMATIC SAMPLING

Natta A.K., de Gier A. and van der Maesen L.J.G.

Chapter 10

ASSESSING THE DENSITY OF *KHAYA* SPECIES THROUGH SIMPLE RANDOM SAMPLING, STRATIFIED SAMPLING AND SYSTEMATIC SAMPLING

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ABSTRACT

Three sampling designs (i.e. Simple Random, Stratified and Systematic) were used to estimate the density of *Khaya senegalensis* and *K. grandifoliola* trees in the Pénéssoulou forest reserve (Central Benin). For both *Khaya* species, stratified random sampling provided the lowest variance, coefficient of variation, standard error, and sampling error, thus was taken as the most precise and reliable design over simple random and systematic samplings. Densities of trees per ha (dbh ≥ 10 cm) were 5.4 ± 1.9, and 2.3 ± 1.1 for *Khaya senegalensis* and *K. grandifoliola* respectively. Stratification with proportional allocation of sampling units has proven valuable in providing precise and reliable density estimates in the study area. On the contrary, systematic sampling gave the least precise and reliable estimates. Other things being equal we recommend stratified random sampling for the assessment of population estimates of *Khaya* trees in the Pénéssoulou reserve forest. Results have confirmed empirical knowledge about the ecology of *Khaya* species and shown that the selection of the most precise sampling design, with regards to estimating a given parameter, can be useful for the sustainable management of forest trees in the study area. Meanwhile the assessment of the properties of more complicated sampling designs, such as adaptive sampling and distance sampling, could bring out issues not covered or revealed by the three conventional methods that were applied here.

Key words: sampling designs, endangered species, *Khaya senegalensis, Khaya grandifoliola*, density, Pénéssoulou forest, Benin.

10.1. INTRODUCTION

Khaya senegalensis (Desv.) A. Juss. and *K. grandifoliola* C. DC. (Meliaceae) are among the most best-known endangered species in the West African savanna and pre-forest regions. They are very important for the local economy in the whole West African region. They are well-known for their good timber, fuel wood and charcoal quality (Eyog Matig *et al.* 2002), medicinal values (Kerharo & Adam 1974, Berhaut 1979, Adjanohoun *et al*. 1989, Keita *et al*. 1999, Sokpon & Ouinsavi 2002), as well as for the high nutritive value of their leaves as livestock fodder (Sinsin 1991, Touré 1991, Meurer 1994). Overexploitation of natural stands, weak recruitment of seedlings, and habitats degradation have resulted in a high level of threat and genetic erosion. These two species of *Khaya* are classified among those threatened most on a world scale (Oldfield *et al*. 1998). They are mostly found in riparian forests in the savanna regions, but also in semi-deciduous forest and forest outliers, and Northern limits of the Guinea and Congo rain forest blocks (Keay & Hepper 1958). In the Ibadan region and in

Southern Kaduna State (Nigeria), the two *Khaya* species were once dominant in riparian forests (Onochie 1979).

K. senegalensis (also called dry-zone mahogany, or Acajou wood), with a shining foliage, has a wide range up to the Sahelo-Sudanian region in West Africa. In Benin, it spreads from 8°N to the far Northern part, but has disappeared from many natural stands in the guineo-congolese zone (see Sinsin *et al.* 2002a). It usually grows on clayey-silty or sandy-silty soils. *K. senegalensis* constitutes the first timber species for Sudano-Sahelian countries (Eyog Matig *et al.* 2002), and has the highest conservation priority ranking for five West African countries: Benin, Togo, Ghana, Niger and Chad (Adjanohoun *et al.* 1989, Eyog Matig *et al.* 2001). It also contributes to the cure of 55 diseases in Benin (Sokpon & Ouinsavi 2002). Meanwhile, missing regeneration indicate that *K. senegalensis* stands are jeopardised in several sites, particularly in North Benin (Sinsin *et al.* 2002a). Also the practice of roadside plantation of *K. senegalensis*, promoted during colonial times for shade and landscape beautification, has all but ceased in West Africa. The remaining trees are heavily lopped for fodder and damaged for the medicinal bark. On the other hand, *K. grandifoliola* is a large forest tree, and an important timber tree occurring more frequently in dry semi-deciduous forest and forest outliers (Guillaumet & Adjanohoun 1971). It does not extend beyond the Sudano-Guinean zone (Aubreville 1950). This species seems to reach its optimal growth in riparian and deciduous forests in the Bassila and Djougou regions (Central Benin).

Current management activities of the endangered species of Benin in general, and *Khaya* species in particular, is hampered by lack of knowledge about the spatial distribution, and structure related parameters. The Project Flora of Benin has set as major objectives to contribute in filling the gap of knowledge on vegetation formations, as well as the distribution, structure and threats of most Benin's plants. Although endangered, little is known about the distribution and occurrence of *Khaya* species in Benin. Apart from ethno-botanical studies, there are only a few publications on *Khaya* species in Benin. Sinsin *et al.* (2002a) have documented the spatial distribution of *Khaya senegalensis* in Benin, and linked the distribution map to levels of human disturbance. So far no distribution map have been published for *Khaya grandifoliola*. Not only the spatial distribution of the two species still needs to be fully investigated, but also there is no comprehensive and reliable study on density estimation of *Khaya* species in various ecological regions in Benin.

To estimate a given parameter, it is now acknowledged by scientists and forest resource managers that it is desirable to select an efficient sampling design that provides precise estimates. This can eventually be used in conservation or sustainable harvest planning. Likewise the selection of candidate sampling methods must fulfil certain requirements related to the target species and study area characteristics. To study *Khaya* species we have selected one of the least degraded protected forests, which provides good ecological conditions for the two species. The driving mechanisms of the spatial organisation of the two *Khaya* species are mostly unknown in the country, and as yet unpredictable in the selected study area.

If we assume that the distribution of these species is random, simple random sampling can be applied to be representative of the whole population. This design is the base of most field survey designs, and is also commonly used as a basis of comparison. Also it is sometimes convenient to apply sampling designs that are easy to draw and execute, and that ensures a uniform (i.e. even) coverage of sampling points throughout the whole study area. Therefore systematic sampling was applied. As the study area is relatively flat, we assume that the systematic layout of sampling points is not related to a periodic variation of ecological factors or vegetation types. On the other hand, the vegetation map of the study area allowed us to divide the population into homogeneous and non-overlapping vegetation types (riparian forests, open and dry forests, and savanna), each one having its own characteristics. The assumption here is that the distribution of the target species may be related to one or more strata, hence stratified random sampling could be more efficient. The stratification of the study area is also suggested by empirical knowledge about optimal vegetation type for each *Khaya* species (Keay & Hepper 1958, Aubreville 1950, personal observations).

This study aims at estimating the density and assessing the precision of population estimates of two *Khaya* species through three conventional sampling designs, simple random, systematic and stratified random samplings. A research question is put: what are the densities of *Khaya* species, and which sampling design provides the most precise population estimates? Results from this study are intended to improve knowledge of the ecology of *Khaya* species, and eventually to sustainably manage the remaining natural stands in the area.

10.2. METHODS

10.2.1. Study area

The Pénéssoulou forest (Figure 10.1) was selected for several reasons. It is located in the Sudano-Guinean zone of the Bassila district (Centre West Benin), which is the westernmost part of the semi-deciduous forest, fire-subtype in the sense of Hall & Swaine (1981). According to Adjanohoun *et al.* (1989), the climate of the region is transitional between the subequatorial climate of the Guinean region (South Benin), and the Sudanian climate (North Benin). It is characterised by progressive fusion of the two peaks of rainfall typical of the subequatorial climate. There are two seasons: a rainy season from mid-April to end-October, and a dry season from end-October to mid-April. Annual rainfall ranges between 1100 and 1300 mm/year, and average temperature from 26 to 32º C. The relative humidity varies from 15 to 99 % in the dry and rainy seasons respectively. The mean annual insolation is 2420 hours, and the average annual Potential Evapotranspiration is 1536 mm. The relief is flat with gentle slopes. This hygrophile enclave stretches out to Central Togo and Central and South East Ghana (Adjanohoun *et al.* 1989). Forests in the Bassila region are floristically diverse with a emergent stratum, 20 to 25 m high, where species such as *Khaya grandifoliola, K. senegalensis, Zanha golungensis, Cola gigantea, Albizia* spp., *Holoptelia grandis, Antiaris toxicaria, Milicia excelsa, Vitex doniana, Diospyros mespiliformis, Clesitopholis patens, Dalbergiella welwitschii* and *Anogeissus leiocarpus* are frequent (PRRF 1998).

Until recently, the whole district was among the least disturbed forest zones of Benin, but now deforestation due to timber gathering is alarming (PRRF 1998, personal observations). Selective tree cutting has resulted in the disappearance of most large specimens of timber trees (e.g. *Khaya* spp., *Antiaris toxicaria, Milicia excelsa, Afzelia africana, Prosopis africana*). People now have turned to less valuable savanna trees, such as *Isoberlinia doka* and *I. tomentosa*. Within the Bassila region, the Pénéssoulou reserve forest is well known for its dense riparian forest network, which occupies 13% of the total area of the forest, and is the most dense vegetation formation (PRRF 1998). The two *Khaya* species seem to reach their optimal growth in the Sudano-Guinean zone where this protected area is situated. Also, since 1998 the Pénéssoulou reserve forest experiences a management plan in partnership with local populations. We noticed that current management activities appear to have proven efficient in controlling poaching, trapping, fire, and encroaching cultivation. Other things being equal, this protected forest, which provides good conditions for the survival of *Khaya* stands, was selected for the present study.

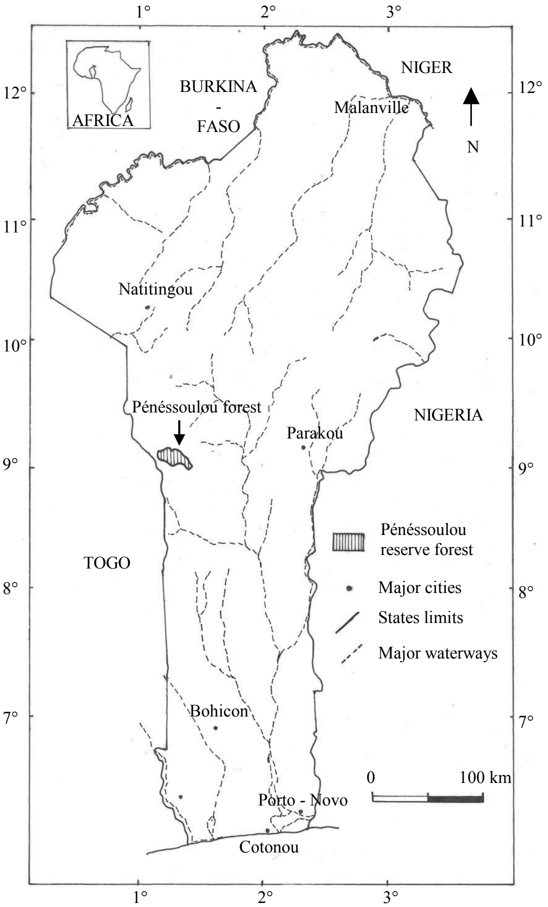

Figure 10.1: The Pénéssoulou forest reserve in Benin.

The Pénéssoulou forest covers some 5470 ha, from which a rectangular area (Figure 10.2), 1 km large and 3.6 km long (i.e. 360 ha or 6.6% of the protected forest), was surveyed in that is known to be the densely wooded and least disturbed part.

10.2.2. Sampling designs and field procedures

Three conventional sampling designs (Simple Random, Stratified and Systematic) were used to estimate tree densities. The population consisted of 9,000 plots from which 180 were actually selected and surveyed. Plot centres were located in the terrain through a GPS, a clinometer, and tapes. Slope-corrected rectangular plots of 400 m^2 were used. In each plot, the diameter of all *Khaya* trees (i.e. dbh ≥ 10 cm) was measured. Field procedures were specific to each sampling design.

Simple random sampling (SRS) is the base of most sampling designs and is widely applied in forest resources inventory. Most other sampling procedures that are designated to achieve greater economy and precision are modification of SRS. The central idea behind SRS is the equal probability selection, i.e. every possible combination of *n* units is equally likely to be the sample selected. The estimates of population mean and variance are design-unbiased, as they do not depend on any assumptions about the population itself (Cochran

1977, Freese 1990, Thompson 1992, Ott & Longnecker 2001). 180 out of 9000 plots were randomly selected without replacement from their x and y coordinates on the study area map, and then located accurately in the field. The recorded characteristic in each sampling unit is the number of stems of *Khaya* trees.

Units in a systematic sampling (SS) are selected according to a pre-specified pattern throughout the population. Here the study site is divided in 90 blocks, each containing 100 plots. Two starting points were randomly selected in the first block, resulting in two sets (primary units) of systematically selected plots. Therefore 180 plots (secondary units) were surveyed under the systematic design. The chosen design permits the calculation of means and standard deviations. All properties of estimates are obtained based on the design by which the sample of primary units is selected (Thompson 1992).

In stratified random sampling (StRS), the population is divided in strata on the basis of similarity of some characteristics, here vegetation types. The underlying assumption was that the variable of interest (tree density) was related to the different strata. The vegetation map of the Pénéssoulou forest (Figure 10.2), which is derived from satellite images from 1998, was used to determine the size of each vegetation type. The three vegetation types were proportionally sampled with regards to their size (Table 10.1). Within each stratum, a random sample without replacement has been independently selected, and estimates computed per stratum. The strata estimates are combined to give a population estimates. StRS usually offers two major advantages over SRS: it provides separate estimates of the mean and variance of each stratum, and for a given sampling intensity, it often gives more precise estimates of the population parameters than would a SRS of the same size.

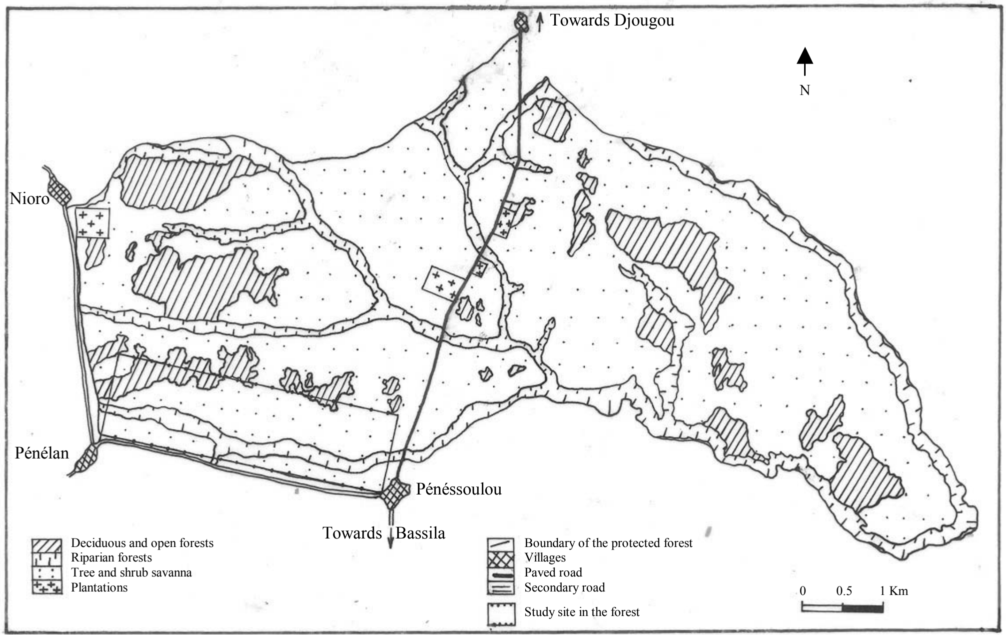

Figure 10.2: Location of the study site in the Pénéssoulou forest (From PRRF/Bassila, 1998)

Table 10.1: Vegetation types and plot characteristics in the study area

Vegetation types (or strata)	Plots in the site	Percentage (%)	Simple Random Sampling (SRS)	Stratified Random Sampling (StRS)	Systematic Sampling (SS)
Riparian forests	1620	18	-	32	-
Dry & open forests	1800	20	-	36	-
Savanna	5580	62	-	112	-
Total	9000	100	180	180	180

10.2.3. Assessment of the precision of population estimates

Many authors have used or suggested various estimators (e.g. variance, variance ratio, standard error, sampling error, coefficient of variation, etc.) to compare sampling designs and assess their relative precision, reliability, accuracy or efficiency. An unbiased estimate of variability can be used to assess the reliability of a survey result. Along with getting unbiased estimates come goals of precise or low variance and procedure that are convenient or cost-effective to carry out. Standard error, or standard error of the means is considered as the standard deviation among sample means. It gives an indication of the reliability of the mean: the smaller its value, the more reliable the mean. As pointed out by Cochran (1977) and Ott & Longnecker (2001), standard error of the population mean and total can be used to estimate the precision actually attained in a survey that has been completed, compare the precision obtained by SRS with that given by other sampling methods, or indicate how accurate any estimate should be. Likewise confidence intervals (t*standard error) are used to assess the accuracy of the computed estimate (Thompson 1992).

Likewise, the ratio of the variance, also called design effect by Kish (1965), obtained from any sampling design over the one obtained from SRS for the same number of units, is used in appraising the efficiency of sampling designs. The coefficient of variation is the standard deviation expressed as a percentage of the mean. It is often used as an index of process or population variability (Ott & Longnecker 2001). According to Snedecor & Cochran (1989), one may judge the success of a statistics, evaluate experiments or compare populations by looking at the coefficient of variation.

For Cochran (1977) better precision or lower variance is sometimes reached while minimising the cost, expressed as time or money to locate and enumerate sampling points. As the objective of study was not to assess the efficiency (i.e. lowest variance for a given cost) of the three sampling designs, time involved in data collection was not measured. However, we have used the same number of sampling units (i.e. 180) for the three designs, and have assumed that locating and enumerating these sampling units for the 3 designs cost the same time.

Following the authors cited above, we used five estimators (i.e. variance, variance ratio, standard and sampling errors, and coefficient of variation) to compare the precision and reliability of the three designs with regards to density estimation. They were selected because of their well-known utility. Ample explanations and more complicated issues related to the five estimators are provided by classical and specialised statistical publications. Generally the lower (or smaller) the variance, variance ratio, standard and sampling errors, or coefficient of variation, obtained from a given sampling design, the more reliable and precise is the estimated parameter. The combination of two or more lowest values of the selected estimators is much sough-after, and indicates the potential of a sampling design as being the most reliable and/or precise.

The formulae that were used to estimate population mean, density, total, variance, variance ratio, standard error of the mean, sampling error, coefficient of variation (see Table

10.2) are given by Cochran (1977), Snedecor & Cochran 1989, Freese 1990, Thompson (1992), and Ott & Longnecker (2001).

10.2.4. Data processing

Data were processed through Excel, using the formulae given in Table 10.2.

Table 10.2: Unbiased estimators of population parameters from Simple Random Sampling (SRS), Stratified Random Sampling (StRS) and Systematic Sampling (SS).

Estimators	Simple Random Sampling (SRS)	Stratified Random Sampling (StRS)	Systematic Sampling (SS)
Mean/plot	$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i$	$\overline{X}_{st} = \frac{1}{N}\sum_{h=1}^{L} N_h \overline{x}_h$	$\overline{y} = \frac{1}{Mn}\sum_{i=1}^{n} y_i$
Variance	$S^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{X})^2}{n-1}$	$S^2(\overline{y}_{st}) = \frac{1}{N^2}\sum_{h=1}^{L} N_h (N_h - n_h)\frac{S_h^2}{n_h}$	$\mathrm{var}\,\overline{y} = \frac{N-n}{M^2 Nn} * \frac{\sum_{i=1}^{n}(y_i - M\overline{y})^2}{n-1}$
Variance ratio (design effect)	$S^2/S^2 = 1$	$S^2(\overline{y}_{st})/S^2$	$\mathrm{var}\,\overline{y}/S^2$
Standard error	$S_{\overline{X}} = \sqrt{\frac{S^2}{n} * \left(1 - \frac{n}{N}\right)}$	$S_{\overline{X}_{st}} = \sqrt{\frac{1}{N^2} * \sum_{h=1}^{L}\left[\frac{N_h^2 S_h^2}{n_h}\left(1 - \frac{n_h}{N_h}\right)\right]}$	$S_{\overline{X}} = \sqrt{\frac{S^2}{n} * \left(1 - \frac{n}{N}\right)}$
Sampling error (*)	$(t * S_{\overline{X}})/\overline{x} * 100\,\%$	$(t * S_{\overline{X}_{st}})/\overline{x}_{st} * 100$	$(t * S_{\overline{X}})/\overline{x} * 100\,\%$
Coefficient of variation	$CV = \frac{s}{\overline{x}} * 100\,\%$	$CV = \frac{s}{\overline{x}} * 100\,\%$	$CV = \frac{s}{\overline{x}} * 100\,\%$
Density/ha	$\overline{x} \pm t * S\overline{x}(ha)$	$\overline{x}_{st} \pm t * S\overline{x}_{st}(ha)$	$\overline{x} \pm t * S\overline{x}(ha)$
Total (i.e. 360 ha for the study area)	$\overline{x} \pm t * S\overline{x}(360\,ha)$	$\overline{x}_{st} \pm t * S\overline{x}_{st}(360\,ha)$	$\overline{x} \pm t * S\overline{x}(360\,ha)$

(*) All confidence intervals are calculated at probability level of 0.05.

10.3. RESULTS

Outputs from the three sampling designs are summarised in Tables 10.3 and 10.4 for *Khaya senegalensis* and *K. grandifoliola*, respectively. For *Khaya senegalensis*, stratification resulted in the lowest variance (0.001), ratio variance (0.004), coefficient of variation (18.55 %), standard error (0.040), and sampling error (36.36 %). Therefore it gave the most precise estimate of the population density (i.e. 5.4 ±1.9 trees/ha), and total (i.e. 1945 ± 707 trees/360 ha). Mean and variance per stratum show the absence of *Khaya senegalensis* in riparian forests in the study area.

With *Khaya grandifoliola*, stratification gave also the lowest variance (0.0006), ratio variance (0.001), coefficient of variation (25.62 %), and standard error (0.024). The sampling error from StRS was a bit higher (50.2 %) than the one obtained from SRS (47.6 %), and this is related to a smaller value of the mean (i.e. 0.095) obtained with StRS compared to 0.172 from SRS. A close look at the formula of sampling error (see Table 10.2) shows that for a given t-value and standard error: the smaller the mean, the higher the sampling error. This is actually the case as: sampling error (StRS) = 1.059*sampling error (SRS). The lowest stratified mean results from the fact that *K. grandifoliola* is absent from the savannas, which occupy 62 % of the study area. Therefore the mean/plot in savanna is null and this has lowered the overall stratified mean/plot. Because it provided the lowest values for variance, ratio variance, coefficient of variation and standard error (4 estimators over 5), StRS was taken as the most precise sampling for the estimation of *K. grandifoliola* density. Therefore the most precise estimate of population density and total for *K. grandifoliola* were 2.3 ± 1.1 trees/ha, and 855 ± 429 trees/360ha respectively.

SS appeared to be, in both cases, the least precise sampling design, as in all cases it gave the highest variance, variance ratio, standard error, sampling error and coefficient of variation.

Table 10.3: Results from the three sampling designs for *Khaya senegalensis*

Estimated parameters	Simple Random Sampling (SRS)	Stratified Random Sampling (StRS)	Systematic Sampling (SS)
Mean/plot (0.004 ha)	0.211	0.216 Stratified mean 0.000 (riparian forests) 0.250 (dry, open forests) 0.267 (savanna)	0.270
Variance	0.379	0.001 Stratified variance 0.000 (riparian forests) 0.364 (dry, open forests) 0.360 (savanna)	6.396
Ratio of variance (design effect)	1	0.004	16.844
Density/ha (*)	5.2 ± 2.2	5.4 ± 1.9	6.8
Total abundance (360 ha)	1900 ± 802	1945 ± 707	2450
Coefficient of variation in %	291.9	18.55	929.09
Standard error of the mean	0.045	0.040	1.770
Sampling error in % (*)	42.21	36.36	1274.72

* 95% confidence interval

Table 10.4: Results from the three sampling designs for *Khaya grandifoliola*

Estimated parameters	Simple Random Sampling (SRS)	Stratified Random Sampling (StRS)	Systematic Sampling (SS)
Mean/plot (0.004 ha)	0.172	0.095 Stratified mean 0.250 (riparian forests) 0.250 (dry, open forests) 0.000 (savanna)	0.160
Variance	0.3221	0.0006 Stratified variance 0.3226 (riparian forests) 0.2500 (dry, open forests) 0.0000 (savanna)	2.0897
Ratio of variance (design effect)	1	0.001	6.487
Density/ha (*)	4.3 ± 2.05	2.3 ± 1.1	3.9
Total abundance (360 ha)	1550 ± 738	855 ± 429	1400
Coefficient of variation in %	329.55	25.62	929.3
Standard error of the mean	0.041	0.024	1.011
Sampling error in % (*)	47.66	50.21	1275

(*) 95% confidence interval

10.4. DISCUSSION

Considerable study is often required to be able to select the proper design for a given problem in a given situation. So far such a study, comparing several sampling designs, is the first one done in the Pénéssoulou reserve forest.

Own data collected in several riparian forest sites throughout the country showed that densities of *Khaya* species varied from 1.6 to 18 trees/ha, and 5 to 13 trees/ha for *Khaya senegalensis* and *K. grandifoliola*, respectively. *Khaya grandifoliola* is meanly encountered in the Bassila region, where the Pénéssoulou forest is located. We could not compare our results with other similar studies in various vegetation types in Benin, as published data are non-existent.

Field observations confirm empirical knowledge about the ecology of the two *Khaya* species in the study area. *Khaya senegalensis* is not observed in riparian forests, the wettest vegetation type in the study area. This suggests that *K. senegalensis* favours less humid conditions such as savannas and open forests. On the contrary *Khaya grandifoliola* is not observed in savanna because it favours wetter vegetation types. Therefore, values for mean densities of *Khaya* species can be misleading if they are not linked to the ecological preferences of each species. Although we have not collected data on the regeneration of these species, observations throughout the whole country suggest that the study area with its current management activities, is comparatively well-off, and has a great potential for the long term conservation of *Khaya* species.

For both species, StRS gave the lowest values for all the five estimators for *K. senegalensis*, and four out of five (i.e. variance, variance ratio, coefficient of variation and standard error) for *K. grandifoliola*. Considering variance ratio, stratification has reduced the variance obtained from SRS to about 235 and 545 times for *K. senegalensis* and *K. grandifoliola*, respectively. Generally the reduction of sampling variation is obtained by sub-dividing the population into relatively homogeneous strata. But the efficacy of stratification depends on foreknowledge of the behaviour of experimental material (Snedecor & Cochran 1989.), i.e. an expected relationship between stem density and vegetation type for the species concerned. We have used a recent vegetation map (from 1998), and stratification of the study area in three vegetation types appeared to be effective, in comparison to SRS and far better than SS, for the same number of sampling units. If we assume that 180 sampling units of the three designs cost the same in time to locate and enumerate, then the designs can be compared for efficiency. Under this assumption, we might say that StRS is also more efficient than SRS and SS. Additional field investigations will provide new insights in this issue.

Although relatively easy to draw, to execute, and to control, the coverage of the whole population in a systematic way is not a guarantee for a better precision of *Khaya* species density. The performance of SS in relation to that of StRS or SRS is greatly dependent on the properties of the population (e.g. observations/items in random order, with linear trend, stratification effects, periodic variation, auto correlated, or unpredictable) (Cochran 1977). Following this author we might say that it is difficult to give general advice about the situations in which SS is to be recommended in the study area, because the specific properties of the *Khaya* species are not yet well known. From the data available, the vegetation map and our own knowledge of the study area, we could not yet detect any particular property of *Khaya* populations. Further research should document this issue.

Once a particular distribution pattern or population property is suspected or has been detected, appropriate surveys designated to getting more precise and cost-efficient estimates are available. It is now acknowledged that if a species is known or can be expected to cluster (*i.e.* gregarious distribution of individuals), more efficient adaptive sampling designs are available (Thompson 1992, Thompson & Seber 1996). Also, distance sampling provides biologists with a powerful yet practical method for estimating density of various populations, including plant populations (Buckland *et al*. 1993).

The approach followed here for *Khaya* species can be tested with other valuable timber trees, such as *Milicia excelsa, Antiaris toxicaria, Afzelia africana*, *Vitex doniana, Diospyros mespiliformis, Albizia* spp., *Anogeissus leiocarpus, Pterocarpus erinaceus, Holoptelea grandis*, etc. Therefore we could get consistent results for most of the timber tree in the study area. Starting from 1998, the Pénéssoulou protected forest management plan has set as objective to harvest 30% of the increment of wood on the basis of a 10 year rotation. Knowledge on the reliability of species density and precision of sampling designs can eventually be useful for the management of tree populations in the study area, if consistent results are obtained for other timber species. Although the Pénéssoulou protected forest management plan has specified the attributions of each stakeholder, there is still room to improve current and future management activities (e.g. number of trees to be harvested).

10.5. CONCLUSION

The present study facilitates the choice between several sampling designs for the estimation of the density of *Khaya* species, which are endangered in Benin. In the study area, StRS with proportional allocation of sampling units was the most precise sampling design in comparison to SRS and SS to estimate *Khaya* stem density. The mean densities/ha were 5.4 ± 1.9 and 2.3 ± 1.1 for *Khaya senegalensis* and *K. grandifoliola* trees, respectively ($p = 0.05$). Our results also have confirmed empirical knowledge about the ecology of the two *Khaya* species. If consistent results are also obtained for most timber trees in the study area, this may be helpful to manage (e.g. for sustainable harvest) the remaining natural stands of these valuable trees. Ongoing research should clarify several issues, such as the detection of population characteristics and the assessment of non-conventional sampling designs. This could bring out issues not covered by the three conventional sampling designs compared here.

Chapter 11

GENERAL DISCUSSION

A.K. Natta

Chapter 11

GENERAL DISCUSSION

11.1. CHARACTERISTICS OF RIPARIAN FORESTS

Riverine landscapes are heterogeneous, dynamic, and biologically and spatially complex (Ward *et al*. 2002). Within riverine landscapes, riparian forests (RFs) are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological process, and biota. They are portions of terrestrial ecosystems that influence exchanges of energy and matter between aquatic and uplands ecosystems (NRC 2002), and contribute to the diversity and function of both terrestrial and aquatic ecosystems (Acker *et al*. 2003). At all latitudes, riparian or streamside forests are recognized as distinct components of the landscape because of their unique ecotonal nature, linking aquatic and terrestrial ecosystems (Naiman & Décamps 1990, Gregory *et al*. 1991, Malanson 1993, Hancock *et al*. 1996, Cordes *et al*. 1997). They occupy areas of intense land-water interaction and are known to support concentrated and diverse assemblages of wildlife and plant species (Nilsson 1992, Naiman *et al.* 1993). This enhanced biodiversity is believed to be related to landscape mosaic, spatial heterogeneity, complex environmental gradients and unique natural disturbance regimes (Robinson *et al*. 2002), which instigate a wide variety and abundance of resources and substrates (Manuwal 1983, Knopf 1985, Szaro & Jakle 1985, Acker *et al*. 2003). As pointed out by Brinson (1990), RFs own their dynamics, structure, and composition to river processes of inundation, transport of sediments, hence the erosive forces of water.

The characteristic plant species, plant communities and associated aquatic or semi-aquatic animal species in RFs are intrinsically linked to the role of water as both agent of natural disturbance and as critical requirement of biota survival. Alternating environmental stress (Hancock *et al*. 1996), such as periodic flooding, is a form of disturbance to which many of the taxa occurring in riparian communities appear well adapted (Jongkind 1996), by sprouting from remaining root or trunk (e.g. *Pterocarpus santalinoides, Cola laurifolia, Syzygium guineense, Cynometra megalophylla*, personal observations). According to Acker *et al*. (2003), flooding apparently promotes complexity at the life form, species composition, and stand structural levels, thus the significance of channel constraint for severity of floods may be different in mountainous versus relatively flat terrain. Frequent floods are known to maintain the native riparian vegetation in a mosaic of different successional stages (Salo *et al*. 1986, Kalliola & Puhakka 1988, Naiman *et al*. 1993). Sediments deposited by floods can create initial seedbeds for germination, but also injure seedlings (Levine & Stromberg 2001). Research on the effects of flooding have shown that it increases wood and leaf decomposition rates, and sites that are flooded generally have a lower accumulation of organic matter (Bell & Sipp 1975, Bell *et al.* 1978, Peterson & Rolfe 1982, Shure *et al*. 1986, Ellis *et al*. 1999). As a result RFs tend to be very diverse in species composition and physical structure (Gregory *et al*. 1991).

Also, RFs at either waterway side are often related to gradients of environmental factors perpendicular to the stream, all linked with water availability. Changes in environmental factors across RFs are shown by: (a) decreasing humidity, soil moisture, nutrient level, productivity (Hancock *et al.* 1996, Ettema *et al.* 1999); (b) decreasing flood intensity, frequency and duration (Stromberg *et al.* 1993a, Hupp & Osterkamp 1996, Piegay & Bravard 1997, Swanson *et al.* 1998); and (c) increasing light availability (Dignan & Bren 2003).

In the West-African savanna region, riparian forests are the natural wooded vegetation types, of varying successional states, bordering (i.e. lining) fresh water bodies such as rivers, streams, brooks and lakes. Riparian forests occupy 2.37 % of Benin's the total area of the country, and dense deciduous and semi-deciduous forests 1.05 %. Therefore dense forests in Benin occupy some 3.42 % of total area of Benin (CENATEL 2001). Compared to the figure given by FAO in 1980 (i.e. 0.55 % for deciduous, semi-deciduous forests, and important riparian forests), the updated value seems more reliable because of computerised data collection, rectification and analysis of remotely sensed data. Yet, it shows how big the difference can be when various sources at different periods interpret and map tropical vegetations.

11.2. ECOLOGICAL IMPORTANCE

RFs are under the influence of fluvial and geomorphic processes (Baker 1990, Fetherston *et al.* 1995), and because of short- and long-term in waterways basin hydrological cycles, they are in constant state of adjustment, with different abiotic and biotic components adjusting with different lag-times, producing a complex-response situation (Cordes *et al.* 1997). Many authors have documented on dynamic processes within riparian ecosystems, and interactions of RFs with waterborne particles and chemicals, microbial assemblages, flood, flood plain, water table, climate and micro-climate, soils, local geology, channel morphology, topography and stream banks (Guillaumet 1967, Hall & Swaine 1976, 1981, Devineau 1975, 1984, van Rompaey 1993, Leinard *et al.* 1999, NRC 2002). The contribution of RFs to the functioning of rivers and biodiversity protection is recognised worldwide (Adjanohoun 1965, Baker 1990, Tabacchi *et al.* 1990, Polansky 1994, Lykke 1996). More than other vegetation types, they are well-known for their roles in controlling water runoff and quality, mineral nutrient flows, bank erosion and stabilisation, sedimentation, flood, air and soil pollution, water shading and cooling, sediment filtering, aquifer recharge, carbon storage, erosion control, etc. (Devineau 1984, Forman & Godron 1986, Gregory *et al.* 1991, Haycock *et al.* 1993, Harper *et al.* 1994, Large & Petts 1994, Forniss 1996, Mander *et al.* 1997, Aide & Rivera 1998).

The processes involved in water quality improvement are: sediment retention, preservation of the floodplain channels from excessive erosion, filtering and decomposition of nutrients and water pollutants (e.g. NO_3^-, see Willems *et al.* 1997, Groffman *et al.* 2001), improved soil water infiltration rates, etc. (Gilliam 1994, Lowrance *et al.* 1997, Trimble 1999). Riparian zones with various types of vegetation are reported to be effective in reducing, removing, or assimilating nutrients, coming from upslope agricultural field via shallow lateral flow (Peterjohn & Correl 1984, Pinay & Décamps 1988, Weller *et al.* 1994, Hefting & Klein 1998, Ettema *et al.* 1999). Here, the processes involved include reduced velocity of runoff flow, increased sedimentation of coarse particles, retention of suspended particles by leaf and the soil, plant uptake, microbial immobilisation, nitrification and denitrification (Lowrance *et al.* 1984, Ambus & Lowrance 1991, Groffman *et al.* 1991, Ambus & Christensen 1993). Contrasting results were found concerning denitrification in temperate countries: rates of denitrification in RFs were higher than in grassland zones (Hefting & Klein 1998, Haycock & Pinay 1993), and lower than in grassland (Groffman *et al.* 1991, Schnabel *et al.* 1996).

Maintaining biodiversity is one of the most important functions of RFs, which are, directly or indirectly, home to an abundance of animal life (e.g. fisheries, birds, invertebrates and micro-organisms, amphibian and reptiles, mammal species, etc.). For Johnson *et al.* (1977), riparian zones perform an essential and unique function in areas where water availability is limited. According to Thomas (1996), typical riparian forest tree species are dependent on river flows, a shallow aquifer, and the community and population structure of riparian forests are related to spatial and temporal patterns of flooding. In most cases, they do not occupy large areas (Varty 1990, Monnier 1990, Medley 1992), nevertheless they are important in the conservation of a large range of plants, animals, water sources, soils and watersheds. In the Amazon Basin, numerous streams and rivers provide huge potential for increasing the conservation value of deforested and fragmented landscape through the protection of linear remnants along waterways (de Lima & Gascon 1999). Not only do they constitute a natural habitat or the last refuge for many species, but also they lodge many endemic species and extinction-menaced species (Roggeri 1995), and usually act as routes for movement of terrestrial plants and animals across the landscape (Forman & Godron 1986).

Mature riparian forests are known to store large quantities of biomass (above ground, roots, litterfall, woody debris, soil carbon, submerged aquatic vegetation) than younger or degraded stages (Burke *et al.* 1999, Giese *et al.* 2003). RFs regulate inputs to streams, including solar radiation, dissolved nutrients, foliage and other food resources (Gregory *et al.* 1991), and large woods, which add to structural and biological diversity of streams by creating pools and other hydraulic features needed by many fishes, algae, and invertebrates (Sedell *et al.* 1988, Fetherston *et al.* 1995, Knutson & Nae 1997, Bragg & Kershner 1999).

All these fundamental and critical ecological functions that RFs perform better than uplands and aquatic ecosystems, fall into three major categories: (a) hydrology and sediments dynamics, (b) biogeochemistry and nutrient cycling, (c) species habitat diversity and food web maintenance.

11.3. PLANT COMMUNITIES DIVERSITY IN RIPARIAN FORESTS

In addition to being characterized by a variety of plant species, and unique assemblages of plants, compared to uplands and wetlands, RFs in Benin harbour a newly described rare and endemic ornamental Acanthaceae (*Thunbergia atacoriensis*), which is found along certain streams at hills feet. Compared to other tropical forests, such occurence is not negligible and cannot be underestimated within the Dahomey Gap.

The structural complexity and species richness of tropical forests make difficult their study by the traditional phytosociological procedures, but numerical methods have proved successful, especially in demonstrating correlations between vegetation and environmental factors in fairly small areas (Hall & Swaine 1976). Also studies utilising direct and indirect gradient analysis have shown that each plant species is distributed in a unique pattern in the landscape and that this pattern results from the interaction of each species with its physical and biological environment. As result, the composition of plant communities changes more or less continuously along environmental gradients as changing conditions cause species to enter or leave (Whittaker 1975).

The direct ordination technique based on environmental variables, does not recommend itself in the present study, which main interests are botany, phytosociology and ecology. Meanwhile, ongoing research should clarify this issue. In the meantime, indirect gradient analysis (here DCA) was applied and environmental gradients were inferred from species composition data. Also it is worthwhile noting that, sometimes classification of vegetation into communities or associations may obscure the true situation in the terrain that is characterised by gradual changes of the floristic composition of plant assemblages over environmental gradients.

Traditional methods of plant community ecology usually rely on the dominance of overstorey trees to define species associations and establish plant community boundaries, however, as shown by Sagers & Lyon (1997) species associations in the overstorey are not necessarily good predictors of understorey associations. To overcome this, we have taken all species of the least degraded relevés (presence/absence data file), and no species was downweighted in the classification analysis. Ordination and classification analyses provided evidence that RFs are structured along gradients relating to moisture, flood conditions, regional variations in climate and relief. These factors have created and maintained several riparian forests plant communities, some of which have not yet been described. Also, micro-topographic variations across waterways, created by diverse fluvial process, support floristic richness that would not otherwise occur. The repetitive plant assemblages in riparian forests are made of species that can tolerate greater water table and flow variation, physical disturbance, and hydric stress either due to drought or soil saturation.

Elsewhere, e.g. in riparian ecosystems of the South Western USA, salinity, disturbance from fire and community maturity were the most important gradients (Busch & Smith 1995). Also, the distribution of vegetation, in general and forests in particular, within riparian zones has been linked to numerous abiotic factors such as hydroperiod, floodplain landform and sediment types as well as to competition and life history factors (Medley 1992, Dunn & Stearns 1987, Nilsson *et al*. 1989, Hughes 1990). The type and severity of disturbance also have a major impact on the diversity of RFs plant communities. In East Gippsland in Victoria (Australia), Melick (1990) found that undisturbed riparian rain forests were the most species poor plant community, and disturbed ones the most species rich. In a riparian forest of the Buffalo National River (Arkansas, USA), species associations were influenced by environmental gradients dominated by pH and elevation, but secondary gradients differed among forest layers (Sagers & Lyon 1997).

Moreover dispersal (Skoglund 1990, Malanson 1993, Johansson *et al*. 1996, Malanson & Armstrong 1996), floating (Danvind & Nilsson 1997, Jansson *et al*. 2000a), as well as colonisation (Auble *et al*. 1997, Stromberg 1997) strategies of seeds in riparian ecosystems, and the ability of riverbanks to trap waterborne diaspores (Andersson *et al*. 2000), are known to influence patterns of species richness and abundance of RF and predict vegetation changes. However, diversity patterns of riparian plant community were found to be complicated, with contrasting relationships.

11.4. RIPARIAN FORESTS AND WILDLIFE CONSERVATION

Waterways and their dynamic forested banks are known to serve as a focal point for animals of many kinds. They host a diverse and abundant fauna of aquatic, terrestrial and amphibious species (Robinson *et al*. 2002). Also, studies in very different areas have documented the importance of riparian areas for birds, that these have typically different assemblages and higher species richness than neighbouring areas (Skagen *et al*. 1998, Rottenborn 1999, Saab 1999, Woinarski *et al*. 2000). The importance of RFs as critical, seasonally or temporary habitat for a variety of animals is reported by numerous authors (e.g. Knopf *et al*. 1988, Hunter 1990) and confirmed by our own field observations in Benin. The reproduction, growth and nutrition depend on the presence of more or less dense and safe stands of riparian forests: e.g. nesting in trees along streams and rivers, food consisting of fish or other aquatic animals from inundation plains near water courses.

In Benin, animals such as *Cephalophus rufilatus, Tragelaphus scriptus, Kobus defassa, Loxodonta africana africana, Python sebae, Crocodylus niloticus, Osteolamus tetrapis, Heliosciurus gambianus,* etc. very much like gallery forests and forests edges (Sinsin *et al*. 1997). Likewise *Cercopithecus mona, Cercopithecus nictitans*, *Cercopithecus diana* live in forest areas and large and dense galleries. *Cercopithecus erythrogaster erythrogaster*, the endemic primate found so far in Benin (Grubb *et al*. 1999, Sinsin *et al*. 2002b) shares a part of only its time in riparian forests and forest patches in the Ouémé valley region. Raynaud & Georgy (1969) reported that *Syncerus cafer nanus* that was usually seen in woodlands and humid sites in the South and Central Benin follows gallery forests up to the latitude of Djougou to Bembèrèkè. *Tragelaphus scriptus* and *Cephalophus rufilatus* main habitats are forests, its edges and gallery forests. *Limnotragus spekei* lives in humid or swampy areas, gallery forests and upland forests. *Cephalophus sylvicultor* lives in dense forest or large and dense galleries. *Phacochoerus aethiopicus* lives in groups in savannas, gallery and edges of forest. The *Potamochoerus porcus* was found in dense forest and Guinean savanna and gallery forests as far as in the W National Park along the Mékrou stream. Generally in regions where dense forest does not exist, riparian forests play the role of residual forest and provide, when they are undisturbed, the best conditions for wildlife that normally lives in forest zone.

In Central Africa, species such as squirrels (*Helioscirus gambianus* var. *punctatus, Protoxerus stangeri, Paraxerus poensis*), anomalure (*Anomalurops beecrofti, Anomalure derbianus*), and civet (*Nandinia binotata*) are mainly seen either in dense forest or RFs (Depiere & Vivien 1992). Likewise certain bird species (e.g. *Tigriornis leucolopha, Butorides striatus atricapillus, Hagedashia hagedash brevirostris, Stephanoaetus coronatus, Podica senegalensis, Tympanistria fraseri, Centropus monachus occidentalis, Musophaga violacea*) depend on RFs, dense forests or stream and river shores with periodic inundation for feeding and nesting.

Many studies on wildlife ecology highlight the potential of linear remnant forests along waterways to serve as habitat for small forest vertebrates and suggest they could function as corridors for some species to increase landscape connectivity (Forman 1997, Machtans *et al.* 1996). Examples are given by de Lima & Gascon (1999) in Central Amazonia for small mammal and litter-frog communities; Burbrink *et al.* (1998) in Illinois (USA) for frogs and lizards; Darveau *et al.* (2001) in the riparian zone of the Laurentian mountains (Québec) for small mammals. In the USA, RFs are much more important to bird communities than surrounding habitats because the vegetation is structurally complex and floristically diverse within the vertical and horizontal dimensions (Anderson & Ohmart 1977, Best *et al.* 1979, Hehnke & Stone 1979, Szaro 1980, Bull & Skovlin 1982, Szaro & Jakle 1985). It has also been shown that a mosaic of riparian woodlands, containing mixture of native tree and shrub species of different classes, is necessary to maintain avian species richness (Farley *et al.* 1994).

11.5. WATERWAYS ORDER AND SIZE RELATIONSHIP WITH RIPARIAN FOREST BIODIVERSITY

Outputs from the DCA and TWINSPAN suggest that waterways can be grouped into two types: large (= rivers) and small (= streams). Field observations also support this simplification of the reality. This analysis was based neither on measured environmental variables nor on previous floristic data and hydrographic network maps. Indeed, physical characteristics of streams vary from low to high order (Brierley & Hickin 1985, Forman & Godron 1986, Billy & Ward 1989), and RF characteristics are known to change with increasing stream order (Swanson & Lienkamper 1982, Swanson *et al.* 1982, Minshall *et al.* 1985, Nilsson *et al.* 1989). As pointed out by Gregory *et al.* (1991) and Naiman *et al.* (1992) stream size or order, is an important factor that determines the nature of interactions between geomorphology, fluvial and terrestrial disturbance, and riparian community characteristics. Diversity of RFs and their distinctiveness from upslope forests tend to increase with increasing stream size (Naiman *et al.* 1993). Therefore we expect concomitant changes in the flora and plant community structure, and associated animals.

In Benin, RFs along streams are more species rich than those along rivers. In South West Ghana, Jongkind (1996) found that the floristic difference between large rivers and small streams is striking, and this was probably caused by the much smaller seasonal changes in the water level and the absence of an open space above the water of the small streams (see also Devineau 1984 in Côte d'Ivoire). Similar stream order patterns were identified in numerous overseas studies. In South West of Western Australia, RFs along tributaries (low order streams) had higher species richness (at $p < 0.05$) than those along the largest river (higher order streams) (Hancock *et al.* 1996). This was related to the more intimate association between streamside and upland communities along first order streams due to less developed environmental gradient away from the usually ephemeral streams. In several RFs in the USA, Naiman *et al.* (1987) and Lock & Naiman (1998) found that bird communities on large rivers differ from those on small rivers and these differences occur predictably with stream order. Also deciduous vegetation and patch types appeared to be linked to river size through stream valley shape and disturbance history.

As waterways size and order have been shown to have a great impact on vegetation types as well as wild- and bird life, ongoing research in Benin should integrate several environmental (abiotic factors) variables (e.g. river order and size, sediment deposition, debris flow, position in the watershed, patch size, RFs width and elevation within the watershed, etc.) in multivariate analysis. Likewise, the concepts of ephemeral, perennial, and quasi-perennial waterways should be re-investigated from field observations (e.g. hill headwaters, stream related to hills, waterways on plateau with or no extended flood plains).

11.6. RIPARIAN FORESTS RELATIONSHIPS WITH UPLAND PLANT COMMUNITIES

RFs occur in various climatic, geomorphic, edaphic, hydroperiod and geographic settings, and have similar as well as contrasting features with surrounding upland plant communities, with regards to species composition, structure, and ecosystem diversity.

In most savanna regions, narrow bands of vegetation in the vicinity of the river contrast strongly with open forests and savanna woodlands which otherwise dominate the landscape (Woinarski *et al.* 2000). Numerous studies confirm not only the great richness of RFs over upland forests (Brinson 1990, Nilsson 1992, Nilsson *et al.* 1994, Spackman & Hughes 1995), but also that the structure of RFs is generally more complex than upland forests (Hancock *et al.* 1996, Melick & Ashton 1991). It is now accepted that RFs harbour more species of birds (Stauffer & Best 1980, Gates & Giffen 1991, McGarigal & McComb 1992, Larue *et al.* 1995, Whitaker & Montevecchi 1997), and mammals (Geier & Best 1980, Doyle 1990) than uplands habitats. Roché (1993) found bird species richness in riverine flood plains to be twice that in adjacent uplands, while Wakentin & Reed (1999) documented that the majority of bird species in arid regions of Great Basin (USA) are associated with riparian habitats. Also in the extensive natural landscape of Australia's tropical savanna, species richness and abundance of birds was significantly greater in riparian forests than in matched non-riparian areas, and riparian vegetations allow many species to extend their distributions into lower rainfall areas (Woinarski *et al.* 2000). The physical and vegetation characteristics of the streamside area differ from those upslope because of frequent inundation, soil saturation, and physical disturbance of streamside vegetation due to flood flows, mass soil movement, etc. (Brinson 1990, Gregory *et al.* 1991, Fetherston *et al.* 1995).

On the contrary, along the Helena River and its tributaries, and in the Grampians (Western Australia), RFs were generally less species rich than adjacent upland communities (Enright *et al.* 1994, Hancock *et al.* 1996). According to these authors their results were corroborated by other studies in other parts of Australia and South Africa (see Cowling & Holmes 1992), but not in Europe. RFs in the Oregon Coast Range are said to have lower tree density than upland stands (Gregory *et al.* 1990, Pabst & Spies 1999, Nierenberg & Hibbs 2000). Reasons of such richness pattern are not yet fully investigated.

Light penetration, which depends upon topographic position, slope and vegetation characteristics, plays a major role in the ecology of the riparian forest, and protection of the light environment is generally seen as an important function of buffers that aim to protect riparian habitat values (Barton *et al.* 1985, MacDougall & Kellman 1992, Dignan & Bren 2003). The ecotone between the riparian and upland vegetation may be very narrow or gradual depending on the fact that gradients are sharp or not. In the latter case it could be the site of highest species richness because of the presence of species from both communities (Tilman 1988, Hancock *et al.* 1996). In Benin, field observations show that RFs tree flora is not only more diverse, but also has marked differences in structure, abundance and composition with surrounding upland plant communities (e.g. in Yarpao, Pénéssoulou, Idadjo, etc.). However, this issue was not analysed with environmental data and numerical analysis of the whole floristic data. Therefore we could not yet draw any conclusion about the entire RF flora (i.e. trees, shrubs and herbaceous).

11.7. DEGRADATION OF RIPARIAN FORESTS

It is generally agreed that species extinction is largely related to the reduction and fragmentation of their habitats, therefore the protection of species can best be done through protecting habitats (Swaminathan 1990). So, a wide range of plants and animals will benefit from the protection of forest ecosystems along rivers and streams. Despite their importance to biodiversity in many countries, native RFs have been severely degraded. This is attributed to a variety of factors including dam construction, river channelisation, cattle ranching, agricultural development, and recreational development (Décamps *et al.* 1988, Knopf *et al.* 1988, Roods & Mahoney 1990, Busch & Smith 1993, Busch 1995, Braatne *et al.* 1996, Lonard *et al.* 2000). Dams and water diversions are known to modify surface flow rates, flood periodicity, and sediment and nutrient transport, often to the detriment of riparian plants (Jansson *et al.* 2000b, Levine & Stromberg 2001). When channelling occurs within riparian systems, removal of sediment and nutrients from surface runoff is less effective (Norris 1993).

Modification of the frequency, duration and intensity of floods, draining and lowering of floodplain water tables, contribute to change in RF communities (Stromberg *et al.* 1996, Crawford *et al.* 1996, Molles *et al.* 1998). As sites become drier, width of riparian corridor declines and species composition shifts from obligate and facultative wetland plants to those with xerophytic adaptations (Baker 1989, Szaro 1990), and changes in physiognomy and biomass may also occur, sometimes independently with compositional shifts (Stromberg *et al.* 1993b, Stromberg 2001). Many authors (e.g. Medina 1990, Stromberg & Patten 1990, Smith *et al.* 1991, Rood *et al.* 1995) observed that water reduction impact on riparian tree populations include lowered tree densities, loss of class diversity due to death of susceptible age classes, reduced reproductive output, increased seed size. Changes in water regime inhibit recruitment of native plants, and, thus create ‘functional gaps’ in riparian communities (Levine & Stromberg 2001).

Urbanisation on lands adjacent to intact riparian woodland has substantial impacts on riparian bird species richness, density, and community composition (Katibath 1984, Smith & Schaefer 1992, Cubbedge & Nilon 1993, Ohmart 1994, Rottenborn 1999). Likewise invasion of the naturalized shrubs potentially alters competitive hierarchies and disturbance regimes in riparian systems (Busch & Smith 1995, Ellis 2001).

Riparian plants are not dependent upon fire for renewal, but fire can influence the composition and structure of riparian ecosystems (Kellman & Meave 1997), in particular the understorey (personal observations), in combination or not with other factors such as flooding (Kellman & Tackaberry 1993, Bendix 1994, DeBano & Neary 1996, Ellis 2001, Everett *et al.* 2003). In Central New Mexico (USA), the suppression of flooding along RFs has also increased forest floor litter and woody debris, which may have contributed to the increased frequency and severity of fires (Ellis *et al.* 1998, 1999). In tropical savanna regions, when the gallery forests degrade, forest species become sparse, leaving the vegetation open for the savanna species to invade (Lykke 1996). The environmental impacts of such degradations are generally tremendous. For example, the changes in plant physiology, population dynamics, and community structure affect functional roles such as provision of habitat for riparian-dependent animals (Stromberg 2001).

Many studies have shown that in Benin riparian forests have waned during the last decades. Interpretations of aerial photographs and satellite images show that degradation rates varied from 0.14 to 8.6 during the period 1949 -1998 (Table 11.1). So far, no study has shown an increase in riparian forests area during that period.

Table 11.1: Degradation rates of riparian forests in Benin

Study area	Latitude (°N)	Degradation rate (%)	Period (number of years)	Authors
Klouékanmè	6°55’ – 7°10	1.58	1982-1994 (12)	Adambiokou-Akakpo (2001)
Dekpo-Lonkly	7° – 7°10	2	1982-1994 (12)	Gnele (1999)
Kétou	7°20’ – 7°35	8.59	1949-1994 (45)	Houndagba *et al.* (in press)
Dogo	7°30’ – 7°40	3.32	1949-1995 (46)	Houndagba *et al.* (in press)
Ouémé-Boukou	7°45’ – 7°55	0.3	1949-1998 (49)	Houndagba *et al.* (in press)
Bantè	8°05’ – 8°36	0.14	1979-1987 (8)	Akoègninou *et al*. 2001
Wari-Maro	9°– 9°10	0.51	1975-1997 (22)	Sounon (2001)
Djougou	9°45	3.4	1949-1975 (25)	FAO (1980)
Natitingou region	10°05’– 10°30	0.8	1975-1994 (19)	Tenté (2000)
Péhunco	10°05’– 10°35	1.14	1975-1997 (22)	Wotto (2001)
Alibori forest	10°40’– 10°50	3.5	1975-1998 (23)	Arouna (2002)
Malanville	11°45	3.4	1949-1975 (25)	FAO (1980)

Periodic removal of trees (either by selective tree cutting or farming) along waterways has modified the structure, composition, hence the functions of riparian forests. Beside farming and illegal tree cutting, livestock animals have a disproportionate effect on riparian forests ecosystems, because they tend to concentrate in areas, which are close to rangelands and water reservoirs. Long-term cumulative effects of domestic livestock grazing involve changes in the structure, composition, and productivity of plants and animals at community, ecosystem and landscape level (e.g. along the Ouémé river at Bétérou). Less often seen disturbances in RFs in Benin are industrial, urbanization and recreational activities. Nevertheless their impact is very destructive.

11.8. FLORISTIC RELATIONSHIPS OF RFS IN BENIN WITH OTHER TROPICAL DENSE FORESTS

There are marked floristic affinities as well as differences between RFs in the Dahomey Gap and those in the Guinean and Congo forest blocks. Certain RF plants in the Dahomey Gap are also found in forests along waterways in the Guinean and Congo rain forest blocks (Table 11.2). Among the most important we have *Cola laurifolia, Pterocarpus santalinoides, Ficus asperifolia, Entada manii, Leptoderris brachyptera, Psychotria calva, Manilkara multinervis, Synsepalum brevipes, Parinari congensis* and *Uapaca heudelotii*. These species can be termed typical stream and riverside forest plants of West and Central Africa. They also can be seen as specialists of a fixed habitat of limited area, because they are tied to special topographic or edaphic site factors (see Hubbell & Foster 1986). However, riparian habitat specialists are often common where RFs are extensive.

Among fresh water (swamp) forest species found in RFs in the Dahomey Gap, *Syzygium guineense* var. *guineense*, *Cleistopholis patens, Cynometra megalophylla,* and *Mitragyna inermis* are common. Floristic data indicate that large numbers of upland forest species in drier parts of the rain forest zones (e.g. *Dialium guineense, Diospyros mespiliformis, Elaeis guineensis, Xylopia parviflora, Dennettia tripetala, Hexalobus crispiflorus, Isolona thonneri, Drypetes floribunda,* etc.), coexist locally within RF patches in the Dahomey Gap. Also, large specimens of *Cola gigantea, Ceiba pentandra, Milicia excelsa,* and *Antiaris toxicaria* are frequent at RF edges. Most of these species are typical of the three drought resistant or dry semi-deciduous forest types of the Guineo-Congolian forest belt (Ern 1988, Hall & Swaine 1981). Generally at RF edges we have a host of open forest, forest outliers or woodland species, such as *Albizia* spp., *Combretum* spp., *Terminalia* spp., which augment RF phytodiversity.

Table 11.2: Typical riparian forest species of West and Central African regions

Species	Life forms*	Geographic affinity**	Habitat	Source
Cola laurifolia	mPh	GC	River banks tree in forest and savanna zone	(1),(2),(7),(8)
Cynometra megalophylla	mPh	GC	River banks and fresh water swamp forest species	(1),(2),(3),(6),(8)
Entada mannii	mph	GC	A climbing forest shrub in streamside forest	(2)
Ficus asperifolia	nph	GC	Shrub near water	(1),(2),(4),(9)
Gardenia imperialis	mph	GC	River banks and fresh water swamp forest species	(1),(2),(4)
Irvingia smithii	mPh	PRA	Riparian forest tree	(4),(9)
Leptoderris brachyptera	LmPh	GC	Climbing shrub in riparian forest	(2)
Manilkara multinervis	mPh	TA	Riparian forest tree	(1),(4)
Mimosa pigra	nph	Pan	Shrub often on sandy bars along rivers	(9)
Morelia senegalensis	mph	SZ	Shrub of gallery and swamp forests	(1),(4),(9)
Napoleonaea vogelii	mph	G	Riparian forest tree or near to sea shore	(1),(2)
Ouratea glaberrima	nph	GC	Erected shrub or small tree in forest by streams	(1)
Parinari congensis	MPH	GC	Evergreen tree on river banks and fringing forest	(1),(2),(4),(6),(8),(9)
Pterocarpus santalinoides	mPh	PRA	Forest tree on river banks	(1),(2),(3),(6),(7),(8),(9)
Psychotria calva	nph	GC	Erected shrub beside streams in forest	(2),(4)
Synsepalum brevipes	mph	GC	Riparian forest tree	(4)
Syzygium spp.	mPh	-	River banks and fresh water swamp forest species	(9)
Uapaca heudelotii	mPh	GC	River banks and fresh water swamp forest species	(1),(4),(6),(9)
Xylopia aethiopica	mPh	GC	Riverine forest tree, also in dry forest	(5),(6)

* Life forms follow Raunkaier (1934), Schnell (1971), and Keay & Hepper (1954-1972).

** Geographic affinity of each species (i.e. phytogeographic types) follows White (1986), Keay & Hepper (1954-1972), Keay *et al*. (1964).

(1) Keay *et al*. (1964); (2) Keay & Hepper (1954-1972); (3) Aubreville (1950); (4) Pauwels (1993); (5) de Koning (1983); (6) Hawthorne (1996); (7) Onochie (1979); (8) Adjanohoun (1968); (9) Schmitz (1988).

On the other hand, there are marked floristic differences between RFs in the rain forest zone and those in the Dahomey Gap. Numerous plants bound to waterways in the rain forest zones are absent in the Dahomey Gap. Among the most common riverine plants, we have *Brachystegia* spp., *Cathormion* spp., *Coelocaryon* spp., *Cynometra* spp., *Gilbertiodendron* spp., *Hymenocardia heudelotii, Millettia* spp., *Psychotria* spp., *Sacoglottis gabonensis,* etc. (see Keay & Hepper 1954-1972). So far, apart from a few evergreen forest trees adapted to swampy situations (e.g. *Cynometra megalophylla*, *Pentadesma butyracea, Xylopia aethiopica*, etc.), no true rain forest species of the Guinean-Congo regions are present in riparian forests in the Dahomey Gap.

11.9. STRUCTURAL RELATIONSHIPS OF RFS IN BENIN WITH OTHER TROPICAL DENSE FORESTS

In contrast of savanna regions, the physiognomy of RFs in rain forest regions is similar to that of adjacent rain forests. The distinction between the two forest types can therefore only be made through their specific floristic composition and topographic position. In the Zaire basin (Central Africa), RFs that fringe waterways are narrow where the banks are high but expanding into great swamp forests in the sump-lands (Kingdon 1990). The difference between RF in the Dahomey Gap and dense forest in the rain forest zone is well illustrated in terms of tree density, basal area and plant richness. Although our own data indicate that high plant species numbers can be sustained in isolated RFs habitats, tree richness and diversity in RFs are lower in the Dahomey Gap than in the continuous West and Central Africa rain forests (see Table 11.3).

Table 11.3: Characteristics of some riparian and rain forest sites in Africa and tropical America

Locality	Shannon index (H')	Tree density (stem/ha)*	Basal area (m^2/ha)	TR/ha **	SR/ha ***	Rainfall (mm)	Source
RIPARIAN FORESTS IN THE DAHOMEY GAP (BENIN & TOGO)							
South Benin (Samiondji 7°20N)	2.4	726	41.7±17.4	27	249	1200	(1)
Central Benin (Ouèssè 8°30N)	3.9	748-785	45.6±15.8	34	129-195	1150	(1)
Benin: various RFs	3.7-4.9	312-665	21.8-41	-	-	1100	(2)
South Togo: various RFs	1.89	-	-	-	-	1000	(3)
RIPARIAN FORESTS IN SOUTH AND CENTRAL AMERICA							
Belize: Río Bravo	-	-	-	56	-	1517	(4)
Brazil: Mobi-Guaçu	-	476	-	-	-	1280	(5)
Belize: Mountain Pine Ridge	-	766±241	21.9±8.8	52	-	-	(6)
WEST AND CENTRAL AFRICAN RAIN FORESTS							
Nigeria: Okumu forest reserve	-	360-523	-	34-70	-	2400	(7),(8)
Nigeria: Shasha forest reserve	-	523	-	-	-	2080	(8)
Nigeria: Omo forest reserve	-	520	-	42	-	2400	(9)
Cameroon: Bakundu reserve	-	375	-	109	-	3250	(9)
Cameroon: Dja	5.4	461	30.5	-	-	3900	(10)
Cameroon: Korup 0.65 ha plot (African pleistocene refugia)	-	-	-	138	-	3900	(11)
Gabon: various rain forests	-	-	35-43	69-131	-	3000	(12),(13)
Côte d'Ivoire: Yapo	-	605-649	-	77	-	2100	(14)
Côte d'Ivoire: Taï National Park	-	376-555	25.3-36.3	86-122	-	3000	(15)
Ghana: dense forests	-	-	25.5	-	-	2000	(16)
Ghana: Kade research station	-	539-565	28.4-32.2	120	-	1640	(17)
African non-refugial sites	-	-	-	< 100	-	-	(11)

* (dbh ≥ 10 cm); ** TR = Tree Species Richness per ha; *** SR = Species Richness per ha.

Sources: (1) Natta *et al.* (in prep.); (2) Sokpon *et al.* (2001); (3) Kokou *et al.* (2002); (4) Kellman *et al.* 1994; (5) Gibbs & Leitão (1978); (6) Meave & Kellman (1994); (7) Jones (1955); (8) Richards (1939); (9) Richards (1963); (10) Sonké & Lejoly (1998); (11) Whitmore (1990); (12) Reitsma (1988); (13) Hladik (1982), (14) Corthay (1996); (15) Dengueadhe (1999); (16) Hall & Swaine (1981); (17) Swaine *et al.* (1987).

Also, most RFs of the Dahomey Gap are characterised by many small-stemmed communities of low height (12-18 m) compared to tropical rain forest canopy height. In rain forest regions, the uniformity in the physiognomy at riversides makes it difficult to differentiate between RFs and adjacent dense evergreen forests. Swamps can be distinguished easily, but lower slopes and riverbank forests, which are fed by groundwater as well, are more difficult to distinguish from upland forest (van Rompaey 1993). Therefore from the viewpoint of forest physiognomy, we prefer to use the term 'riverine forest species' instead of 'riparian forest' for rain forest regions.

11.10. CONSERVATION OF DENSE FOREST SPECIES IN RIPARIAN FORESTS IN THE DAHOMEY GAP: implications for periods of climate change

As many as 350 out of 410 (i.e. 85.4 %) species recorded in RFs in South and Central Benin are not specialised to riparian systems, but are rather a subset of the general flora without endemic species. One would expect many rain forest taxa in RFs of the Dahomey Gap, because it is the wettest vegetation formation in this relatively dry savanna corridor. However, present days distribution pattern of plants show that the greater water availability owing to higher water tables in RFs seems not to favour many rain forest taxa. In Northern Australia, riparian vegetation has many elements of monsoonal rain forests, and has probably been an important refugium area for rain forest species in period of increased aridity during the Pleistocene (Russell-Smith 1991), as it was postulated for RFs in neotropical systems (see Meave & Kellman 1994). In Belize and Venezuela, RF fragments often contain a non-specialised tree flora with species characteristic of continuous forests. Provided that the local diversity of riparian systems is complemented by high regional diversity (this is lacking in the Dahomey Gap), RFs may have provided plausible refugia for tropical forest taxa in drier periods (Meave *et al.* 1991). Also, studies on the geographic patterns of genetic diversity of certain lowland species in Central America showed that these species might have persisted in riparian zones during the late Pleistocene (Aide & Rivera 1998). Likewise in the Neotropical savanna region, it has been suggested that tropical rain forest taxa may have persisted in small mesic, fire-protected pockets within Pleistocene non-forest communities (Leyden 1985, Colinvaux 1987).

For Whitmore (1990) parts of the world's rain forests that are most rich in species are those that the evidence shows have been the most stable, where species have evolved and continued to accumulate with the passage of time without episodes of extinction caused by unfavourable climatic periods. Therefore the floristic dissimilarity between RFs in the Dahomey Gap and those in the African rain forest zones as well as the presence of only a few rain forest taxa in the former, suggest three hypotheses:

1 - The most recent regression of dense forests in West Africa, and subsequent reopening of the Dahomey Gap, which occurred from the end of the middle Holocene to the beginning of the late Holocene (see Sowunmi 1986, Maley 1991, 1997, 2001, 2002, Tossou 2002) has resulted in a localised extinction of African rain forest taxa in RFs of the Dahomey Gap. Support to this hypothesis is given by e.g. Léonard (1965) and White (1979), who found that the Dahomey Gap constitutes a barrier to the distribution of very few typical forest plant species in West Africa (see also Kingdon 1990).

2 - Even during favourable periods, the 'Gap' may have been too much of an obstacle for some species (Kingdon 1990), probably for rain forest taxa. We now known that the shaping of the Dahomey Gap vegetation is linked to historical retreats and invasions of forests, which occurred several times during the Pleistocene and Holocene (Guillaumet 1967, Maley 1989, Dupond & Weinelt 1996, Dupond *et al.* 2000, Tossou 2002). Therefore the absence of many rain forests taxa in RFs might be the result of cumulative effects of these historical events at the actual location of the Dahomey Gap.

3 - Despite the higher water balance of RFs over upland forests, the environmental stress (i.e. recurrent flooding but also periodic drought) is unfavourable for the establishment and survival of many rain forest taxa in RFs of the Dahomey Gap.

These hypotheses need to be documented from palynologic records and comprehensive floristic data from little disturbed sites. As RFs of the Dahomey Gap possess a floristic richness lower than those of continuous tropical rain forests (see Table 11.3), and sustain few typical rain forest species, they can not effectively act as refugia for many rain forest taxa in the Dahomey Gap. Nevertheless, a significant number of species from deciduous and semi-deciduous forest types can survive in RFs; therefore they could act as refuge ecosystems for less luxuriant forest types taxa in the Dahomey Gap.

In addition to their importance in conserving biological diversity, RFs also provided important ecosystems functions in geological times (Naiman *et al*. 1993) and may have helped to maintain and create biodiversity in evolutionary time (Aide & Rivera 1998). RFs are typically narrow, but can have high species diversity, and palaeoecological data suggest that this diversity can be maintained for thousands of years, even during dry periods (Kellman *et al*. 1996). This viewpoint is shared by Kingdon (1990) when he points out that during the most arid periods, the riverine forest trailed over a much larger area than the vestigial jungles of Biafra and Central African uplands. At such times, riverine galleries became by far the most extensive microrefugia of all forest habitats in Africa. For Meave *et al*. (1991), patches of RFs differ from neighbouring non forests plant communities in that they are protected by a river, have high levels of humidity, and some occur within steep ravines (see also RFs at hills feet in North Benin). These factors contribute to making RFs an important habitat during periods of climate change. RFs are known to have played a crucial role in maintaining biodiversity for more than 10,000 years in the past, so we expect that these forests may be able to do the same in the future (Kellman *et al*. 1996). The mentioned properties show the potential of riparian forests to act as refuge ecosystem during dry periods in savanna as they are in rain forest regions.

Chapter 12

GENERAL CONCLUSION

TOWARDS A BETTER PRESERVATION AND REHABILITATION OF RIPARIAN FORESTS IN BENIN

A.K. Natta

Chapter 12

GENERAL CONCLUSION

TOWARDS A BETTER PRESERVATION AND REHABILITATION OF RIPARIAN FORESTS IN BENIN

12.1. RIPARIAN FORESTS AS BIODIVERSITY VEGETATION HOTSPOTS IN BENIN

Hotspots of biodiversity are areas particularly rich in species, rare, endemic, threatened species or some combination of these attributes (Reid 1998). In Benin, more than other vegetation types, RFs can be considered as hotspots of biodiversity for several reasons:

- they are among the most vulnerable forest formations at all latitudes, yet of high ecological importance.
- their high species richness on relatively small areas (patches and narrow corridors). We collected 1/3 of the estimated number of species in the Benin flora in just 20 ha of RFs. At this stage of the investigation on RFs diversity, we might say that 2.37 % of Benin's total area harbours at least 33 % of the estimated number of plant species in the country.
- their numerous species either rare, threatened, or with superior adaptability to a specific habitat.
- they are habitat for an endemic plant species in a fire-prone environment. So far just a few endemic plant species have been found in Benin.
- they are a vital ecosystem for numerous wild and bird life species.
- they protect many water resources all over the country.

Riparian ecosystems are essential multifunctional elements of the worldwide ecological network (Mander *et al.* 1997), and the maintenance of riparian forests is recognised as being vital to the integrity of waterways (Hancock *et al.* 1996). Given that RFs can support high levels of biodiversity, and have played an important role during periods of climate change over geological time (Kingdon 1990, Meave *et al.* 1991, Naiman *et al.* 1993, Kellman & Tackaberry 1993, Meave & Kellman 1994, Kellman *et al.* 1994, Kellman *et al.* 1996, Aide & Rivera 1998), their conservation in Benin is of utmost importance with the threat of a rapid increase in human occupation of land and possible change in climate.

12.2. LEGAL PROTECTION OF RIPARIAN FORESTS IN BENIN

The uniqueness, vulnerability and diversity of riparian forests are the most important criteria to protect them. In Côte d'Ivoire, 29 out of 46 biological reserves are protected to preserve genuine riparian forests, inter alia, because of their fragile soils in relationship with slope and hydromorphy (Kadio 1999). The uniqueness of individual populations suggests that conservation efforts directed only at species preservation can result in the loss of genetic diversity (Aide & Rivera 1998). Therefore the preservation of endemic animal species (e.g. *Cercopithecus erythrogaster erythrogaster*, a primate sub-species still found in Benin (Oates 1996, Grubb *et al.* 1999, Sinsin *et al.* 2002b), and the ornamental *Thunbergia atacoriensis* (Acanthaceae), should be coupled with the protection of their habitats.

The distribution pattern of the endemic primate sub-species of Benin, suggest the protection of all RFs of the Ouémé valley, which are among its most important habitat. Likewise, RFs at Yarpao (Natitingou district) and many others in the Atacora hills should have higher legal protection priority for their great plant diversity, and because they are remnant habitats for *Thunbergia atacoriensis*. Likewise the boundaries of certain protected areas (East of Kouffé Mountains; West of Kétou, Dogo and Ouémé-Boukou; and North East of the Pendjari Biosphere Reserve) that coincide with rivers should be extended to include RFs at both riversides.

Legislation and policies for the protection or rehabilitation of RFs in Benin, like in many developing countries, must take into account the economic and social costs as well as the environmental benefits at various scales. Before improving the actual forest law, there is an urgent requirement to increase enforcement of existing legislation, which is often unknown or ignored by many stakeholders. As suggested by de Lima & Gascon (1999), proactive educational initiatives are direly needed and should be coupled with legislation enforcement to reduce deforestation of riverbanks and maintain corridors between ecosystems in populated regions.

12.3. STRATEGIES FOR SUSTAINABLE MANAGEMENT OF RIPARIAN FORESTS

Cost-effective conservation of biodiversity requires that maximum biodiversity should be protected in a minimum area (Williams *et al*. 1991). The current degraded status of many riparian forests in Benin represents the cumulative and persistent impacts of unplanned and uncontrolled land uses and poor management of RFs themselves but also of adjacent uplands. Strategies that reflect a spectrum of goals linked to improving the ecological functions and sustainability of riparian ecosystems (i.e. natural integrity and diversity of the system) are needed. For example, strategies that focus on returning the hydrologic regime to a more natural state have the greatest potential for restoring riparian vegetation, and forests in particular that have evolved with and adapted to the patterns of changing flows in waterway environments. As pointed out by Cordes *et al.* (1997), to maintain existing and restore riparian woodland and to ensure their long-term regeneration, it has become important to understand in some detail both the contemporary and historical relationships between riparian vegetation and hydrological and geomorphological factors.

Also, management practices to maintain RF biodiversity need to be tailored to the conditions of each particular area (Hancock *et al.* 1996), in particular one must take into consideration the types of disturbances that typically affect these forests (Agee 1988). Therefore, activities aiming at protecting and rehabilitating RFs in their watershed should be implemented at the national, province, district and local levels, while taking into account ecological benefits (i.e. physical variables) as well as social costs represented by the loss of arable land (Cooper *et al*. 1987, Flanagan *et al*. 1989, Xiang 1993).

Because riparian forests perform a more than proportionate number of critical biological and physical functions on a unit area basis, their restoration when degraded, and protection of undisturbed stands can have a major influence on the local and regional environment. Meanwhile, deciding on priorities between rehabilitation and preservation may be difficult. Following Geraghty & Vollebergh (1993), we might say that it is more cost effective initially to maintain systems that are in reasonable condition and build from them, rather than at first attempting difficult rehabilitation tasks of very degraded river sections.

The preservation of intact riparian forest stands is vital because they represent valuable reference sites for understanding the goals and efficacy of restoration efforts, and are important sources of genetic material for the reintroduction of native species into degraded areas. The restoration of RFs should refer firstly to the process of removing the degrading factor or reducing its negative effects, and secondly repairing the condition and functioning of degraded riparian vegetation. Ecological restoration of degraded RFs, in which biodiversity is greatly decreased, has the stated goal to enhance the value of the ecosystem, moderate degrading influences and regain pre-disturbance characteristics (NRC 2000). This approach may include planting native trees, facilitating development of certain species, preserving and rehabilitating threatened and endemic species. The problem of isolated populations could be partially solved by reforesting corridors between riparian forests patches and belts along watercourses. Qualitative and quantitative knowledge of hydrology and ecology (including the range of natural variability, disturbance regimes, soils and landforms, and vegetation) are therefore required for successful rehabilitation of RFs.

12.4. CHALLENGES TO RIPARIAN FORESTS ASSESSMENT IN BENIN

As significant as climate changes are likely to be, land- and water-use changes have had and will continue to have the greatest effects on riparian vegetation. Therefore, more qualitative and quantitative assessments of the effects of land and water management on RFs have to be undertaken. The main variables to be considered should be related to physical, biological and anthropogenic factors. Research on RFs in Benin should document or clarify:

- ecological conditions (e.g. seed bank, germination, gap dynamics, edge effects, patterns in the succession, and long-term survival of plant communities), geomorphic, as well as hydrologic issues related to riparian systems;
- relationships between land forms, and RFs composition and structure dynamics;
- the effects of hydrologic (i.e. ground water table, surface water) changes on the composition, physiognomy and productivity of RFs;
- relationships between RFs diversity and structure, and waterways order and size;
- the relationship between flooding, accumulation of organic debris, and severity of fire;
- the effects of dissolved nutrients, foliage, or woody debris from RFs, as food resources for fishes, algae, and invertebrates;
- the influence of interactions of abiotic factors on relative growth and flood survivorship rates of native RF species;
- the rate and pattern of tree mortality in RFs, and the role of subsequent delivery of wood to waterways;
- the influence of fire on regeneration, recruitment patterns of plant species and RFs diversity;
- the potential role of such forest fragments as animal habitat or refuge, and movement corridors throughout the landscape;
- the usefulness of direct gradient analysis based on environmental variables (e.g. soils profile, structure, texture, fertility and nutrient content, water and flood related variables, types and levels of disturbance) to explain RFs diversity and dynamics;
- the genetic diversity within and among little known, valuable or rare plant populations;

From the list of RFs species, a database of suitable riparian species needs to be established to provide information on the type of plants and their ecological requirements at various latitudes and river systems. Research should set up tolerances and thresholds at least for the dominant RF trees regarding ground and surface waters, as a basis for predicting and preventing adverse ecological effects from stream draining or severe drought. Likewise dispersal and colonisation strategies of seeds, as well as ability of riverbank to trap waterborne diaspores on riparian vegetation diversity should be investigated. Remote sensing and geographical information systems are known to be powerful tools for assessing spatial and temporal changes of natural resources in general, and riparian habitats in particular.

Effective management strategies must be devised to preserve and restore riparian corridors (Brinson *et al*. 1981, Albernathy & Turner 1987, Gosselink & Lee 1989, Taylor *et al*. 1990), while relying on accurate understanding of the structure and dynamics of RF communities (Sagers & Lyon 1997). However, simply protecting RFs in a buffer zone may not be adequate to ensure their existence in the long term (Hibbs & Bower 2001). Instead the management of riparian forests must be a component (*i.e.* subset) of good watershed or landscape management. So awareness has to be raised to various stakeholders on riparian forests as unique physical and natural systems in their own right, and warranting special management and protection. Integrated management of riparian forests that optimise their values as habitat for native plants and animals requires planning and acting, with all stakeholders, at both site-specific and watershed levels. Through improved and long-term scientific, educational and recreational programs, the ecological importance and intrinsic human values associated with riparian forests may be better balanced against the competing wants of unplanned urbanisation, short-term local inhabitants' demands, and unknown motivations of other stakeholders.

SUMMARY

A.K. Natta

SUMMARY

The present research deals with the flora, phytosociology and ecology of riparian forests in Benin.

In **chapter 1** (General introduction), the research background, objectives and approach for riparian forests biodiversity assessment, and the organisation of the thesis are presented.

Chapter 2 introduces the study area which covered about 70 % of Benin, from 7° 10' to 12° 20' N.

Chapter 3 presents an overview of riparian forests biodiversity, their importance and the threats they face making them endangered ecosystems. A definition of riparian forests (or gallery forests) is given in the Benin context. The floristic characteristics of riparian forests in each phytogeographic district are presented. Issues related to legal protection and rehabilitation of the function and resources of riparian forests are documented: specifications and weaknesses of the forest law regarding riparian forests are presented; challenges for various stakeholders are discussed, and some improvements of the current forest law are proposed.

Chapter 4 assesses plant species diversity, as well as species abundance models that best fit representative collections of plant species of riparian forests throughout the country. This study shows the richness and diversity of riparian forests in Benin, in comparison to other vegetation types in this country. They harbour about 1/3 of the estimated total number of plant species of the whole country in sample plots totalling 19 ha. This flora shares many features with riparian forests and dense forests worldwide: e.g. most abundant families, species richness/ha, trees species richness/ha, Shannon index, equitability index of Pielou, and species abundance models. Endemism is very low compared to that in rain forests, what is not surprising in the Dahomey Gap. The main conclusion is that relatively large numbers of species are still maintained in small forest fragments along waterways. These remnants with their specific plant species composition can be used for the restoration of degraded forest stands.

Chapter 5 assesses the structure and ecological spectra of 19 ha of riparian forests through selected parameters (e.g. life form, geographic affinity, diameter class distribution, basal area, stem density, species dominance) that give a general picture of different vegetation types present. Figures obtained for these parameters show that riparian forests in Benin are on the one hand similar to many riparian forests in West Africa as well as in South and Central America, and on the other hand to many tropical upland forests. A brief description of the process of riparian forests degradation is also presented.

Chapter 6 deals with the phytosociological assessment of representative relevés of riparian forests of Benin. Floristic ordination (DCA analysis) and classification (TWINSPAN) were derived from a comprehensive floristic inventory of a data set of 818 plant species and 180 relevés. This yielded 12 plant communities or associations, most of which had not yet been formally described:

1 - Community of *Isolona thonneri* and *Callichilia barteri* (10 relevés) along streams. This community occurs at the lowest parts of the gallery forest with frequent inundation in the centre of Pénéssoulou protected forest.

2 - Community of *Motandra guineensis* and *Pararistolochia goldieana* (24 relevés) along streams at the East and West parts of Pénéssoulou reserve forest. This community is mainly present on drained sites (*i.e.* seldom inundated).

3 - Community of *Chrysobalanus icaco* subsp. *atacoriensis* and *Pentadesma butyracea* (22 relevés) along streams at hill feet in the Atacora mountain chain.

4 - Community of *Alchornea cordifolia* and *Ficus trichopoda* (9 relevés) along streams on regularly inundated plateaus all over the country.

5 - Community of *Berlinia grandiflora* and *Khaya senegalensis* (8 relevés) along streams on drained plateaus (*i.e.* seldom inundated), mainly in the Sudanian region of the country.
6 - Community of *Raphia sudanica* and *Oxytenanthera abyssinica* (8 relevés) along streams on drained plateaus, mainly in the Sudanian region.
7 - Community of *Cynometra megalophylla* and *Parinari congensis* (31 relevés) along the Ouémé river in the Guinean region of Southern Benin.
8 - Community of *Capparis thonningii* and *Crateva adansonii* (30 relevés) along the Ouémé river in the Sudano-Guinean region of Central Benin.
9 - Community of *Lepisanthes senegalensis* and *Drypetes floribunda* (17 relevés) along the Ouémé river in the Sudano-Guinean region of Central Benin.
10 - Community of *Uapaca heudelotii* and *Irvingia smithii* (8 relevés) along the Sota river in the Sudanian region of North East Benin.
11 - Community of *Garcinia livingstonei* and *Combretum acutum* (12 relevés) along the Pendjari river in the Sudanian region of North West Benin.
12 - Community of *Mimosa pigra* and *Ficus asperifolia* (20 relevés) widely distributed on sandy banks along rivers.

Ordination proved invaluable in the exploration of environmental characteristics of the phytosociological groups. The environmental factors (waterways, relief, topography, latitude and longitude) helped in the grouping of floristic relevés in the above mentioned 12 plant communities. The distinguished plant communities were compared with syntaxonomic data in literature. Riparian forests in Benin belong to the *Mitragynetea* Schmitz 1963, which is the phytosociological class of hygrophile fresh water forests of tropical Africa. Based on similarities of ecological conditions and floristic composition, the 12 plant communities can be classified into 3 orders that are *Alchornetalia cordifoliae* Lebrun 1947, *Lanneo-Pseudospondietalia* Lebrun & Gilbert 1954 and *Pterygotetalia* Lebrun & Gilbert 1954.

Chapter 7 presents the spatial distribution and ecological factors determining the occurrence of *Pentadesma butyracea* (Clusiaceae), a rain forest and multipurpose species found in Benin only along certain streams. Among the 224 tree species found along waterways, *Pentadesma* is one of the least known, yet of great ecological and economic importance. Field survey reveals the presence of this rain forest species in four non-contiguous remnant riparian areas, some located far from its optimal ecological range. If urgent actions are not taken to protect the remaining fragmented and dispersed riparian habitats, current human-induced disturbance could result in the disappearance of this species in Benin.

Chapter 8 deals with the variation of the floristic composition, structural parameters (e.g. abundance, average height, basal area, tree richness) and spatial distribution of tree species at river edges across riparian forests. Horizontal and vertical structures of tree species exhibit complex patterns at riverside. On the one hand, tree stems are characterised by an uneven distribution across riparian forests, on the other hand height and basal area variations at riverside do not show any easily interpretable patterns. The numerical analysis confirms a gradual variation in the floristic composition across riparian forests and neighbouring plant communities. These results suggest a partitioning of riparian forests in three habitats (*i.e.* river front, middle and riparian forest edge). An implication for diversity assessment is that plot size, shape and layout in the terrain should take into account the river front, the middle and the edge of riparian forest. Due to the non-coverage of the whole riparian forest width and unequal chance of species and stems to be sampled, circular and square plots are not suitable for structural parameters and phytodiversity assessment in riparian forests. Instead rectangular plots with varying length and width, and covering the whole cross section of riparian forest are the most suitable sampling units under the study area conditions, and probably for savanna regions too. The present study also provides scientific guidelines for an improvement of the forest law regarding the distance to be protected at riverside, and suggests 100 m instead of 25 m.

In **chapter 9** the floristic composition, species richness and structure of two riparian ecosystems in West Africa (the Comoé in Ivory Coast and the Ouémé in Benin), are compared. The overall physiognomy of the two gallery forest sites seems similar and they share the most prominent families. However, there are marked differences in terms of canopy density and height, herb layer density, number of individuals, tree richness and diversity (*H’*), and species composition. The phenomenon of single species dominance at both sites is documented from *Cynometra megalophylla*, an evergreen tree species, which was time and again the most frequent and dominant tree at both riversides and in the middle of the gallery forests. Only detailed comparison shows the difference and complexity of ecological processes between and within gallery forests sites.

The research carried out in **chapter 10** facilitates the choice between several sampling designs for the estimation of a population parameter for endangered species. This study was carried out in the Pénéssoulou forest, in Central Benin. Stratified random sampling provided the lowest variance, coefficient of variation, standard error and sampling error. This method was taken as the most precise and reliable design over simple random and systematic samplings for the density estimation of *Khaya senegalensis* and *K. grandifoliola* trees. Results have confirmed empirical knowledge about the ecology of *Khaya* species and shown that the selection of the most precise sampling design, with regards to estimating a given parameter, can eventually be useful for the sustainable management of forest trees in the study area. A reliable density estimate for *Khaya* species within the given vegetation types facilitates the selection of areas to be protected and sustainably exploited.

Chapter 11 presents a general discussion on issues discussed in this thesis.

Sustainable rehabilitation and restoration of riparian forests biodiversity in Benin are discussed in the general conclusion (**chapter 12**).

This study has provided detailed site-specific data on plant species that can serve for further scientific research, as well as for conservation management and planning. It fills a gap of knowledge on the flora of Benin, and can contribute to better land-use planning and conservation of riparian forests.

RESUME

A.K. Natta

RESUME

TITRE DE LA THESE

ETUDE ECOLOGIQUE DES FORETS GALERIES DU BENIN: PHYTODIVERSITE, PHYTOSOCIOLOGIE ET DISTRIBUTION DES ESPECES LIGNEUSES.

Le **chapitre 1** (**Introduction générale**) présente les fondements, objectifs et l'approche suivie pour l'étude de la biodiversité des forêts galeries (*i.e.* riparian forests en Anglais) du Bénin.

Le **chapitre 2 (Milieu d'étude)** introduit la zone d'étude qui couvre environ 70 % de la surface totale du Bénin de 7° 10' à 12° 20' N. Tous les districts phytogéographiques de Bénin reconnus par Adjanohoun *et al.* (1989), et Houinato *et al.* (2000) y ont été sillonnés et des sites représentatifs installés.

Le **chapitre 3** (**Forêts galeries du Bénin: un écosystème unique mais en voie de disparition**) fait le point des connaissances actuelles sur la diversité de la flore, l'importance écologique, économique et socioculturelle des forêts galeries du Bénin. Une définition des forêts galeries dans le contexte du Bénin est proposée. Les causes de la dégradation actuelle des forêts galeries sont présentées. Un accent particulier est mis sur la protection légale de ces bandes boisées longeant les cours d'eau et les défis actuels pour la protection et l'aménagement durable de leur biodiversité.

Le **chapitre 4** (**Diversité floristique des forêts galeries du Bénin**) évalue la flore et la phytodiversité de l'ensemble des 19 ha de forêts galeries étudiées de 1999 à 2002 au Bénin. Au total quelque 1003 espèces ont été recensées, ce qui représente environ le 1/3 du nombre total d'espèces estimé de la flore du Bénin. Ces espèces se regroupent en 120 familles et 513 genres. 224 espèces ligneuses ont été recensées. Les (sous) familles les plus représentées sont les Papilionioideae, Poaceae, Rubiaceae et Euphobiaceae. Les forêts galeries sont caractérisées par une flore typique adaptée aux inondations récurrentes et par une multitude d'espèces typiques de forêt et savane de plateau. Selon les sites, l'indice de Shannon varie de 2,4 à 5,8 bits et l'Equitabilité de Pielou de 0,51 à 0,86. La richesse spécifique varie de 120 à 358 plantes par ha et celle des espèces ligneuses (dbh ≥ 10 cm) de 27 à 99 par ha. Cette étude montre que dans la majorité des paysages savanicoles, les forêts galeries du Bénin constituent des îlots de grande biodiversité qu'il faudrait restaurer et conserver durablement.

Le **chapitre 5** (**Structure et spectres écologiques des forêts galeries du Bénin**) traite des principales caractéristiques structurales de 19 ha de forêts galeries du Bénin, à travers : les types biologiques, phytogéographiques, la distribution par classe de diamètre, la surface terrière et la densité des ligneux. La physionomie des forêts galeries est très variable en terme de stratification verticale et hauteur de la canopée, cependant le sous-bois est généralement dense. Les forêts galeries du Bénin sont similaires à de nombreuses forêts galeries et forêts semi-décidues d'Afrique de l'Ouest, concernant: les types phytogéographiques (forte présence de espèces Guinéo-Congolaises), les types biologiques (forte abondance des thérophytes et des micro et méso phanérophytes, faible abondance des méga-phanérophytes et lianes ligneuses), la distribution par classe de diamètre (J renversé), la surface terrière (23 à 59 m^3/ha) et la densité des ligneux (253 à 785 tiges/ha). La dominance d'une ou de plusieurs espèces en terme d'abondance et de surface terrière est une caractéristique

essentielle des forêts galeries du Bénin. Malheureusement les sites les plus denses et ayant une structure assez développée sont assez rares de nos jours.

Le **chapitre 6** (**Phytosociologie des forêts galeries du Bénin**) traite en large de la classification et de l'ordination de relevés phytosociologiques les moins dégradés et les plus représentatifs de l'ensemble du milieu d'étude. L'analyse multivariée de 180 relevés et 818 espèces a permis d'individualiser 12 associations qui s'ordonnent suivant cinq facteurs ou gradients: l'importance du cours d'eau (rivière ou fleuve), le relief, la topographie, la latitude et la longitude. Il s'agit des associations végétales à :
1 - *Isolona thonneri* et *Callichilia barteri* (10 relevés), le long de rivières dans le centre de la forêt classée de Pénéssoulou, sur sol très inondable.
2 - *Motandra guineensis* et *Pararistolochia goldieana* (24 relevés), le long des rivières à l'Est et à l'Ouest de la forêt classée de Pénéssoulou, sur sol rarement inondé (*i.e.* bon ressuyage du sol).
3 - *Chrysobalanus atacoriensis* et *Pentadesma butyracea* (22 relevés), le long des rivières de bas de collines.
4 - *Alchornea cordifolia* et *Ficus trichopoda* (9 relevés), le long des rivières de plateaux sur substrats engorgés d'eau pendant la saison de pluie (mauvais ressuyage du sol).
5 - *Berlinia grandiflora* et *Khaya senegalensis* (8 relevés), le long des rivières de plateaux à bon ressuyage du sol en milieu Soudanien.
6 - *Raphia sudanica* et *Oxytenanthera abyssinica* (8 relevés), le long des rivières de plateaux à bon ressuyage du sol en milieu Soudanien.
7 - *Cynometra megalophylla* et *Parinari congensis* (31 relevés), le long du fleuve Ouémé en région Guinéenne.
8 - *Capparis thonningii* et *Crateva adansonii* (30 relevés), le long du fleuve Ouémé en région Soudano-Guinéenne.
9 - *Lepisanthes senegalensis* et *Drypetes floribunda* (17 relevés), le long du fleuve Ouémé en région Soudano-Guinéenne.
10 - *Uapaca heudelotii* et *Irvingia smithii* (8 relevés), le long de la Sota dans le Nord Est du Bénin.
11 - *Garcinia livingstonei* et *Combretum acutum* (12 relevés), le long de la Pendjari dans le Nord Ouest du Bénin.
12 - *Mimosa pigra* et *Ficus asperifolia* (20 relevés), sur les bancs de sable proche du lit des cours d'eaux.
Une classification syntaxonomique est aussi présentée. Les forêts galeries du Bénin sont rangées dans la classe des *Mitragynetea* Schmitz 1963 qui regroupe toutes les forêts édaphiques hygrophiles d'eau douce d'Afrique tropicale. Les associations individualisées se regroupent en trois ordres (*Alchornetalia cordifoliae* Lebrun 1947, *Lanneo-Pseudospondietalia* Lebrun & Gilbert 1954, et *Pterygotetalia* Lebrun & Gilbert 1954). Trois associations sur les douze ont pu être classifiées dans des Alliances préexistantes. L'approche phytosociologique de Braun-Blanquet couplée aux analyses multivariées se sont avérées concluantes quant à l'individualisation des groupements végétaux de forêts galeries et la détection de gradients / facteurs majeurs de cette typologie.

Le **chapitre 7 (Distribution spatiale et facteurs écologiques de la présence de *Pentadesma butyracea* (Clusiaceae) au Bénin**), traite de la répartition spatiale d'une espèce de forêt sempervirente qui se retrouvent curieusement au Bénin uniquement dans les forêts galeries en milieux Soudano-Guinéen (région de Bassila et près du village Agbassa, commune de Tchaourou) et Soudanien (région de Perma à Tandafa et près du village de Gbèssè, commune de Ségbana). *Pentadesma* est une espèce relativement peu connue du monde scientifique béninois, pourtant elle est à but multiple, et pourrait jouer un rôle de premier choix dans la diversification des filières agro-forestières. La présence de cette espèce de forêt dense sempervirente dans les forêts galeries du Bénin dans la zone Soudano-Guinéenne, et aussi loin qu'à 11° N, nous a permis de valider quelques hypothèses concernant l'importance écologique de ces formations édaphiques d'eau douce.

Le **chapitre 8** (**Variation de la structure et de la composition floristique dans la direction perpendiculaire aux fleuves**) fait usage de l'analyse multivariée (DCA et TWINSPAN) et des courbes de distribution des ligneux pour tester l'existence d'espèces typiques du front d'eau, du milieu et de lisière des galeries. L'abondance des ligneux décroît constamment du lit du cours d'eau vers la lisière de la galerie. Cependant la hauteur des arbres et la surface terrière varient très peu lorsqu'on s'éloigne du cours d'eau. Quant à la composition floristique, elle varie graduellement dans la galerie perpendiculairement au cours d'eau vers les groupements végétaux adjacents aux galeries. Ces résultats nous ont permis de définir des espèces du front des fleuves, du milieu des galeries, de lisière de galeries, et des espèces typiques des groupements végétaux contigus aux galeries.
Les espèces typiques de galeries constamment au contact de l'eau des fleuves sont: *Syzygium guineense, Pterocarpus santalinoides, Parinari congensis, Cola laurifolia* et *Napoleonaea vogelii*;
Les espèces constamment au centre des galeries sont: *Cynometra megalophylla, Drypetes floribunda* et *Manilkara multinervis*;
Les espèces de bordure de galerie ou dans l'écotone avec les groupements végétaux adjacents aux galeries sont: *Dialium guineense, Diospyros mespiliformis, Elaeis guineensis, Cola gigantea* et *Ceiba pentandra*.
Cette recherche confirme le savoir empirique sur l'écologie des arbres en bordure des cours d'eau, mais montre que, bien que linéaires et fragmentées, les galeries ne peuvent être considérées comme uniformes sur les plans floristique et structural dans la direction perpendiculaire aux cours d'eaux. Une conséquence de ces résultats est que les placeaux rectangulaires avec des longueurs et largueurs variables et qui couvrent toute la section perpendiculaire des galeries sont les mieux adaptés en milieux Soudanien et Soudano-Guinéen. Aussi la distance légale minimale à être protégée de part et d'autre des cours d'eau (*i.e.* 25 m) apparaît-elle trop faible. Les résultats obtenus suggèrent de porter cette distance à 100 m, cela permettra aux galeries forestières de mieux assurer leurs importantes fonctions.

Le **chapitre 9** (**Comparaison de l'interface forêt galerie/ savanes le long de l'Ouémé (Bénin) et de la Comoé (Côte d'Ivoire)**), traite des relations forêt galerie / savane dans deux systèmes riverains en milieu Soudano-Guinéen. Les deux sites comparés sont approximativement à la même latitude, mais distants d'au moins 600 km à vol d'oiseau au Bénin (Idadjo-Bétérou) et dans le Sud Ouest du Parc National de la Comoé en Côte d'Ivoire. On constate une similarité concernant les familles ayant une grande richesse spécifique (i.e. Leguminosae, Rubiaceae et Sapotaceae) mais aussi des différences notables (e.g. densité des espèces de la canopée, hauteur moyenne, densité du sous-bois, richesse spécifique et composition floristique). *Cynometra megalophylla* est dans les deux sites l'espèce la plus fréquente et dominante. C'est un exemple typique de dominance mono-spécifique dans les forêts galeries en Afrique de l'Ouest. Une analyse plus fine des interactions entre les trois portions des galeries (front du cours d'eau, milieu de la galerie et l'écotone) montre la variabilité et la complexité des phénomènes écologiques entre sites et au sein d'un même site.

Le **chapitre 10** (**Comparaison de trois méthodes d'échantillonnage pour l'estimation de la densité de *Khaya senegalensis* et *K. grandifoliola* dans la forêt classée de Pénéssoulou**) évalue les performances relatives des systèmes d'échantillonnage aléatoire, systématique et stratifié pour l'obtention des valeurs crédibles et précises (en terme statistique) des densités des deux espèces de *Khaya* présentent au Bénin. Il est généralement admis que l'obtention des valeurs précises pour des paramètres d'espèces en voie de disparition est une nécessité pour tout aménagement durable. Ainsi nous avons testé dans la partie la plus dense et la moins perturbée de la forêt classée de Pénéssoulou, les trois méthodes d'échantillonnage conventionnelles. L'échantillonnage stratifié, avec allocation proportionnelle de placeaux, est le plus fiable et précis, puisqu'il donne les valeurs les plus faibles de la variance, du ratio de variance, de l'erreur standard, et du coefficient de variation. Cette approche pourrait être testée pour d'autres espèces de valeur dans la même zone d'étude. Cela permettrait d'avoir des résultats consistants pour plusieurs espèces dans la zone d'étude.

Une discussion générale de tous les aspects abordés dans la présente thèse est présentée au **chapitre 11**. La conclusion générale (**Chapitre 12**) traite des stratégies les plus adaptées et les nouveaux défis pour une meilleure conservation de la biodiversité des forêts galeries au Bénin.

SAMENVATTING

A.K. Natta

SAMENVATTING

Dit onderzoek behandelt de flora, de vegetatiekundige aspecten en de ecologie van oeverbossen in Benin.

In **Hoofdstuk 1** (Algemene Inleiding) worden de achtergronden van het onderzoek, de doelstellingen en benaderingen om de biodiversiteit van oeverbossen te beoordelen, evenals de indeling van dit proefschrift beschreven.

Hoofdstuk 2 beschrijft het gebied in Benin waar het onderzoek plaatsvond. Het studiegebied beslaat ca. 70% van het land en is gelegen tussen $7^{0}10$ en 12^{0} 20’ Noorderbreedte.

Hoofdstuk 3 geeft een overzicht van de biodiversiteit in oeverbossen, het belang daarvan en de aantastingen waaraan ze blootstaan. Dit ecosysteem moet in Benin als bedreigd worden beschouwd. Een definitie van oever- (of galerij-)bossen is gegeven in de Beninese context. De floristische eigenschappen van oeverbossen worden vermeld in elk fytogeografisch district. Vraagstukken i.v.m. de wettige bescherming en herstel van de functie en bronnen van het oeverbos komen aan de orde; uitdagingen voor diverse betrokkenen worden besproken, en verbeteringen voor de huidige Boswet worden voorgesteld.

Hoofdstuk 4 beschrijft de soortenrijkdom, en de op de representatieve verzamelingen uit oeverbossen uit de meeste delen van het land best passende abundantie-modellen. Dit onderzoek laat zien hoe rijk en divers oeverbossen zijn in Benin, in vergelijking met andersoortige bossen in het land. Oeverbossen herbergen ongeveer 1/3 van het aantal soorten van de gehele flora van Benin, zoals aangetoond in vele proefvlakken die bij elkaar 19 ha besloegen. De oeverbosflora heeft veel gemeen met andere oeverbossen en dichte laaglandregenbossen in de wereld: bijv. de soortenrijkste plantenfamilies, soortenrijkdom per ha, boomsoortenrijkdom per ha, Shannon index, de Equitability Index van Pielou, en abundantie modellen. In de oeverbossen is het endemisme veel lager dan in dichtere regenwouden, dat is echter niet verrassend in de Dahomey Gap. De belangrijkste conclusie is dat relatief veel soorten zich nog steeds handhaven in kleine bosfragmenten langs waterwegen. Deze bosfragmenten en bepaalde soorten kunnen worden gebruikt als uitgangsmateriaal voor het herstel van gedegenereerde vegetaties.

Hoofdstuk 5 bekijkt de structuur en ecologische spectra van 19 ha oeverbos door middel van geselecteerde parameters (levensvorm, geografische verbanden, verdeling van diameter klassen, basis oppervlak, dichtheid van stammen, dominantie van soorten) welke een overzicht leveren van vegetatietypes. Cijfers verkregen voor deze parameters bewijzen dat oeverbossen in Benin vergelijkbaar zijn met vele oeverbossen in West Afrika en Zuid- en Centraal Amerika, maar ook met vele tropische bossen op drogere gronden. Het degradatieproces van oeverbossen wordt kort beschreven.

Hoofdstuk 6 behandelt de vegetatiekundige opnamen in representatieve proefvlakken in Beninese oeverbossen. Ordinatie (DCA analyse) en classificatie (TWINSPAN) werden toegepast op 180 proefvlakken en 818 plantensoorten. Dit leverde liefst 12 plantengemeenschappen op, waarvan de meeste nog niet eerder formeel zijn beschreven.

1 - *Isolona thonneri* en *Callichilia barteri* gemeenschap (10 proefvlakken) langs stroompjes in het midden van het beschermde bos van Pénéssoulou. Deze associatie vindt men in de laagstgelegen delen van het bos welke vaak overstroomd worden.

2 - *Motandra guineensis* en *Pararistolochia goldieana* gemeenschap (24 proefvlakken) langs riviertjes in het oosten en het westen van het Pénéssoulou bos. Deze associatie komt voor op goed ontwaterde plekken welke zelden overstromen.

3 - *Chrysobalanus icaco* subsp. *atacoriensis* en *Pentadesma butyracea* gemeenschap (22 proefvlakken) langs stroompjes aan de voet van de Atacora heuvels.

4 - *Alchornea cordifolia* en *Ficus trichopoda* gemeenschap (9 proefvlakken) langs riviertjes op regelmatig overstroomde plateaus door het hele land.

5 - Gemeenschap van *Berlinia grandiflora* en *Khaya senegalensis* (8 proefvlakken) langs stroompjes op goed ontwaterde plateaus, vooral in de Sudan zone van het land.
6 - Gemeenschap van *Raphia sudanica* en *Oxytenanthera abyssinica* (8 proefvlakken), ook langs stroompjes op goed gedraineerde plateaus in de Sudan zone.
7 - Gemeenschap van *Cynometra megalophylla* en *Parinari congensis* (31 proefvlakken) langs de Ouémé rivier in de Guinee-zone van Zuid Benin.
8 - Gemeenschap van *Capparis thonningii* en *Crateva adansonii* (30 proefvlakken) langs de Ouémé rivier in de Sudano-Guinee zone van midden-Benin.
9 - Gemeenschap van *Lepisanthes senegalensis* en *Drypetes floribunda* (17 proefvlakken) langs de Ouémé rivier in de Sudano-Guinee zone van midden-Benin.
10 - Gemeenschap van *Uapaca heudelotii* en *Irvingia smithii* (8 proefvlakken) langs de Sota rivier in het noordoosten van het land.
11 - Gemeenschap van *Garcinia livingstonei* en *Combretum acutum* (12 proefvlakken) langs de Pendjari rivier in het noordwesten van Benin.
12 - *Mimosa pigra* en *Ficus asperifolia* gemeenschap (20 proefvlakken) zeer wijdverspreid op zandbanken langs rivieren.

Ordinatie blijkt waardevol om de eigenschappen van het milieu van de fytosociologische groepen te onderzoeken. De gevonden factoren (aard van watergangen, reliëf, topografie, lengte- en breedtegraad) hielpen bij het groeperen van de floristische opnamen in de bovengenoemde 12 gemeenschappen. Een syntaxonomische indeling van de onderscheiden plantengemeenschappen wordt gegeven. Oeverbossen in Benin behoren tot het *Mitragynetea* Schmitz 1963, de fytosociologische klasse van vochtminnende zoetwaterbossen van tropisch Afrika. Gebaseerd op overeenkomsten van ecologische gesteldheid en floristische samenstelling deelden wij de 12 plantengemeenschappen in 3 ordes in: *Alchornetalia cordifoliae* Lebrun 1947, *Lanneo-Pseudospondietalia* Lebrun & Gilbert 1954 en *Pterygotetalia* Lebrun & Gilbert 1954.

Hoofdstuk 7 onderzoekt de ruimtelijke verspreding en de ecologische factoren die het voorkomen van *Pentadesma butyracea* (Clusiaceae) bepalen. Deze op diverse manieren bruikbare soort uit het regenbos komt in Benin alleen langs sommige riviertjes voor. Onder de 224 boomsoorten gevonden langs grote en kleine stromen, is *Pentadesma* een van de minst bekende, ofschoon deze van groot ecologisch en economisch belang is. Veldstudies toonden aan dat deze regenwoudsoort in vier disjuncte relictgebiedjes voorkomt, sommige ver verwijderd van de optimale ecologische gebieden. De huidige verstoring door de mens kan leiden tot de verdwijning van de soort in Benin tenzij onmiddellijk actie wordt ondernomen de laatste versnipperde habitats, de oeverbossen, te beschermen.

Hoofdstuk 8 behandelt de variatie in de floristische samenstelling, structurele parameters (bijv. abundantie, gemiddelde hoogte, basisoppervlakte, rijkdom aan bomen) en ruimtelijke verdeling van boomsoorten in oeverbossen. Horizontale en verticale structuren laten complexe patronen zien. Enerzijds wordt het aantal stammen gekarakteriseerd door een ongelijke verdeling in het oeverbos dwars op de richting van de stroom, anderzijds zijn de variaties van boomhoogte en basisoppervlakten langs de stromen niet eenvoudig te interpreteren. De numerieke analyse bevestigt een geleidelijke variatie van de floristische samenstelling vanaf de rivier, in het midden van het oeverbos, tot bij de naburige vegetatie. De resultaten wijzen op een onderverdeling van het oeverbos in deze drie genoemde habitats langs de horizontale gradiënt. Bij onderzoek aan diversiteit van oeverbossen, de omvang, vorm en plaatsing van proefvlakken in het terrein moeten steeds de oevers, het middenstuk en de buitenrand in beschouwing dienen genomen te worden. Ronde en vierkantige proefvlakken zijn ongeschikt om structurele parameters en biodiversiteit te meten, omdat hiermee niet de gehele breedte van het oeverbos wordt bemonsterd. Rechthoekige proefvlakken van variabele lengte en breedte lijken beter geschikt te zijn voor het studiegebied, en vermoedelijk ook voor savannegebieden. Deze studie levert ook wetenschappelijke onderbouwing ter verbetering van de Boswet wat betreft de te beschermen breedte langs de rivieren, en stelt 100 m voor in plaats van 25 m.

In **Hoofdstuk 9** worden de floristische samenstelling, soortenrijkdom en structuur van twee oeverbossystemen in West Afrika (de Comoé in Ivoorkust en de Ouémé in Benin) vergeleken. Hoewel de fysiognomie van de twee bossen overeen lijken te komen en dezelfde plantenfamilies er prominent in voorkomen, zijn er duidelijke verschillen in dichtheid en hoogte van het kronendak, dichtheid van de kruidlaag, aantal exemplaren, rijkdom aan bomen en boomsoorten (*H'*) en soortensamenstelling. Het verschijnsel dat één soort dominant voorkomt is gedocumenteerd aan de hand van *Cynometra megalophylla*, een altijdgroene boomsoort, welke steeds de meest algemene de dominante soort is, zowel langs de rivier als in het midden van het oeverbos, in beide landen. Alleen gedetailleerde vergelijkingen maken de verschillen en complexiteit van de ecologische processen tussen en binnen oeverbossen duidelijk.

Het onderzoek zoals gerapporteerd in **hoofdstuk 10** vergemakkelijkt een keuze tussen verschillende bemonsteringsmethoden om populatieparameters van bedreigde soorten in te schatten. In het bos van Pénéssoulou bleek stratified random sampling de laagste variantie, variatiecoëfficient, standaardafwijking en monsterfouten op te leveren. Deze methode werd dus gekozen als de meest nauwkeurige in vergelijking met simple random en systematic sampling, om de dichtheid te meten van *Khaya senegalensis* en *K. grandifoliola* bomen. De resultaten bevestigen de empirische kennis van de ecologie van *Khaya* soorten en lieten zien dat de keuze van de meest nauwkeurige monstermethode, om bepaalde parameters te schatten, uiteindelijk nuttig kan zijn bosbomen in het studiegebied duurzaam te beheren. Een betrouwbare schatting van *Khaya* in de betreffende vegetatietypes vergemakkelijkt de keuze van te beschermen of duurzaam te exploiteren arealen.

Hoofdstuk 11 bevat een algemene bespreking over de problemen zoals gegeven in het proefschrift als geheel. Duurzaam herstel van oeverbosdiversiteit in Benin wordt gepresenteerd in de algemene conclusie (**hoofdstuk 12**).

Dit onderzoek levert nauwkeurige terrein-specifieke gegevens die kunnen dienen als uitgangspunt voor verder wetenschappelijke studie, en ook voor beheer en planning van behoudsmaatregelen. Het draagt bij aan de leemten in de kennis van de flora van Benin, en wij verwachten dat het bijdraagt aan verbetering van het behoud van oeverbossen en een verhoging van de prioriteit daarvan in landgebruiksplanning.

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ANNEX

LIST OF RIPARIAN FORESTS PLANT SPECIES OF BENIN

A.K. Natta

List of riparian forests plant species of Benin

no.	LF	PT	Families	Plant list
1	Lnph	TA	Papilionaceae	Abrus canescens Welw. ex Wight & Arn.
2	Lnph	TA	Papilionaceae	Abrus fruticulosus Wall. ex Wight & Arn syn. A. pulchellus Wall. ex Thwaites
3	Lnph	Pan	Papilionaceae	Abrus precatorius L.
4	Ch	TA	Malvaceae	Abutilon mauritianum (Jacq.) Medic.
5	Lmph	TA	Mimosaceae	Acacia erythrocalyx Brenan syn. Acacia pennata (L.) Willd.
6	mPh	S	Mimosaceae	Acacia gourmaensis A. Chev.
7	mph	SZ	Mimosaceae	Acacia macrostachya Reichenb. ex DC.
8	mPh	SZ	Mimosaceae	Acacia polyacantha Willd. subsp. campylacantha (Hochst. ex A. Rich.) Brenan
9	mph	SZ	Mimosaceae	Acacia sieberiana DC. var. sieberiana
10	mph	_	Mimosaceae	Acacia sp.
11	Th	Pan	Euphorbiaceae	Acalypha ciliata L.
12	Th	Cosmo	Amaranthaceae	Achyranthes aspera L.
13	Lmph	GC	Malpighiaceae	Acridocarpus alternifolius (Schum. & Thonn.)
14	He	SG	Poaceae	Acroceras amplectens Stapf.
15	He	Pan	Poaceae	Acroceras zizanoides (Kunth.) Dandy
16	Lnph	GC	Passifloraceae	Adenia cissampeloides (Planch. ex Hook) Harms
17	Lmph	GC	Passifloraceae	Adenia lobata (Jacq.) Engl.
18	Lnph	GC	Passifloraceae	Adenia rumicifolia Engl. & Harms var. miegei
19	Lnph	G	Passifloraceae	Adenia tennuispira (Stapf.) Engl.
20	Ch	SZ	Papilionaceae	Adenodolichos paniculatus (Hua) Hutch. & Dalz. syn. Dolichos paniculatus Hua
21	Lmph	TA	Cucurbitaceae	Adenopus brevifolius Benth.
22	Th	TA	Asteraceae	Adenostemma caffrum DC. var. caffrum
23	Th	GC	Asteraceae	Adenostemma perrottetii DC.
24	Ch	Pan	Adiantaceae	Adiantum philippensis L.
25	Ep	GC	Orchidaceae	Aerangis biloba (Lindl.) Schltr. excl.
26	Ch	PRA	Papilionnaceae	Aeschynomene afraspera J. Leonard
27	Th	Pan	Papilionnaceae	Aeschynomene indica L.
28	Ge	GC	Zingiberaceae	Aframomum sceptrum (Oliv. & Hanb.) K. Schum.
29	Ge	_	Zingiberaceae	Aframomum sp.
30	mPh	SZ	Caesalpiniaceae	Afzelia africana Smith ex Pers.
31	Th	Pan	Asteraceae	Ageratum conyzoides L. subsp. conyzoides
32	LmPh	GC	Apocynaceae	Alafia barteri Oliv.
33	LmPh	GC	Apocynaceae	Alafia benthamii (Baill. ex Stapf) Stapf var. benthamii
34	LmPh	GC	Apocynaceae	Alafia scandens (Thonning) De Wild. syn A. landolphioides
35	mPh	PRA	Mimosaceae	Albizia coriaria Welw. ex Oliv.
36	mPh	GC	Mimosaceae	Albizia ferruginea (Guill. & Perr.) Benth.
37	mph	GC	Mimosaceae	Albizia glaberrima (Schum. & Thonn.) Benth.
38	mPh	GC	Mimosaceae	Albizia zygia (DC.) J. F. Macbr.
39	Lmph	GC	Euphorbiaceae	Alchornea cordifolia (Schum. & Thonn.) Müll. Arg.
40	mph	GC	Sapindaceae	Allophyllus spicatus (Poir.) Radlk.
41	mph	GC	Sapindaceae	Allophyllus africanus P. Beauv. syn A. cobbe (L.) Raeusch.
42	Th	TA	Poaceae	Alloteropsis paniculata (Benth.) Stapf. syn. Urochloa paniculata Benth.
43	Th	Pan	Amaranthaceae	Alternanthera sessilis (L.) DC.
44	Th	Cosmo	Amaranthaceae	Amaranthus hybridus L.
45	Th	Pan	Amaranthaceae	Amaranthus spinosus L.
46	Th	Pan	Amaranthaceae	Amaranthus viridis L.
47	mPh	S	Papilionnaceae	Amblygonocarpus andongensis (Welw. ex Oliv.) Exell & Torre syn. Tetrapleura andongensis
48	Ge	G	Araceae	Amorphophallus aphyllus (Hook.) Hutch.
49	Ge	G	Araceae	Amorphophallus dracontioides (Engl.) N. E. Br.
50	Ge	G	Araceae	Amorphophallus flavovirens N. E. Br.
51	Ge	G	Araceae	Amorphophallus johnsonii N. E. Br.
52	Lmph	GC	Vitaceae	Ampelocissus bombycina Planch.
53	Lmph	GC	Vitaceae	Ampelocissus leonensis (Hook. f.) Planch.
54	Lmph	PRA	Vitaceae	Ampelocissus multistriata (Baker) Planch. syn. A. pentaphylla (Guill. & Perr.) Gilg. & Brandt
55	mph	Pan	Anacardiaceae	Anacardium occidentale L.
56	Ge	G	Araceae	Anchomanes difformis (Blume) Engl.
57	Ge	SZ	Araceae	Anchomanes welwitschii Rendle

58	Lmph	GC	Apocynaceae	Ancylobotrys scandens (Schumach. & Thonn.) Pichon
59	mph	SZ	Papilionaceae	Andira inermis (Wright) DC. subsp. rooseveltii (De Wild.) Gillett ex Polhill
60	He	SG	Poaceae	Andropogon gayanus Kunth. var. bisquamulatus (Hochst.) Hack.
61	He	SG	Poaceae	Andropogon gayanus Kunth. var. gayanus
62	He	SG	Poaceae	Andropogon gayanus Kunth. var. polycladus (H.) W.D. Clayton syn. A. gayanus var. squamulatus
63	He	GC	Poaceae	Andropogon macrophyllus Stapf.
64	He	_	Poaceae	Andropogon sp.
65	He	SG	Poaceae	Andropogon tectorum Schum. & Thonn.
66	He	GC	Commelinaceae	Aneilema beninense (P. Beauv.) Kunth
67	He	TA	Commelinaceae	Aneilema dispermum Brenan
68	He	GC	Commelinaceae	Aneilema umbrosum (Vahl) Kunth
69	Lnph	Pan	Convolvulaceae	Aniseia martinicensis (Jacq.) Choisy
70	Lmph	G	Asclepiadaceae	Anisopus manii N.E.Br.
71	nph	PRA	Annonaceae	Annona senegalensis Pers.
72	mPh	PRA	Combretaceae	Anogeissus leiocarpa (DC.) Guill. & Perr. syn. A. leiocarpus (DC.) Guill. & Perr.
73	Ge	_	Liliaceae	Anthericum sp.
74	Th	PRA	Melastomataceae	Antherotoma naudini Hook. F.
75	mPh	TA	Loganiaceae	Anthocleista djalonensis A. Chev.
76	mPh	G	Loganiaceae	Anthocleista nobilis G. Don
77	mPh	GC	Loganiaceae	Anthocleista vogelii Planch.
78	MPh	GC	Moraceae	Antiaris toxicaria Lesch. var africana A. Chev. syn. A. africana Engl.
79	mph	GC	Euphorbiaceae	Antidesma membranaceum Müll. Arg.
80	mph	TA	Euphorbiaceae	Antidesma venosum Tul.
81	mph	GC	Sapindaceae	Aphania senegalensis (Juss. ex Poir.) Radlk. syn. Lepisanthes senegalensis (Juss. ex Poir.) Leenh
82	LGe	SG	Aristolochiaceae	Aristolochia albida Duchartre
83	LGe	AA	Aristolochiaceae	Aristolochia ringens Vahl.
84	Lnph	GC	Annonaceae	Artabotrys velutinus Sc. Elliot
85	Ge(Fern)	TA	Davalliaceae	Artopteris orientalis (Gmel.) Posth.
86	Lnph	SZ	Liliaceae	Asparagus africanus Lams
87	Th	TA	Asteraceae	Aspilia africana (Pers.) C.D. Adams
88	Th	GC	Asteraceae	Aspilia angustifolia Oliv. &Hiern.
89	Th	G	Asteraceae	Aspilia bussei (Schum. & Thonn.) Oliv. & Hiern
90	Th	G	Asteraceae	Aspilia paludosa Berhaut
91	Ch	SG	Asteraceae	Aspilia rudis C. D. Adams subsp. fontinaloides Adams
92	Ge(Fern)	GC	Aspleniaceae	Asplenium diplazorum Hieron.
93	Th	G	Acanthaceae	Asystasia calycina Benth.
94	Th	Pan	Acanthaceae	Asystasia gangetica (L.) T. Anders
95	He	Pan	Poaceae	Axonopus flexuosus (Peter) C.E. Hubbard ex Troupin
96	mPh	Paleo	Meliaceae	Azadirachta indica A. Juss.
97	mph	SZ	Balanitaceae	Balanites aegyptiaca (L.) Del.
98	He	Pan	Poaceae	Bambusa vulgaris Schrader ex Wendel.
99	Lnph	SG	Acanthaceae	Barleria oenotheroides Dum.
100	Th	TA	Lamiaceae	Basilicum ploystachion (L.) Moench.
101	mPh	TA	Caesalpiniaceae	Berlinia grandiflora (Vahl) Hutch. & Dalz.
102	Th	Pan	Asteraceae	Bidens pilosa L.
103	Th	Pan	Oxalidaceae	Biophytum umbraculum Welw. syn. B. petersianum Klotszch
104	Ch	TA	Acanthaceae	Blepharis maderaspatensis (L.) Heyne ex Roth.
105	mPh	Pan	Sapindaceae	Blighia sapida Koenig
106	mph	GC	Sapindaceae	Blighia unijugata Baker
107	Th	SG	Asteraceae	Blumea viscosa (Mill.) Badillo syn. B. aurita DC.
108	Th	SG	Nyctaginaceae	Boerhavia coccinea Mill.
109	Th	Pan	Nyctaginaceae	Boerhavia diffusa L.
110	Th	Cosmo	Nyctaginaceae	Boerhavia erecta L.
111	Ge(Fern)	PRA	Lomariopsidaceae	Bolbitis heudelotii (Bory ex Fee) Aston
112	mPh	SZ	Bombacaceae	Bombax costatum Pellegr. & Vuill.
113	mPh	SZ	Arecaceae	Borassus aethiopum Mart.
114	He	TA	Poaceae	Brachiaria brizantha (Hochst. ex A. Rich.) Stapf
115	Th	Paleo	Poaceae	Brachiaria deflexa (Schumach.) Robyns
116	He	SZ	Poaceae	Brachiaria jubata (Figari & De Notaris) Stapf.
117	Th	Paleo	Poaceae	Brachiaria lata (Schumach.) C.E. Hubbard

118	He	_	Poaceae	Brachiaria sp.
119	Th	SZ	Poaceae	Brachiaria villosa (Lam.) A. camus syn. B. distichophylla (Trin.) Stapf.
120	mph	GC	Euphorbiaceae	Bridelia atroviridis Müll. Arg.
121	mph	SZ	Euphorbiaceae	Bridelia ferruginea Benth.
122	mPh	TA	Euphorbiaceae	Bridelia micrantha (Hochst.) Baill.
123	mph	SC	Euphorbiaceae	Bridelia scleroneura Müll. Arg.
124	mPh	SZ	Rubiaceae	Brenadia salicina (Vahl) Hepper & Wood syn. Adina microcephala (Del.) Hiern
125	Th	Pan	Cyperaceae	Bulbostylis barbata (Rottb.) C.B.Cl.
126	Ge	_	Cyperaceae	Bulbostylis sp.
127	mph	SZ	Caesalpiniaceae	Burkea africana Hook.
128	nph	Paleo	Capparidaceae	Cadaba farinosa Forsk.
129	nph	Paleo	Papilionaceae	Cajanus cajan (L.) Millsp.
130	nph	GC	Apocynaceae	Callichilia barteri (Hook. f.) Stapf syn. Hedranthera brateri (Hook. f.) pichon
131	Ep(fern)	GC	Orchidaceae	Calyptrochilum christyanum (Rchb. f.) Summerh.
132	Ep(fern)	GC	Orchidaceae	Calyptrochilum emarginatum (Sw.) Schltr.
133	nph	GC	Ochnaceae	Campylospermum flavum (Schumach.&Thonn. ex Stapf) Farron syn. Ouratea flava
134	nph	SG	Ochnaceae	Campylospermum glaberrimum (P. Beauv.) Farron syn. Ouratea glaberrima
135	mph	GC	Ochnaceae	Campylospermum reticulatum (P.Beauv) Farron var. reticulatus syn. Ouratea reticulata
136	Lmph	GC	Celastraceae	Campylostemon warneckeanum Loes. ex Fritsch
137	Lmph	Pan	Papilionaceae	Canavalia ensiformis (L.) DC.
138	Th	Pan	Gentinaceae	Canscora decussata (Roxb.) Roem. & Schult.
139	Th	Pan	Gentinaceae	Canscora diffusa (Vahl) R. Br. ex Roem. & Schult
140	Lnph	SG	Rubiaceae	Canthium cornelia Cham. & Schlecht.
141	Lnph	GC	Rubiaceae	Canthium henriquesianum (K. Schum.) G. Tayl.
142	Lnph	SG	Rubiaceae	Canthium horizontale (Schum. & Thonn.) Hiern
143	Lnph	GC	Rubiaceae	Canthium setosum Hiern
144	mph	TA	Rubiaceae	Canthium vulgare (K. Schum.) Bullock. F.R.
145	Th	GC	Euphorbiaceae	Caperonia senegalensis Müll. Arg.
146	nph	S	Capparidaceae	Capparis decidua (Forsk.) Edgew.
147	Lnph	SZ	Capparidaceae	Capparis sepiaria L. var. fischeri (Pax) De Wolf syn. C. corymbosa Lam.
148	Lmph	G	Capparidaceae	Capparis thonningii Schum. syn. C. brassii DC.
149	Lnph	G	Capparidaceae	Capparis viminea Hook. f. & Th. ex. Oliv. var. viminea
150	Th	Pan	Solanaceae	Capsicum frutescens L.
151	Lnph	AA	Sapindaceae	Cardiospermum grandiflorum Swartz
152	Lnph	Pan	Sapindaceae	Cardiospermum halicacabum L.
153	mph	Pan	Caricaceae	Carica papaya L.
154	mph	SZ	Caesalpiniaceae	Cassia sieberiana DC.
155	Ch	_	Caesalpiniaceae	Cassia sp.
156	mPh	GC	Rhizophoraceae	Cassipourea congoensis R. Br. ex DC.
157	Par	Pan	Lauraceae	Cassytha filiformis Linn.
158	MPh	Pan	Bombacaceae	Ceiba pentandra (L.) Gaertn.
159	Th	Paleo	Amaranthaceae	Celosia argentea L.
160	LTh	GC	Amaranthaceae	Celosia isertii C. Towns. syn. C. laxa Schum. & Thonn.
161	LTh	Paleo	Amaranthaceae	Celosia trigyna L.
162	mPh	SZ	Ulmaceae	Celtis toka (Forssk) Hepper & Wood syn. C. integrifolia
163	Th	G	Poaceae	Centosteca latifolia (Osb.) Trin. syn. C. lappacea (L.) Desv.
164	Lnph	AA	Papilionaceae	Centrosema pubescens Benth.
165	Th	TA	Adiantaceae	Ceratopterix cornuta (P. Beauv.) Lepr.
166	Ge	G	Asclepiadaceae	Ceropegia fusiformis N. E. Br.
167	Ge	_	Asclepiadaceae	Ceropegia sp.
168	Ge	G	Asclepiadaceae	Ceropegia yorubana Schlechter
169	nph	Pan	Caesalpiniaceae	Chamaecrista mimosoides (L.) Greene syn. Cassia mimosoides L.
170	Lnph	GC	Menispermaceae	Chasmanthera dependens Hochst.
171	Th	SZ	Poaceae	Chasmopodium caudatum (Hack.) Stapf
172	nph	GC	Rubiaceae	Chassalia kolly (Schumach.) Hepper
173	mph	SZ	Oleaceae	Chionanthus niloticus (Oliv.) Stearn syn. Linociera nilotica Oliv.
174	He	PRA	Poaceae	Chloris gayana Kunth
175	He	GC	Liliaceae	Chlorophytum alismifolium Baker
176	He	GC	Liliaceae	Chlorophytum andongense Baker
177	He	PRA	Liliaceae	Chlorophytum blepharophyllum Schweinf. ex. Baker

178	He	GC	Liliaceae	Chlorophytum macrophyllum (A. Rich.) Aschers.
179	Ge	_	Liliaceae	Chlorophytum sp.
180	Ge	SG	Liliaceae	Chlorophytum togoense Engl.
181	Ch	Pan	Asteraceae	Chromolaena odorata (L.) R.M.King & H. Robinson
182	mPh	SC	Chrysobalanaceae	Chrysobalanus icaco L. subsp. atacorensis
183	Lnph	SZ	Menispermaceae	Cissampelos mucronata A. Rich.
184	Lnph	GC	Menispermaceae	Cissampelos owariensis P. Beauv. ex DC.
185	Lnph	TA	Vitaceae	Cissus aralioides (Welw. ex Baker) Planch.
186	Lnph	PRA	Vitaceae	Cissus cymosa Schum. & Thonn.
187	Lnph	G	Vitaceae	Cissus glaucophylla Hook.
188	Lnph	TA	Vitaceae	Cissus gracilis Guill. & Perr.
189	Lnph	S	Vitaceae	Cissus kouandeensis A. Chev.
190	Lnph	SG	Vitaceae	Cissus palmatifida (Baker) Planch.
191	Lnph	PRA	Vitaceae	Cissus petiolata Hook. f.
192	Lmph	PRA	Vitaceae	Cissus populnea Guill. & Perr. var. populnea
193	LTh	TA	Vitaceae	Cissus rubiginosa (Welw. ex Baker) Planch
194	LGe	PRA	Vitaceae	Cissus rufescens Guill. & Perr.
195	LTh	_	Vitaceae	Cissus sp.
196	mph	Pan	Aurantiaceae	Citrus limonum Risso
197	nph	TA	Rutaceae	Clausena anisata (Willd.) Benth.
198	mPh	GC	Annonaceae	Cleistopholis patens (Benth.) Engl. & Diels
199	Th	S	Cappariadaceae	Cleome rutidosperma DC. syn. C. ciliata Schum. & Thonn.
200	Th	SG	Cappariadaceae	Cleome viscosa L.
201	Lnph	PRA	Verbenaceae	Clerodendrum capitatum (Willd.) Schum. & Thonn.
202	Lnph	GC	Verbenaceae	Clerodendrum dusenii Gurke
203	Lnph	GC	Verbenaceae	Clerodendrum polycephalum Baker
204	Lnph	Paleo	Cucurbitaceae	Coccinia grandis L.
205	nph	SG	Cochlospermaceae	Cochlospermum planchonii Hook. f.
206	MPh	GC	Sterculiaceae	Cola gigantea A. Chev.
207	mPh	GC	Sterculiaceae	Cola laurifolia Mast.
208	mph	G	Sterculiaceae	Cola millenii K. Schum.
209	Lmph	S	Combretaceae	Combretum acutum Laws.
210	mph	SG	Combretaceae	Combretum adenogonium Steud. ex A. Rich. syn. C.ghasalense Engl. & Diels
211	mph	SG	Combretaceae	Combretum collinum Fresen subsp. collinum
212	mph	S	Combretaceae	Combretum collinum Fresen subsp. hypopilinum
213	mph	SZ	Combretaceae	Combretum glutinosum Perr. ex DC.
214	Lnph	G	Combretaceae	Combretum lecardii Engl. & Diels
215	mph	SZ	Combretaceae	Combretum molle R. Br. ex G. Don
216	LmPh	GC	Combretaceae	Combretum mucronatum Schum. & Thonn. syn. C. smeathmannii G. Don
217	mph	SG	Combretaceae	Combretum nigricans Lepr. ex Guill. & Perr.
218	LmPh	TA	Combretaceae	Combretum paniculatum Vent.
219	Lmph	GC	Combretaceae	Combretum racemosum P. Beauv.
220	Lnph	G	Combretaceae	Combretum tomentosum G. Don
221	He	GC	Commelinaceae	Commelina benghalensis L. var. bengalensis
222	He	Pan	Commelinaceae	Commelina diffusa Bum. f. subsp. diffusa
223	He	Cosmo	Commelinaceae	Commelina erecta L. subsp. erecta
224	He	TA	Commelinaceae	Commelina erecta subsp livingstonei (C.B. Cl.) J. K. Morton
225	Th	PRA	Commelinaceae	Commelina nigritana Benth.
226	He	_	Commelinaceae	Commelina sp.
227	He	G	Commelinaceae	Commelina thomasii Hutch.
228	Lmph	SG	Connaraceae	Connarus africanus Lam.
229	Th	Pan	Tiliaceae	Corchorus aestuans L.
230	Th	Pan	Tiliaceae	Corchorus fascicularis Lam.
231	Th	Pan	Tiliaceae	Corchorus olitorius L.
232	mph	TA	Boraginaceae	Cordia africana Lam.
233	mph	Paleo	Boraginaceae	Cordia myxa L.
234	nph	GC	Boraginaceae	Cordia senegalensis Juss.
235	Ge	TA	Zingiberaceae	Costus afer Ker-Gawl.
236	mph	Paleo	Cappariadaceae	Crateva adansonii DC. subsp. adansonii syn. C. religiosa auct. Afr. Fl. non Forst. f.
237	Lmph	TA	Rubiaceae	Cremaspora triflora (Thonn.) K. Schum.

238	Ge	SG	Amaryllidaceae	Crinum glaucum A. Chev.
239	Ge	GC	Amaryllidaceae	Crinum jagus (Thomps.) Dandy
240	Ge	SG	Amaryllidaceae	Crinum zeylanicum (L.) L. syn. C. ornatum (Alt.) Bury
241	mph	SZ	Rubiaceae	Crossopteryx febrifuga (G. Don) Benth.
242	Th	Pan	Papilionaceae	Crotalaria calycina Schrank
243	Ch	TA	Papilionaceae	Crotalaria cephalotes Steud. ex A. Rich.
244	Th	SC	Papilionaceae	Crotalaria comosa Baker
245	Th	S	Papilionaceae	Crotalaria deightonii Hepper
246	Th	PRA	Papilionaceae	Crotalaria hyssopifolia Klotszch
247	Ch	PRA	Papilionaceae	Crotalaria lachnosema Stapf
248	Ch	Pan	Papilionaceae	Crotalaria pallida var. mucronata Desv.
249	Ch	Pan	Papilionaceae	Crotalaria retusa L.
250	Th	_	Papilionaceae	Crotalaria sp.
251	Th	Pan	Euphorbiaceae	Croton lobatus L.
252	Lmph	SG	Asclepiadaceae	Cryptolepis sanguinolenta (Lind.) Schltr.
253	Th	Pan	Poaceae	Ctenium newtonii Hack
254	Lnph	PRA	Cucurbitaceae	Cucumis metuliferus E. Mey. ex Naudin
255	Lmph	G	Araceae	Culcasia scandens P. Beauv.
256	Ge	PRA	Hypoxidaceae	Curculigo pilosa (Schum. & Thonn.) Engl.
257	mph	SG	Araliaceae	Cussonia arborea Hochst. ex A. Rich. syn. C. barteri Seem. & C. kirkii Seem.
258	nph	GC	Amaranthaceae	Cyathula achyranthoides (H. B. et K.) Moq
259	Th	Pan	Amaranthaceae	Cyathula prostrata (L.) Blume
260	Ch	GC	Thelypteridaceae	Cyclosorus striatus Cop.
261	mPh	GC	Caesalpiniaceae	Cynometra megalophylla Harms
262	Ge	Pan	Cyperaceae	Cyperus difformis L.
263	Ge	Pan	Cyperaceae	Cyperus distans L.f.
264	Ge	Pan	Cyperaceae	Cyperus haspan L.
265	Ge	_	Cyperaceae	Cyperus sp.
266	Th	Pan	Cyperaceae	Cyperus sphacelatus Rottb.
267	LGe	_	Vitaceae	Cyphostema sp.
268	Th	Pan	Poaceae	Dactyloctenium aegyptium (L.) P.Beauv
269	Lmph	GC	Papilionaceae	Dalbergia dalzielii Baker f. ex. Hutch. & Dalz.
270	Lmph	PRA	Papilionaceae	Dalbergia lactea Vatke
271	Lmph	G	Papilionaceae	Dalbergia rufa G. Don
272	Lmph	GC	Papilionaceae	Dalbergia saxatilis Hook. f. var. saxatilis
273	LmPh	GC	Papilionaceae	Dalbergiella welwitschii (Baker) Baker f.
274	mPh	SG	Caesalpiniaceae	Daniellia oliveri (Rolfe) Hutch. & Dalz.
275	mPh	Pan	Caesalpiniaceae	Delonix regia (Boj. ex Hook.) Raf.
276	mph	G	Annonaceae	Dennettia tripetala Baker f.
277	Ch	AA	Papilionaceae	Desmodium adscendens (Sw.) DC var. adscendens
278	Ch	AA	Papilionaceae	Desmodium adscendens (Sw.) DC var. robustrum Schubert
279	nph	GC	Papilionaceae	Desmodium gangeticum (L.) DC.
280	Th	TA	Papilionaceae	Desmodium hirtum Guill. & Perr.
281	Th	PRA	Papilionaceae	Desmodium ramosissimum G. Don
282	Ch	GC	Papilionaceae	Desmodium salicifolium (Poir.) DC. var. salicifolium
283	Th	_	Papilionaceae	Desmodium sp1.
284	LTh	_	Papilionaceae	Desmodium sp2.
285	Lnph	Pan	Papilionaceae	Desmodium triflorum (L.) DC.
286	Ch	Pan	Papilionaceae	Desmodium velutinum (Willd.) DC.
287	mph	SZ	Caesalpiniaceae	Detarium microcarpum Harms
288	mPh	GC	Caesalpiniaceae	Detarium senegalense J. F. Gmelin
289	mPh	GC	Caesalpiniaceae	Dialium guineense Willd.
290	mph	G	Dichapetalaceae	Dichapetalum madagascariense Poir var. madagascariense syn. D. guineense
291	nph	TA	Mimosaceae	Dichrostachys cinerea (L.) Wight & Arn
292	Th	TA	Poaceae	Digitaria argyrotricha (Anderss.) Chiov.
293	Th	TA	Poaceae	Digitaria ciliaris (Retz.) Koel.
294	Th	Pan	Poaceae	Digitaria gayana (Kunth) Stapf ex A. Chev.
295	Th	Pan	Poaceae	Digitaria horizontalis Willd. ssp. proximus (Hocht. ex A.Rich.) Maire & Weiler
296	Th	_	Poaceae	Digitaria sp.
297	Lnph	_	Dilleniaceae	Dillenia sp.

298	Lmph	Pan	Papilionaceae	Dioclea reflexa Hook. f.
299	LTh	Pan	Rubiaceae	Diodia sarmentosa Sw. syn. D. scandens auctt
300	LGe	SG	Dioscoraceae	Dioscorea abyssinica Hochst. ex Kunth.
301	LGe	Pan	Dioscoraceae	Dioscorea bulbifera L. var. bulbifera
302	LGe	SZ	Dioscoraceae	Dioscorea dumetorum (Kunth) Pax
303	LGe	SZ	Dioscoraceae	Dioscorea hirtiflora Benth. subsp. hirtiflora
304	LGe	SG	Dioscoraceae	Dioscorea lecardii De Wild.
305	LGe	GC	Dioscoraceae	Dioscorea multiflora Pax syn. D. minutiflora Engl.
306	LGe	SG	Dioscoraceae	Dioscorea odoratissima Pax syn. D. praehensilis Benth.
307	LGe	GC	Dioscoraceae	Dioscorea preussii Pax
308	LGe	SG	Dioscoraceae	Dioscorea sagittifolia Pax
309	LGe	GC	Dioscoraceae	Dioscorea sansibarensis Pax
310	LGe	_	Dioscoraceae	Dioscorea sp.
311	LGe	GC	Dioscoraceae	Dioscorea togoensis Kunth syn. D. callei A. Chev. ex De Wild.
312	Lnph	_	Menispermaceae	Dioscoreophyllum sp.
313	mPh	GC	Ebenaceae	Diospyros abyssinica (Hiern) White
314	mPh	SZ	Ebenaceae	Diospyros mespiliformis Hochst. ex A. DC.
315	mph	GC	Ebenaceae	Diospyros monbuttensis Gürke
316	Ge(fern)	GC	Athyriaceae	Diplazium sammatii (Kuhn) C. Chr.
317	Ch	GC	Umbelliferae	Diplolophium africanum Turcz.
318	Ge	SG	Melastomataceae	Dissotis anthennima (Sm.) Triana
319	Ge	S	Melastomataceae	Dissotis grandiflora (Sm.) Benth. var. lambii (Hutch.) Keay
320	Ge	S	Melastomataceae	Dissotis irvingiana Hook. syn. D. senegambiensis (Guill. & Rev.) triana
321	Ch	_	Melastomataceae	Dissotis sp.
322	mPh	GC	Sterculiaceae	Dombeya ledermanii Engl.
323	mph	TA	Sterculiaceae	Dombeya quinqueseta (Del.) Exell
324	mph	G	Agavaceae	Dracaena arborea Baker
325	mph	GC	Euphorbiaceae	Drypetes floribunda (Müll. Arg.) Hutch.
326	Ch	G	Acanthaceae	Dyschoriste heudelotiana (Nees) O. Ktze.
327	Th	TA	Acanthaceae	Dyschoriste perrottetii (Nees) O. Kuntze
328	Th	Pan	Poaceae	Echinochloa colona (L.) Link. syn. E. colonum (L.) Link.
329	Th	Pan	Asteraceae	Eclipta prostata (L.) L.
330	mPh	SZ	Meliaceae	Ekebergia capensis Sparrm. syn. E. senegalensis A. Juss.
331	mPh	GC	Arecaceae	Elaeis guineensis Jacq.
332	Ch	Pan	Asteraceae	Elephantopus mollis Kunth
333	Th	SG	Asteraceae	Elephantopus senegalensis (Klatt) Oliv. & Hiern
334	Th	Pan	Poaceae	Eleusine indica Gaertn.
335	He	SZ	Poaceae	Elymandra androphila (Stapf) Stapf
336	He	GC	Acanthaceae	Elytraria marginata Vahl
337	Th	SG	Lamiaceae	Englerastrum gracillimum Th. C. E. Fries
338	Th	PRA	Lamiaceae	Englerastrum schweinfurthii Briq.
339	mph	TA	Mimosaceae	Entada abyssinica Steud. ex A. Rich.
340	mph	PRA	Mimosaceae	Entada africana Guill. & Perr.
341	Lmph	GC	Mimosaceae	Entada mannii (Oliv.) Tisserant
342	He	Paleo	Poaceae	Eragrostis atrovirens (Desf.) Trin. ex Steud. (Hochst. ex A. Rich.) Maire & Weiler
343	Th	_	Poaceae	Eragrostis sp.
344	Th	Paleo	Poaceae	Eragrostis tremula Horst. & Steud.
345	nph	GC	Acanthaceae	Eremomastax speciosa (Hochst.) Cuf.
346	mPh	GC	Sapindaceae	Eriocoelum kerstingii Gilg. ex Engl. var. kerstingii
347	Ch	PRA	Papilionaceae	Eriosema glomeratum (Guill & Perr) Hook.f. syn. Rhynchosia glomerata Guill. & Perr.
348	Ch	Pan	Papilionaceae	Eriosema psoraleoides (Lam.) G. Don syn. Crotaliaria psoralioides Lam.
349	mPh	GC	Papilionaceae	Erythrina excelsa Baker
350	mph	SG	Papilionaceae	Erythrina senegalensis A. DC.
351	mPh	GC	Caesalpiniaceae	Erythrophleum africanum (Wel. ex Benth.) Harms
352	mPh	GC	Caesalpiniaceae	Erythrophleum suaveolens (Guill. & Pierr.) Brenan syn. E. guineense G. Don
353	mph	TA	Erytroxylaceae	Erythroxylum emarginatum Thonn.
354	mph	GC	Capparidaceae	Euadenia trifoliolata (Schum. & Thonn.) Oliv.
355	Th	Pan	Poaceae	Euclasta condylotricha (Steud.) Stapf (Hochst. ex A. Rich.) Maire & Weiler
356	Ge	PRA	Orchidaceae	Eulophia guineensis Lindl.
357	Ge	PRA	Orchiadaceae	Eulophia quartiniana A. Rich.

358	Th	AA	Asteraceae	Eupatorium microstemon Cass.
359	Th	Pan	Asteraceae	Eupatorium triplinerve Vahl.
360	Th	Paleo	Euphorbiaceae	Euphorbia aegyptiaca Boiss.
361	Th	AA	Euphorbiaceae	Euphorbia glomerifera (Millesp.) Wheeler
362	Th	Pan	Euphorbiaceae	Euphorbia heterophylla L.
363	Th	Pan	Euphorbiaceae	Euphorbia hirta L.
364	Th	AA	Euphorbiaceae	Euphorbia hyssopifolia L.
365	Th	-	Euphorbiaceae	Euphorbia sp.
366	Th	Pan	Euphorbiaceae	Euphorbia thymifolia L.
367	Ch	S	Euphorbiaceae	Excoecaria grahamii Stapf. syn. Sapium grahamii (Stapf) Prain
368	nph	SZ	Rubiaceae	Feretia apodanthera Del.
369	nph	GC	Moraceae	Ficus asperifolia Miq.
370	mph	SZ	Moraceae	Ficus capreifolia Del.
371	mPh	SC	Moraceae	Ficus congensis Engl. syn. Ficus trichopoda Baker
372	mph	GC	Moraceae	Ficus cordata Thunb. Warb.
373	mph	GC	Moraceae	Ficus dicranostyla Mildbr.
374	mPh	TA	Moraceae	Ficus exasperata Vahl
375	mPh	SZ	Moraceae	Ficus glumosa Del.
376	mPh	SZ	Moraceae	Ficus ingens (Miq.) Miq.
377	mph	S	Moraceae	Ficus kerstingii Hutch. syn. Ficus abutilifolia (Miq.) Miq.
378	mPh	GC	Moraceae	Ficus lyrata Warb.
379	mph	SC	Moraceae	Ficus ovata Vahl
380	MPh	SG	Moraceae	Ficus platyphylla Del.
381	mPh	GC	Moraceae	Ficus polita Vahl
382	mph	_	Moraceae	Ficus sp.
383	mph	SG	Moraceae	Ficus sur Forssk. syn. Ficus capensis Thunb.
384	mph	SZ	Moraceae	Ficus sycomorus L. subsp. gnaphalocarpa (Miq.) Berg
385	mPh	TA	Moraceae	Ficus sycomorus L. var psychomorus
386	mph	G	Moraceae	Ficus tesselata Warb.
387	mph	TA	Moraceae	Ficus thonningii Blume syn. F. basarensis Mildbr. & Burret
388	mPh	GC	Moraceae	Ficus vogeliana (Miq.) Miq.
389	mph	GC	Moraceae	Ficus vogelii (Miq.) Miq.
390	He	Pan	Cyperaceae	Fimbristylis dichotoma (L.) Vahl subsp. dichotoma
391	He	SG	Cyperaceae	Fimbristylis hispidula (Vahl.) Kunth
392	Th	_	Cyperaceae	Fimbristylis sp.
393	Lmph	GC	Malpighiaceae	Flabellaria paniculata Cav.
394	mph	GC	Flacourtiaceae	Flacourtia flavescens Willd.
395	Lnph	GC	Flagellariaceae	Flagellaria guineensis Schumacher
396	He	GC	Commelinaceae	Floscopa africana (P. Beauv.) C. B. Clarke
397	Th	SZ	Commelinaceae	Floscopa flavida C. B. Cl.
398	nph	Pan	Euphorbiaceae	Flueggea virosa (Roxb ex Willd) Voigt subsp.virosa syn. Securinega virosa (Roxb ex Willd)
399	Th	TA	Urticaceae	Fluerya aestuans (L.) ex Miq.
400	Ch	TA	Urticaceae	Fluerya ovalifolia (Schum. & Thonn.) Dandy
401	Th	_	Cyperaceae	Fuirena sp.
402	Th	PRA	Cyperaceae	Fuirena stricta Steud.
403	mPh	GC	Apocynaceae	Funtumia africana (Benth.) Stapf
404	mPh	GC	Apocynaceae	Funtumia elastica (Preuss) Stapf
405	mph	GC	Rubiaceae	Gaertnera paniculata Benth.
406	mPh	SZ	Clusiaceae	Garcinia livingstonei T. Anders.
407	mph	SZ	Clusiaceae	Garcinia ovalifolia Oliv.
408	nph	SG	Rubiaceae	Gardenia erubescens Stapf & Hutch.
409	mph	GC	Rubiaceae	Gardenia imperialis K. Schum.
410	nph	_	Rubiaceae	Gardenia sp.
411	nph	SG	Rubiaceae	Gardenia ternifolia Schum. & Thonn. syn. G. triacantha DC.
412	LTh	GC	Rubiaceae	Geophila obvallata (Schumach.) F. Didr.
413	LTh	Pan	Rubiaceae	Geophila reniformis D. Don syn. G. repens (L.) I.M. Johnston
414	Th	Paleo	Molluginaceae	Gisekia pharnacioides L.
415	Ch	_	Iridaceae	Gladiolus sp.
416	Th	Pan	Molluginaceae	Glinus oppositifolus (L.) Aug. DC.
417	LGe	GC	Liliaceae	Gloriosa superba L. syn. G. simplex L.

418	mph	TA	Tiliaceae	Glyphaea brevis (Spreng.) Monachino
419	mPh	Pan	Verbenaceae	Gmelina arborea Roxb.
420	Lmph	TA	Asclepiadaceae	Gongronema latifolium Benth.
421	Ep	PRA	Orchidaceae	Graphorkis lurida (Sw.) O. Ktze.
422	Lmph	GC	Tiliaceae	Grewia carpinifolia Juss.
423	nph	Paleo	Tiliaceae	Grewia flavescens Juss.
424	nph	SZ	Tiliaceae	Grewia mollis Juss. var. mollis syn. G. pubescens P. Beauv.
425	nph	Paleo	Tiliaceae	Grewia ternax (Forssk.)
426	Lnph	Pan	Asclepiadaceae	Gymnema sylvestre (Retz.) Schultes
427	Ge	PRA	Orchidaceae	Habenaria laurantii De Wild.
428	Ge	TA	Amaryllidaceae	Haementhus multiforus Martyn
429	MPh	GC	Simaroubaceae	Hannoa klaineana Pierre & Engl. syn. Quassia undulata (Guill. & Perr.) D. Dietr.
430	Th	Pan	Boraginaceae	Heliotropium indicum L.
431	Ch	Paleo	Boraginaceae	Heliotropium strigosum Willd.
432	Th	SG	Compositeae	Herderia truncata Cass.
433	mPh	GC	Annonaceae	Hexalobus crispiflorus A. Rich.
434	mph	SZ	Annonaceae	Hexalobus monopetalus (A. Rich.) Engl. & Diels var. monopetalus
435	Th	TA	Malvaceae	Hibiscus asper Hook. F.
436	Th	TA	Malvaceae	Hibiscus esculentus L.
437	nph	G	Malvaceae	Hibiscus grewioides Baker. F.
438	Ch	Paleo	Malvaceae	Hibiscus lunariifolis Willd.
439	Ch	Paleo	Malvaceae	Hibiscus micranthus L.
440	Lmph	Pan	Malvaceae	Hibiscus panduriformis Burm. f.
441	Ch	PRA	Malvaceae	Hibiscus physaloides Guill. & Perr.
442	Ch	TA	Malvaceae	Hibiscus rostellatus Guill. & Perr.
443	Ch	Pan	Malvaceae	Hibiscus sabdariffa L.
444	Ch	PRA	Malvaceae	Hibiscus sidiformis Baill.
445	nph	_	Malvaceae	Hibiscus sp.
446	Th	Pan	Malvaceae	Hibiscus surratensis L.
447	Lmph	GC	Hippocrateaceaae	Hippocratea welwitchii Oliv. syn. Simirestis welwitchii (Oliv.) Halle
448	mPh	TA	Apocynaceae	Holarrhena floribunda (G. Don) Dur. & Schinz
449	nph	PRA	Lamiaceae	Hoslundia opposita Vahl
450	Ch	Pan	Violaceae	Hybanthus enneaspermus (L.) F. Muell.
451	Th	PRA	Hippocrateaceaae	Hydrolea glabra Schum. & Thonn.
452	Th	Pan	Acanthaceae	Hygrophila auriculata (Schumach.) Heine
453	Th	_	Acanthaceae	Hygrophila sp.
454	mph	SZ	Euphorbiaceae	Hymenocardia acida Tul. var. acida
455	nph	PRA	Rubiaceae	Hymenodiction floribundum (Steud. & Hochst.) B.L.Rob.
456	Th	S	Poaceae	Hyparrhenia involucrata Stapf
457	He	Pan	Poaceae	Hyparrhenia rufa (Nees) Stapf
458	Th	_	Poaceae	Hyparrhenia sp.
459	Th	GC	Acanthaceae	Hypoestes cancellata Nees
460	Th	_	Acanthaceae	Hypoestes sp.
461	Ge	GC	Marantaceae	Hypselodelphys violacea (Ridley) Milne. Redh.
462	Ge	GC	Marantaceae	Hypselodelphys poggeana (K. Schum.) Milne-Redh.
463	Th	AA	Lamiaceae	Hyptis lanceolata Poir
464	Th	Paleo	Lamiaceae	Hyptis spicigera Lam.
465	Th	Pan	Lamiaceae	Hyptis suaveolens Poit.
466	He	Pan	Poaceae	Imperata cylindrica (L.) Raeuschel
467	Th	SZ	Papilionaceae	Indigofera dendroides Jacq.
468	Th	GC	Papilionaceae	Indigofera geminata Baker
469	Ch	SG	Papilionaceae	Indigofera hirsuta L. var hirsuta
470	Th	GC	Papilionaceae	Indigofera longicalyx Gillett
471	Lnph	GC	Papilionaceae	Indigofera macrophylla Schum.
472	Ch	GC	Papilionaceae	Indigofera nigritana Hook. f.
473	Th	PRA	Papilionaceae	Indigofera polysphaera Baker
474	Ch	TA	Papilionaceae	Indigofera rhynchocarpa Baker
475	Th	S	Papilionaceae	Indigofera secundiflora Poir.
476	Th	_	Papilionaceae	Indigofera sp.
477	Th	Pan	Papilionaceae	Indigofera subulata Vahl ex Poir.

478	Ch	TA	Papilionaceae	Indigofera trita L.f.
479	Lnph	S	Convolvulaceae	Ipomoea acanthocarpa (Hochst. ex Choisy) Aschers. & Schweinf.
480	LGe	Pan	Convolvulaceae	Ipomoea alba L.
481	Lnph	SG	Convolvulaceae	Ipomoea argentaurata Forssk.
482	Lnph	Pan	Convolvulaceae	Ipomoea asarifolia (Desr.) Roen. & Schult.
483	Lnph	Pan	Convolvulaceae	Ipomoea eriocarpa R. Br.
484	Lnph	TA	Convolvulaceae	Ipomoea involucrata P. Beauv.
485	Lnph	Pan	Convolvulaceae	Ipomoea mauritiana Hall. f.
486	LGe	Pan	Convolvulaceae	Ipomoea muricata (L.) Jacq.
487	Lnph	PRA	Convolvulaceae	Ipomoea rubens Choisy
488	Lnph	_	Convolvulaceae	Ipomoea sp.
489	mPh	GC	Simaroubaceae	Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill.
490	mPh	PRA	Simaroubaceae	Irvingia smithii Hook. F.
491	mPh	SZ	Caesalpiniaceae	Isoberlinia doka Craib & Stapf.
492	mPh	SZ	Caesalpiniaceae	Isoberlinia tomentosa (Harms) Craib & Stapf.
493	Ch	G	Lamiaceae	Isodictyophorus reticularus (A. Chev.) J. K. Morton
494	mPh	GC	Annonaceae	Isolona thonneri (De wild. Th. Dur.) Engl. & Diels
495	mph	PRA	Rubiaceae	Ixora brachypoda DC.
496	Lmph	PRA	Oleaceae	Jasminum dichotomum Vahl
497	Lmph	SG	Oleaceae	Jasminum obtusifolium Baker
498	Lnph	TA	Oleaceae	Jasminum pauciflorum Benth.
499	Lnph	G	Oleaceae	Jasminum preussii Engl. & Knobl.
500	Lmph	GC	Connaraceae	Jaundea pinnata (P. Beauv.) Schellenb.
501	Th	TA	Acanthaceae	Justicia anselliana (Nees) T. Anderson
502	Ge	TA	Zingiberaceae	Kaempferia aethiopica (Solms-Laub.) Benth.
503	Lmph	GC	Rubiaceae	Keetia hispida (Benth.) Bridson
504	Lnph	PRA	Rubiaceae	Keetia multiflora (Schum.& Thonn.) Bridson syn. Canthium multiflorum (S.&T.) Hiern
505	Lmph	GC	Rubiaceae	Keetia venosa (Oliv.) Bridson syn. Canthium venosum (Oliv.) Hiern
506	MPh	GC	Meliaceae	Khaya grandifoliola C. DC.
507	mPh	SZ	Meliaceae	Khaya senegalensis (Desv.) A. Juss.
508	mPh	GC	Bignoniaceae	Kigelia africana (Lam.) Benth.
509	Ch	PRA	Asteraceae	Kinghamia macrocephala (Oliv. & Hiern.) Jeffrey
510	Ge	PRA	Cyperaceae	Kyllinga erecta Schumach. var. erecta
511	Ge	AA	Cyperaceae	Kyllinga odorata Vahl
512	Ge	Cosmo	Cyperaceae	Kyllinga pumila Michx.
513	Ge	_	Cyperaceae	Kyllinga sp.
514	Th	G	Compositeae	Laggera alata (D.Don) Sch. Bip. ex Oliv.
515	Th	Pan	Asteraceae	Laggera aurita (L.f.) Benth ex C.B. Clarke syn. Blumea aurita (L.f.) DC.
516	LmPh	GC	Apocynaceae	Landolphia hirsuta (Hua) Pichon
517	LMPh	PRA	Apocynaceae	Landolphia owariensis P. Beauv.
518	Lmph	_	Apocynaceae	Landolphia sp.
519	Lmph	G	Apocynaceae	Landolphia togolana (Hallier f.) Pichon
520	mPh	PRA	Anacardiaceae	Lannea acida A. Rich.
521	mPh	PRA	Anacardiaceae	Lannea kerstingii Engl. & K. Krause syn. Lannea barteri (Oliv.) Engl.
522	mPh	SZ	Anacardiaceae	Lannea microcarpa Engl. & K. Krause
523	mPh	G	Anacardiaceae	Lannea nigritana (Sc. Elliot) Keay var. nigritana
524	mph	GC	Sapindaceae	Lecaniodiscus cupanioides Planch.
525	Ch	TA	Leeaceae	Leea guineensis G. Don
526	He	Pan	Poaceae	Leersia hexandra Sw.
527	Lnph	TA	Convolvulaceae	Lepistemon owariense (P. Beauv.) Hall. f.
528	Lmph	Paleo	Asclepiadaceae	Leptadenia arborea (Forsk.) Schweinf.
529	Lnph	PRA	Asclepiadaceae	Leptadenia hastata (Pers.) Decne.
530	Th	TA	Poaceae	Leptochloa caerulescens Steud.
531	LmPh	GC	Papilionaceae	Leptoderris brachyptera (Benth.) Dunn.
532	Lmph	_	Papilionaceae	Leptoderris sp.
533	mph	Pan	Mimosaceae	Leucaena leucocephala Benth.
534	mph	GC	Gentianaceae	Lindackeria dentata (Oliv.) Gilg.
535	Th	GC	Scrophulariaceae	Lindernia diffusa (L.) Wettst.
536	Th	_	Scrophulariaceae	Lindernia sp.
537	Ge	TA	Cyperaceae	Lipocarpha albiceps Ridl.

538	Ge	TA	Cyperaceae	Lipocarpha atra Ridl.
539	Ge	TA	Cyperaceae	Lipocarpha prieuriana Steud.
540	nph	SG	Verbenaceae	Lippia multiflora Moldenke
541	Th	PRA	Campanulaceae	Lobelia sapinii De Wild.
542	LmPh	TA	Hippocrateaceae	Loeseneriella africana Willd. var. africana syn. Hippocratea africana (Willd.) Loes.
543	LmPh	_	Hippocrateaceae	Loeseneriella sp.
544	LmPh	GC	Papilionaceae	Lonchocarpus cyanescens (Schum. & Thonn.) Benth.
545	mph	PRA	Papilionaceae	Lonchocarpus laxiflorus Guill. & Perr. syn. Philenoptera laxiflora (Guill. & Perr.) G. Roberty
546	mPh	PRA	Papilionaceae	Lonchocarpus sericeus (Poir.) H. B. & K.
547	mph	GC	Ochnaceae	Lophira lanceolata Van Tiegh. ex Keay
548	He	TA	Poaceae	Loudetia phragmitoides (Peter) C. E. Hubb.
549	He	_	Poaceae	Loudetia sp.
550	Th	S	Poaceae	Loudetia togoensis (Pilg.) C. E. Hubb.
551	He	TA	Poaceae	Loudetiopsis ambiens (K. Schum.) Conert
552	He	_	Poaceae	Loudetiopsis sp.
553	Th	PRA	Onagraceae	Ludwigia abyssinica A. Rich. syn. Jussiaea abyssinica (A. Rich.) Dandy & Brenan
554	Th	TA	Onagraceae	Ludwigia hyssopifolia (G. Don) Exell syn. Jussiaea linifolia Vahl
555	Th	TA	Onagraceae	Ludwigia octovalvis (Jacq.) Raven
556	Th	_	Onagraceae	Ludwigia sp.
557	Ch	TA	Onagraceae	Ludwigia stenorraphe (Brenan) Hara subsp. stenorraphe
558	Lnph	Pan	Cucurbitaceae	Luffa cylindrica (L.) M. J. Roem syn. Luffa aegyptiaca Mill
559	Th	Cosmo	Solanaceae	Lycopersicon esculentum Mill syn. Solanum lycopersicon L.
560	He(Fern)	Pan	Lycopodiaceae	Lycopodium cernuum L.
561	nph	SG	Rubiaceae	Macrosphyra longistyla (DC.) Hiern
562	mph	TA	Capparidaceae	Maerua angolensis DC.
563	mph	PRA	Euphorbiaceae	Mallotus oppositifolius (Geisel.) Müell. Arg. var. oppositifolius
564	mPh	Pan	Anacardiaceae	Mangifera indica L.
565	Ge	Pan	Euphorbiaceae	Manihot esculenta Crantz
566	mPh	G	Euphorbiaceae	Manihot glaziovii Müll. Arg.
567	mPh	TA	Sapotaceae	Manilkara obovata (Sabine & G. Don) syn. M. multinervis (Baker) Dubard
568	mph	SG	Chrysobalanaceae	Maranthes kerstingii (Engl.) Prance
569	mph	SG	Chrysobalanaceae	Maranthes polyandra (Benth.) Prance
570	mPh	G	Chrysobalanaceae	Maranthes robusta (Oliv.) Prance syn. Parinari robusta Oliv.
571	Ge	G	Maranthaceae	Maranthochloa purpurea (Ridley) Milne. Redh.
572	Ge	_	Maranthaceae	Maranthochloa sp.
573	mph	TA	Euphorbiaceae	Margaritaria discoidea (Baill.) Webster
574	He	Pan	Cyperaceae	Mariscus cylindristachyus Steud. syn. M. alternifolius auct.
575	Th	Paleo	Cyperaceae	Mariscus dubius (Rottb.) C.E.C. Fisch.
576	Ge	AA	Cyperaceae	Mariscus flabelliformis Kunth
577	Ge	TA	Cyperaceae	Mariscus longibracteatus Cherm.
578	He	GC	Cyperaceae	Mariscus soyauxii (Boech.) C.B. Clarke
579	He	_	Cyperaceae	Mariscus sp.
580	mph	GC	Bignoniaceae	Markhamia tomentosa (Benth.) K. Schum. ex Engl.
581	Th	PRA	Marsileaceae	Marsilea crenulata Desv.
582	mph	SZ	Celastraceae	Maytenus heterophylla (Eckl. & Zeyh.) Robson
583	mph	PRA	Celastraceae	Maytenus undatus (Thunb.) Blakelock
584	He	GC	Marantaceae	Megaphrynium macrostachyum (Benth.) Milne-Redh.
585	Th	TA	Asteraceae	Melanthera scandens (Schum. & Thonn.) Rob.
586	Ch	G	Melastomataceae	Melastomastrum segregatum (Benth) A.&R.Fern. syn. Dissotis segregata (Benth) H.f.
587	Ch	Pan	Sterculiaceae	Melochia corchorifolia Linn.
588	Th	_	Sterculiaceae	Melochia sp.
589	mph	G	Melastomataceae	Memecylon afzelii G. Don var. afzelii
590	Lnph	AA	Convolvulaceae	Merremia cissoides (Lam.) Hallier f.
591	Lnph	Pan	Convolvulaceae	Merremia hederacea Burm. f.
592	Ge	_	Eriocaulaceae	Mesanthemum sp.
593	Lmph	G	Caesalpiniaceae	Mezoneuron benthanianum Baill.
594	mph	GC	Euphorbiaceae	Microdesmis puberula Hook. f. ex Planch.
595	Ch	Paleo	Asteraceae	Microglossa pyrifolia (Lam.) Kuntze
596	Lmph	Pan	Asteraceae	Mikania cordata (Burm. f.) B. L. Robins var. cordata syn. M. Chenopodiifolia Willd.
597	MPh	G	Moraceae	Milicia exelsa (Welw.) Berg syn. Chlorophora excelsa (Welw.) benth.

598	Lmph	GC	Papilionaceae	Millettia barteri (Benth.) Dunn.
599	mPh	G	Papilionaceae	Millettia thonningii (schum. & Thonn.) Baker
600	Lmph	G	Papilionaceae	Millettia warneckei Harms
601	nph	Pan	Mimosaceae	Mimosa pigra L.
602	mPh	GC	Sapotaceae	Mimusops andogensis Hiern
603	mph	SZ	Sapotaceae	Mimusops kummel Bruce ex A. DC.
604	mPh	SZ	Rubiaceae	Mitragyna inermis (Willd.) O. Kuntze
605	Th	Paleo	Molluginaceae	Mollugo nudicaulis Lam.
606	Lnph	Pan	Cucurbitaceae	Momordica balsamina L.
607	Lnph	G	Cucurbitaceae	Momordica charantia L.
608	Lnph	GC	Cucurbitaceae	Momordica cissoides Benth.
609	Lnph	G	Annonaceae	Monanthotaxis parviflora (Oliv.) Verdc.
610	Lnph	G	Annonaceae	Monanthotaxis whytei (Stapf) Verdc.
611	Ch	TA	Acanthaceae	Monechma ciliatum (T. Anders.) C. B. Cl.
612	Ch	SZ	Acanthaceae	Monechma depauperatum (Jacq.) Milne
613	mph	G	Annonaceae	Monodora tenuifolia Benth.
614	mph	SZ	Dipterocarpaceae	Monotes kerstingii Gilg
615	mph	SZ	Rubiaceae	Morelia senegalensis A. Rich.
616	mph	SG	Rubiaceae	Morinda geminata DC.
617	mph	G	Rubiaceae	Morinda lucida Benth.
618	LmPh	GC	Apocynaceae	Motandra guineensis (Thonning) A. DC.
619	Lmph	TA	Papilionaceae	Mucuna poggei (L.) DC. var. poggei
620	LmPh	Pan	Papilionaceae	Mucuna pruriens (L.) DC. var. pruriens
621	Lmph	Pan	Papilionaceae	Mucuna sloanei Fawc. & Rendle
622	LTh	Paleo	Cucurbitaceae	Mukia maderaspatana (L.) M. J. Roem. syn. Melothria maderaspatana (L.) Cogn.
623	He	TA	Commelinaceae	Murdannia simplex (Vahl) Brenan
624	He	Pan	Musaceae	Musa sapientum L.
625	Lmph	GC	Rubiaceae	Mussaenda elegans Schum. & Thonn.
626	Lmph	GC	Rubiaceae	Mussaenda isertiana DC.
627	Th	_	Najadaceae	Naja sp.
628	mph	G	Lecythidaceae	Napoleonaea vogelii Hook. & Planch. syn. N. leonensis Hutch. & Dalz.
629	Th	Pan	Acanthaceae	Nelsonia canescens (Lam.) Spreng.
630	LTh	GC	Papilionaceae	Neorautanenia mitis (A. Rich.) Verdc.
631	mph	G	Annonaceae	Neostenanthera myristicifolia (Oliv.) Exell
632	Ge	Pan	Davalliaceae	Nephrolepis biserrata (Sw.) Schott
633	Ge	_	Davalliaceae	Nephrolepis sp.
634	Ge	PRA	Orchidaceae	Nervilia petraea (Afzel. ex Pers.) Summerch.
635	Ge	PRA	Orchidaceae	Nervilia umbrosa (Rchb.f.) Schltr.
636	mPh	GC	Boraginaceae	Newbouldia laevis (P. Beauv.) Seem. ex Bureau
637	mPh	G	Simaroubaceae	Nothospondias staudtii Engl.
638	Ge	Pan	Nymphaeaceae	Nymphaea lotus L.
639	mph	G	Ochnaceae	Ochna afzelii R. Br. ex Oliv.
640	mph	GC	Ochnaceae	Ochna membranacea Oliv.
641	mph	SG	Ochnaceae	Ochna rhizomatosa (van Tiegh.) Keay
642	mph	SZ	Ochnaceae	Ochna schweinfurthiana F. Hoffm.
643	mph	_	Ochnaceae	Ochna sp.
644	Ch	Paleo	Lamiaceae	Ocimum gratissimum L.
645	Lmph	GC	Olacaceae	Olax subscorpioidea Oliv. var. subscorpioidea
646	Th	Pan	Rubiaceae	Oldenlandia corymbosa L.
647	Th	Paleo	Rubiaceae	Oldenlandia herbacea (L.) Roxb.
648	Th	AA	Rubiaceae	Oldenlandia lancifolia (Schumach.) DC.
649	Th	_	Rubiaceae	Oldenlandia sp.
650	Th	GC	Poaceae	Olyra latifolia L.
651	Lmph	G	Apocynaceae	Oncinotis glabrata (Baill.) Stapf ex Hiern
652	Lmph	G	Apocynaceae	Oncinotis nitida Benth.
653	mph	SZ	Flacourtiaceae	Oncoba spinosa Forssk.
654	LmPh	SZ	Opiliaceae	Opilia amentacea Roxb. syn. O. celtidifolia (Guill. & Perr) Endl. ex Walp.
655	Th	SG	Poaceae	Oplismenus burmannii (Retz.) P. Beauv.
656	Th	SG	Poaceae	Oplismenus hirtellus (L.) P. Beauv.
657	Ch	TA	Papilionaceae	Ormocarpum sennoides (Willd.) DC.

658	He	Pan	Poaceae	Oryza sativa L.
659	He	Pan	Osmundaceae	Osmunda regalis L.
660	Th	PRA	Rubiaceae	Otomeria elatior (A. Rich. ex. DC.) Verdc.
661	mph	GC	Rubiaceae	Oxyanthus formosus Hook. f. ex Planch.
662	nph	GC	Rubiaceae	Oxyanthus pallidus Hiern
663	nph	GC	Rubiaceae	Oxyanthus racemosus (Schum. & Thonn.) Keay
664	nph	_	Rubiaceae	Oxyanthus sp.
665	mph	TA	Rubiaceae	Oxyanthus speciosus DC.
666	mph	GC	Rubiaceae	Oxyanthus unilocularis Hiern
667	Lnph	GC	Asclepiadaceae	Oxystelma bornouense R. Br.
668	He	TA	Poaceae	Oxytenanthera abyssinica (A. Rich.) Munro
669	nph	PRA	Anacardiaceae	Ozoroa insignis Del. syn. Heeria insignis (del.) O. Ktze. Rev.
670	Lnph	Pan	Papilionaceae	Pachyrrhizus angulatus Rich.
671	mph	SG	Pandanaceae	Pandanus candelabrum P. Beauv.
672	Th	PRA	Amaranthaceae	Pandiaka angustifolia (Vahl) Hepper
673	Ch	SZ	Amaranthaceae	Pandiaka involucrata (Moq.) B. D. Jackson
674	Th	GC	Poaceae	Panicum brevifolium L.
675	He	G	Poaceae	Panicum maximum Jacq.
676	Th	_	Poaceae	Panicum sp.
677	LGr	GC	Aristolochiaceae	Pararistolochia goldieana (Hook. f.) Hutch. & Dalz.
678	MPh	GC	Chrysobalanaceae	Parinari congensis F. Didr.
679	mph	SZ	Chrysobalanaceae	Parinari curatellifolia Planch. ex Benth.
680	mPh	SZ	Mimosaceae	Parkia biglobosa (Jacq.) R. Br. ex G. Don f.
681	LmPh	SG	Asclepiadaceae	Parquetina nigrescens (Afzel.) Bullock
682	He	Pan	Poaceae	Paspalum scrobiculatum L. syn. P. orbiculare G. Forest
683	Lnph	Pan	Passifloraceae	Passiflora foetida L.
684	Lmph	AA	Sapindaceae	Paullinia pinnata L.
685	mph	SG	Rubiaceae	Pavetta corymbosa (DC.) F. N. Williams
686	nph	SZ	Rubiaceae	Pavetta crassipes K. Schum.
687	nph	SG	Rubiaceae	Pavetta oblongifolia (Hiern) Bremek.
688	Th	Paleo	Poaceae	Pennisetum pedicellatum Trin.
689	Th	Pan	Poaceae	Pennisetum polystachion (L.) Schult.
690	Th	_	Poaceae	Pennisetum sp.
691	He	TA	Poaceae	Pennisetum unisetum (Nees) Benth. syn. Beckeropsis uniseta (Nees & Thonn.)
692	mPh	GC	Clusiaceae	Pentadesma butyracea Sab.
693	Th	TA	Rubiaceae	Pentodon pentandrus (Schum. & Thonn.) Vatke
694	Lmph	TA	Asclepiadaceae	Pergularia daemia (Forssk.) Chiov.
695	mph	SG	Papilionaceae	Pericopsis laxiflora (Benth.) van. Meeuwen
696	Th	Paleo	Poaceae	Perotis indica (L.) Kuntze
697	Ch	PRA	Acanthaceae	Phaulopsis barteri (T. Anders.) Lindau
698	Th	TA	Acanthaceae	Phaulopsis ciliata (Willd.) Hepper
699	Ch	GC	Acanthaceae	Phaulopsis imbricata (Forssk.) Sweet. subsp imbricata
700	Th	TA	Acanthaceae	Phaulopsis sylvestre (Lindau) Lindau
701	mph	TA	Arecaceae	Phoenix reclinata Jacq.
702	He	PRA	Poaceae	Phragmites australis subsp. altissimus (Benth.) W. D. Clayton
703	He	Paleo	Poaceae	Phragmites karka (Retz.) Trin. ex Steud.
704	Ch	G	Euphorbiaceae	Phyllanthus alpestris Beille
705	Th	Pan	Euphorbiaceae	Phyllanthus amarus Schum. & Thonn.
706	mph	Pan	Euphorbiaceae	Phyllanthus kerstingii Brunel (ined.) syn. P. beillei auct.
707	Ch	Pan	Euphorbiaceae	Phyllanthus maderaspatensis L.
708	LmPh	TA	Euphorbiaceae	Phyllanthus muellerianus (O. Ktze.) Exell
709	Th	Paleo	Euphorbiaceae	Phyllanthus niruri L.
710	Lnph	TA	Euphorbiaceae	Phyllanthus reticulatus Poir. var. reticulatus
711	Th	_	Euphorbiaceae	Phyllanthus sp1.
712	nph	_	Euphorbiaceae	Phyllanthus sp2. (Yarpao stream)
713	Th	Pan	Solanaceae	Physalis angulata L.
714	mPh	G	Simaroubaceae	Pierreodendron kerstingii (Engl.) Little
715	mph	TA	Caesalpiniaceae	Piliostigma thonningii (Schumach.) milne-Redh.
716	Th	Pan	Araceae	Pistia stratrioides L.
717	Th	Paleo	Lamiaceae	Platostoma africanum P. Beauv.

718	Ep	TA	Polypodiaceae	Platycerium angolense Welw.
719	Th	TA	Caryophyllaceae	Polycarpaea eriantha Hochst. ex A. Rich.
720	Th	Cosmo	Polygonaceae	Polygonum salicifolium Brouss. ex Willd. syn. Persicaria salicifolia (Brouss. ex Willd) Assenov (1966)
721	He	TA	Polygonaceae	Polygonum senegalense Meisn. syn. Persicaria senegalensis (Meisn.) Sojak
722	mph	SZ	Rubiaceae	Polysphaeria arbuscula K. Schum.
723	Ep	_	Orchidaceae	Polystachya sp.
724	Th	Pan	Portulacaceae	Portulaca oleracea Linn.
725	nph	SG	Rubiaceae	Pouchetia africana A. Rich. ex DC.
726	mph	GC	Sapotaceae	Pouteria alnifolia (Baker) Roberty syn. Malacantha alnifolia (Baker) Pierre
727	Th	PRA	Urticaceae	Pouzolzia guineensis Benth
728	Lmph	GC	Verbenaceae	Premna angolensis Gürke
729	Lmph	G	Verbenaceae	Premna hispida Benth.
730	Lmph	G	Verbenaceae	Premna lucens A. Chev.
731	Lnph	_	Verbenaceae	Premna sp.
732	mPh	SZ	Mimosaceae	Prosopis africana (Guill. & Perr.) Taub.
733	mph	SZ	Meliaceae	Pseudocedrela kotschyi (Schweinf.) Harms
734	mPh	PRA	Anacardiaceae	Pseudospondias microcarpa (A. Rich) Engl.
735	Lnph	TA	Papilionaceae	Pseudovigna sp.
736	mph	Pan	Myrtaceae	Psidium guajava L.
737	Lnph	GC	Papilionaceae	Psophocarpus tetragonolobus (L.) DC.
738	mph	SG	Hypericaceae	Psorospermum glaberrimum Hochr.
739	nph	G	Hypericaceae	Psorospermum senegalense Spach
740	nph	GC	Rubiaceae	Psychotria calva Hiern
741	nph	GC	Rubiaceae	Psychotria latistipula Benth.
742	nph	GC	Rubiaceae	Psychotria linderi Hepper
743	nph	GC	Rubiaceae	Psychotria psychotrioides (DC.) Roberty
744	nph	_	Rubiaceae	Psychotria sp.
745	nph	GC	Rubiaceae	Psychotria vogeliana Benth.
746	mph	SG	Combretaceae	Pteleopsis suberosa Engl. & Diels
747	Ch	Pan	Adianthaceae	Pteris atrovirens Willd.
748	mPh	SZ	Papilionaceae	Pterocarpus erinaceus Poir subsp. lucens
749	mPh	PRA	Papilionaceae	Pterocarpus santalinoides DC.
750	Lnph	Paleo	Papilionaceae	Pueraria phaseoloides (Roxb.) benth. var javanica
751	Th	Pan	Amaranthaceae	Pupalia lappacea (L.) A. Juss.
752	Ge	Cosmo	Cyperaceae	Pycreus lanceolatus (Poir.) C.B. Clarke
753	He	Pan	Cyperaceae	Pycreus polystachyos (Rottb.) P.Beauv.
754	He	_	Cyperaceae	Pycreus sp.
755	Lmph	Paleo	Combretaceae	Quisqualis indica L.
756	mPh	SZ	Arecaceae	Raphia sudanica A. Chev.
757	Lnph	G	Icacinaceae	Raphiostylis beninensis (Hook. f. ex Planch.) Planch. ex Benth.
758	mph	G	Apocynaceae	Rauvolfia vomitoria Afzel.
759	Lmph	Paleo	Celastraceae	Reissantia indica (Willd.) N. Hallé syn. Hippocratea indica Lam.
760	mph	TA	Anacardiaceae	Rhus natalensis Bernh. ex Krause
761	Th	Pan	Poaceae	Rhynchelytrum roseum (Nees) Stapf. & C.E. Hubbard ex Bews
762	LTh	GC	Papilionaceae	Rhynchosia congensis Baker
763	LTh	Paleo	Papilionaceae	Rhynchosia densiflora (Roth) DC.
764	LTh	Pan	Papilionaceae	Rhynchosia minima (L.) DC. var. minima
765	LTh	_	Papilionaceae	Rhynchosia sp.
766	Lnph	GC	Papilionaceae	Rhynchosia viscosa (Roth) DC.
767	He	Pan	Cyperaceae	Rhynchospora corymbosa (L.) Britt.
768	Th	Paleo	Poaceae	Rhytachne triaristata (Steud.) Stapf
769	nph	Pan	Euphorbiaceae	Ricinus communis L.
770	mph	G	Violaceae	Rinorea dentata (P. Beauv.) O. Ktze
771	Lmph	G	Capparidaceae	Ritcheia capparioides (Andr.) Britten var. capparoides
772	Lmph	G	Capparidaceae	Ritcheia longipedicellata Gilg.
773	Lnph	_	Capparidaceae	Ritcheia sp.
774	mph	GC	Rubiaceae	Rothmannia urcelliformis (Hiern) Robyns
775	nph	_	Rubiaceae	Rothmannia sp.
776	Th	Pan	Poaceae	Rottboellia cochinchinensis (Lour.) syn. R. exaltata L. f.

777	nph	TA	Connaraceae	Rourea coccinea (Baker) Jongkind subsp. Coccinea syn. Byrsocarpus coccineus Thonn.
778	Ch	GC	Acanthaceae	Ruellia praetermissa Schweinf. ex Lindau
779	Ch	G	Acanthaceae	Ruellia togoensis (Lindau) Heine
780	Ch	GC	Acanthaceae	Rungia guineensis Heine
781	Ch	G	Acanthaceae	Ruspolia hypocrateriformis (Vahl) Milne-Redhead
782	Lmph	_	Rubiaceae	Rutidea sp.
783	mph	GC	Rubiaceae	Rytigynia canthioides (Benth.) Robyns
784	mph	SG	Rubiaceae	Rytigynia senegalensis Blume
785	nph	_	Rubiaceae	Rytigynia sp.
786	nph	GC	Rubiaceae	Rytigynia umbellata (Hiern) Robyns
787	LmPh	AA	Apocynaceae	Saba comorensis (Bojer) Pichon
788	LmPh	GC	Apocynaceae	Saba thompsonii (A. Chev.) Pichon
789	Lnph	GC	Rubiaceae	Sabicea brevipes Wernh.
790	Lnph	SG	Rubiaceae	Sabicea calycina Benth.
791	Lnph	_	Rubiaceae	Sabicea sp.
792	He	SZ	Poaceae	Sacciolepis africana C E. Hubbard & Snowden
793	Lmph	GC	Celastraceae	Salacia debilis (G. Don.) Walp.
794	Lmph	GC	Celastraceae	Salacia hispida Blakelock
795	nph	PRA	Celastraceae	Salacia leptoclada Tul.
796	nph	G	Celastraceae	Salacia pallescens Oliv.
797	nph	_	Celastraceae	Salacia sp.
798	Lmph	GC	Celastraceae	Salacia staudtiana Loes.
799	Ge	GC	Agavaceae	Sansevieria guineensis (L) Willd. syn. S. trifasciata prain
800	Ge	GC	Agavaceae	Sansevieria liberica Gérôme & Labory
801	Ge	G	Agavaceae	Sansevieria longiflora Sims
802	mph	TA	Euphorbiaceae	Sapium ellipticum (Hochst. ex Krauss) Pax
803	Lmph	TA	Rubiaceae	Sarcocephalus latifolius (Smith) Bruce syn. Nauclea latifolia Smith
804	Th	AA	Ochnaceae	Sauvagesia erecta L.
805	Ge	TA	Amaryllidaceae	Scadoxus multiflorus (Martyn) Raf. subsp multiflorus
806	Th	Pan	Poaceae	Schizachyrium brevifolium Nees var. brevifolium
807	Th	PRA	Poaceae	Schizachyrium exile (Hochst.) Pilger
808	He	PRA	Poaceae	Schizachyrium platyphyllum (Franch.) Stapf
809	He	Pan	Poaceae	Schizachyrium sanguineum (Retz.) Alston
810	Th	_	Poaceae	Schizachyrium sp.
811	Lnph	Pan	Mimosaceae	Schrankia leptocarpa DC.
812	MPh	GC	Oleaceae	Schrebera arborea A. Chev.
813	He	TA	Cyperaceae	Scleria achtenii De Wild.
814	He	GC	Cyperaceae	Scleria bulbifera A. Rich.
815	He	GC	Cyperaceae	Scleria depressa (C. B. Cl.) Nelmes
816	He	AA	Cyperaceae	Scleria lacustris Wright ex Sauvelle
817	He	GC	Cyperaceae	Scleria naumanniana Boeck.
818	He	_	Cyperaceae	Scleria sp.
819	Th	TA	Scrophulariaceae	Scoparia dulcis Linn
820	Lmph	GC	Asclepiadaceae	Secamone afzelii (Schultes) K. Schum.
821	mph	SZ	Polygalaceae	Securidaca longipedunculata Fres.
822	Th(fern)	_	Selaginaceae	Selaginela sp.
823	nph	Pan	Caesalpiniaceae	Senna alata (L.) Roxb. syn. Cassia alata L.
824	nph	AA	Caesalpiniaceae	Senna hirsuta (L.) HS Irwin & Barneby syn. Cassia hirsuta (L.) Irwin & Barneby
825	nph	Pan	Caesalpiniaceae	Senna obtusifolia (L.) HS Irwin & Barneby syn. Cassia tora L. var obtusifolia (L.) Haines
826	Th	Paleo	Caesalpiniaceae	Senna occidentalis (L.) Link syn. Cassia occidentalis L.
827	Ch	G	Caesalpiniaceae	Senna podocarpa (frill. & Perr.) Lock syn. Cassia podocarpa Guill. & Perr.
828	Ch	SG	Rubiaceae	Sericanthe chevalieri (K. Krause) Robbrecht var chevalieri
829	Th	TA	Pedaliaceae	Sesamum indicum Linn.
830	nph	GC	Papilionaceae	Sesbania leptocarpa DC.
831	nph	Pan	Papilionaceae	Sesbania sesban (L.) Merrill
832	Ch	SG	Papilionaceae	Sesbania sudanica Gillett subsp. occidentalis Gillett
833	Th	Paleo	Poaceae	Setaria barbata (Lam.) Kunth
834	Th	SG	Poaceae	Setaria gracilipes C. E. Hubbard
835	He	TA	Poaceae	Setaria longisepa P. Beauv.
836	He	GC	Poaceae	Setaria megaphylla (Steud.) Th. Dur. & Schinz syn. S. chevaleri Stapf.

837	Th	Pan	Poaceae	Setaria pallidae-fusca (Schumach.) Stapf & C.E.Hubb. ex M.B. Moss
838	Th	TA	Poaceae	Setaria restioidea (Franch.) Stapf
839	Th	_	Poaceae	Setaria sp.
840	He	TA	Poaceae	Setaria sphacellata (Schumach.) Stapf & C.E.Hubb. ex M.B. Moss
841	Th	Pan	Malvaceae	Sida acuta Burm. f. subsp. acuta
842	Ch	Pan	Malvaceae	Sida cordata (Burm. f.) Borss. Waalk.
843	Ch	AA	Malvaceae	Sida linifolia Juss. ex Cav.
844	Ch	GC	Malvaceae	Sida rhombifolia L.
845	Th	_	Malvaceae	Sida sp.
846	Ch	Pan	Malvaceae	Sida spinosa L. syn. S. alba L.
847	Lnph	GC	Malvaceae	Sida urens L. var. urens
848	Ch	Pan	Malvaceae	Sida veronicifolia Lam.
849	Lmph	GC	Hippocrateaceae	Simicratea welwitschii (Oliv.) N. Hallé syn. Simirestis welwitschii (Oliv.) N. Hallé
850	LGe	TA	Smilacaceae	Smilax anceps Willd. syn. S. kraussiana Meissner
851	Ch	Cosmo	Solanaceae	Solanum nigrum L.
852	Ch	Pan	Solanaceae	Solanum torvum Sw.
853	Ch	Cosmo	Solanaceae	Solanum verbascifolium L.
854	Th	TA	Lamiaceae	Solenostemon latifolius (Hoechst. ex Benth.) J. K. Morton
855	Th	TA	Lamiaceae	Solenostemon monostachyus (P. Beauv.) subsp. monostachyus
856	Th	_	Lamiaceae	Solenostemon sp.
857	Th	SZ	Poaceae	Sorghastrum bipennatum (Hack.) Pilg.
858	He	SG	Poaceae	Sorghum arundinaceum (Desv.) Stapf
859	He	AA	Poaceae	Sorghum bicolor (L.) Moench
860	nph	G	Anacardiaceae	Sorindeia warneckei Engl.
861	Th	Pan	Asteraceae	Sparganophorus sparganophara (L.) Jeffrey syn. Struchium sparganophora (L) O. Ktze
862	mPh	TA	Bignoniaceae	Spathodea campanulata P. Beauv.
863	Th	SZ	Rubiaceae	Spermacoce filifolia Perr.& Lepr. ex DC. syn. Borreria filifolia (S.&T) K. Schum.
864	Th	PRA	Rubiaceae	Spermacoce ruelliae DC. syn. Borreria scabra (Schumach. & Thonn.) K. Schum.
865	Th	_	Rubiaceae	Spermacoce sp.
866	Th	SG	Rubiaceae	Spermacoce stachydea DC. syn. Borreria stachydea (DC.) Hutch. & Dalz.
867	Ch	SG	Menispermaceae	Sphenostylis schweinfurthii Harms
868	Th	AA	Loganiaceae	Spigelia anthelmia L.
869	mPh	TA	Anacardiaceae	Spondias mombin L.
870	He	SZ	Poaceae	Sporobolus pyramidalis P. Beauv.
871	Th	_	Poaceae	Sporobolus sp.
872	Lnph	G	Icacinaceae	Stachyanthus occidentalis (Keay & Miege) Boutique
873	Th	AA	Verbenaceae	Stachytarpheta indica (L.) Vahl syn. S. angustifolia (Mill.)
874	Ge	GC	Commelianaceae	Stanfieldiella imperforata (C. B. Cl.) Breman
875	mph	TA	Apiaceae	Steganotaenia araliacea Hochst. var. araliacea
876	mph	SZ	Sterculiaceae	Sterculia setigera Del.
877	mPh	GC	Sterculiaceae	Sterculia tragacantha Lindl.
878	mph	SG	Bignoniaceae	Stereospermum kunthianum Cham. var. kunthianum
879	He	Paleo	Poaceae	Streptogyna crinita P. Beauv.
880	Th	PRA	Scrophlariaceae	Striga micrantha (Benth.) Benth.
881	Lmph	GC	Apocynaceae	Strophanthus hispidus DC.
882	Lmph	GC	Apocynaceae	Strophanthus preussii Engl. & Pax
883	LmPh	GC	Apocynaceae	Strophanthus sarmentosus DC.
884	Th	_	Asteraceae	Struchium sp.
885	Lmph	GC	Loganiaceae	Strychnos afzelii Gilg.
886	LmPh	G	Loganiaceae	Strychnos barteri Solered.
887	LMPh	GC	Loganiaceae	Strychnos congolana Gilg.
888	LmPh	GC	Loganiaceae	Strychnos floribunda Gilg.
889	mph	SZ	Loganiaceae	Strychnos innocua Del.
890	LmPh	GC	Loganiaceae	Strychnos nigritana Baker
891	LmPh	G	Loganiaceae	Strychnos splendens Gilg.
892	LmPh	PRA	Loganiaceae	Strychnos usambarensis Gilg.
893	Ge	G	Araceae	Stylochaeton hostifolius Engl.
894	Ge	SZ	Araceae	Stylochaeton hypogaeus Lepr.
895	Ge	SZ	Araceae	Stylochaeton lancifolius Kotschy & peyr.
896	mph	SG	Papilionaceae	Swartzia madagascariensis Desv.

897	Th	Pan	Asteraceae	Synedrella nodiflora Gaertn.
898	mPh	GC	Sapotaceae	Synsepalum brevipes (Baker) Pennington syn. Pachystela brevipes (Baker) Engl.
899	mph	TA	Sapotaceae	Synsepalum passargei (Engl.) Pennington syn. Vincentella passargei Engl. (Aubréville)
900	mPh	TA	Myrtaceae	Syzygium guineense (Willd.) DC. subsp. guineense
901	Lmph	TA	Asclepiadaceae	Tacazzea apiculata Oliv.
902	Ge	Pan	Taccaceae	Tacca leontopetaloides (L.) O. Ktze syn. T. involucrata Schum
903	Th	Pan	Portulacaceae	Talinum triangulare (Jacq.) Willd.
904	mPh	Pan	Caesalpiniaceae	Tamarindus indica L.
905	mPh	GC	Rubiaceae	Tarenna eketensis Wernham.
906	mPh	Paleo	Verbenaceae	Tectona grandis L. f.
907	Th	SG	Papilionaceae	Tephrosia platycarpa Guill. & Perr. syn. T. humilis. & Perr.
908	Ch	TA	Papilionaceae	Tephrosia vogelii Hook. f.
909	mph	SG	Combretaceae	Terminalia avicennioides Guill. & Perr.
910	mPh	SG	Combretaceae	Terminalia glaucescens Planch. ex Benth.
911	mph	SZ	Combretaceae	Terminalia macroptera Guill. & Perr.
912	mph	_	Combretaceae	Terminalia sp.
913	mPh	GC	Combretaceae	Terminalia superba Engl. & Diels
914	LmPh	GC	Dilleniaceae	Tetracera alnifolia Willd.
915	LmPh	GC	Dilleniaceae	Tetracera potatoria Afzel. ex G. Don
916	mPh	G	Mimosaceae	Tetrapleura tetraptera (Schum. & Thonn.) Taub.
917	Ch(Fern)	_	Thelypteridaceae	Thelypteris sp.
918	Ge(Par)	G	Balanophoraceae	Thonningia sanguinea Vahl.
919	Lnph	Pan	Acanthaceae	Thunbergia alata Boj. ex Sims.
920	Lnph	S	Acanthaceae	Thunbergia atacoriensis Akoègninou & Lisowski
921	Lnph	GC	Acanthaceae	Thunbergia cynanchifolia Benth.
922	Lnph	GC	Acanthaceae	Thunbergia togoensis Lindau
923	Ge	Pan	Cyperaceae	Torulinium odoratum (L.) Hopper
924	mph	GC	Ulmaceae	Trema orientalis (L.) Blume syn. T. guineensis (Schum. & Thonn.) Ficalho
925	Th	Pan	Aïzoaceae	Trianthema portulacastrum L.
926	Lnph	G	Malpighiaceae	Triaspis odorata (Willd.) A. Juss.
927	mph	SZ	Rubiaceae	Tricalysia okelensis Hiern var. okelensis
928	mph	SZ	Rubiaceae	Tricalysia okelensis Hiern var. pubescens
929	nph	G	Rubiaceae	Tricalysia reticulata (Benth.) Hiern
930	mph	_	Meliaceae	Tricalysia sp.
931	nph	GC	Rubiaceae	Tricalysia subquadrata A. Rich. ex DC.
932	mph	SZ	Meliaceae	Trichilia emetica Vahl subsp. emetica
933	mph	GC	Meliaceae	Trichilia prieuriana A. Juss.
934	mPh	GC	Meliaceae	Trichilia retusa Oliv.
935	mph	G	Anacardiaceae	Trichoscypha smythei Hutch. & Dalz.
936	mph	_	Anacardiaceae	Trichoscypha sp.
937	Lnph	G	Menispermaceae	Triclisia subcordata Oliv.
938	Th	Pan	Asteraceae	Tridax procumbens L.
939	mPh	GC	Moraceae	Trilepiseum madagascariense DC. syn. Bosqueia angolensis Ficalho
940	Ch	Pan	Tiliaceae	Triumfetta cordifolia A. Rich
941	Ch	GC	Tiliaceae	Triumfetta dubia De Wild.
942	Ch	S	Tiliaceae	Triumfetta lepidota K. Schum.
943	Th	Pan	Tiliaceae	Triumfetta rhomboidea Jacq. var. rhomboidea
944	Th	_	Tiliaceae	Triumfetta sp.
945	Ch	TA	Tiliaceae	Triumfetta tomentosa Jacq.
946	Lnph	SG	Cucurbitaceae	Trochomeria macrocarpa (Sond.) syn. T. macroura Hook. F.
947	Lnph	GC	Asclepiadaceae	Tylophora camerooniana N. E. Br.
948	Lnph	G	Asclepiadaceae	Tylophora dahomensis K. Schum.
949	Lnph	_	Asclepiadaceae	Tylophora sp.
950	Lnph	GC	Asclepiadaceae	Tylophora sylvatica Decne.
951	mPh	GC	Euphorbiaceae	Uapaca heudelotii Baill.
952	mPh	TA	Euphorbiaceae	Uapaca togoensis Pax syn. U. somon Aubrév. & Léandri
953	Ch	Pan	Malvaceae	Urena lobata L.
954	Ge	SG	Liliaceae	Urginea altissima (L.f.) Baker
955	Lmph	GC	Loganiaceae	Usteria guineensis Willd.
956	Lmph	PRA	Annonaceae	Uvaria chamae P. Beauv.

957	nph	G	Annonaceae	Uvaria ovata (Dunal) A. DC.
958	nph	G	Rubiaceae	Vangueria kerstingii Robyns
959	mph	GC	Rubiaceae	Vangueria madagascariensis Gmelin syn. V. venosa Robyns
960	nph	_	Rubiaceae	Vangueria sp.
961	mph	SG	Rubiaceae	Vangueriella spinosa (Schum & Thonn) syn.Vangueriopsis spinosa (Schumach & Thonn)
962	nph	_	Rubiaceae	Vangueriopsis sp.
963	Ch	SG	Asteraceae	Vernonia bambilorensis Berhaut
964	Ch	G	Asteraceae	Vernonia camporum A. Chev.
965	mph	SZ	Asteraceae	Vernonia colorata (Willd.) Drake
966	Ch	SG	Asteraceae	Vernonia glaberrima Welw. ex O. Hoffm.
967	Th	TA	Asteraceae	Vernonia pauciflora (willd.) Less.
968	Ch	G	Asteraceae	Vernonia poskeana Vartke & Hildebrandt
969	Ch	G	Asteraceae	Vernonia purpurea Sch. Bip. ex Walp.
970	Ch	_	Asteraceae	Vernonia sp.
971	He	SZ	Poaceae	Vetiveria nigritana (Benth.) Stapf
972	Th	TA	Asteraceae	Vicoa leptoclada (Webb) Dandy
973	LTh	GC	Papilionaceae	Vigna gracilis (Guill. & Perr.) Hook. f. syn. Dolichos gracilis Guill. & Perr.
974	Lnph	PRA	Papilionaceae	Vigna racemosa (G. Don) Hutch. & Dalz
975	Lnph	PRA	Papilionaceae	Vigna reticulata Hook. f.
976	Lnph	_	Papilionaceae	Vigna sp.
977	LTh	Pan	Papilionaceae	Vigna unguiculata (L.) Walp. var. unguiculata
978	LGe	AA	Papilionaceae	Vigna vexillata (L.) A. Rich. var. vexillata
979	mPh	SG	Sapotaceae	Vitellaria paradoxa C. F. Gaertn. subsp. paradoxa
980	mph	SZ	Verbenaceae	Vitex chrysocarpa Planch. ex Benth.
981	mPh	SZ	Verbenaceae	Vitex doniana Sweet
982	nph	SZ	Verbenaceae	Vitex madiensis Oliv.
983	mph	TA	Apocynaceae	Voacanga africana Stapf
984	Th	AA	Campalunaceae	Wahlenbergia perrottetii (A. DC.) Thulin syn. Cephalostigma perrottetii A. DC.
985	Ch	Pan	Sterculiaceae	Waltheria indica L.
986	Th	SZ	Malvaceae	Wissadula amplissima (L.) R. E. Fries
987	mph	SZ	Papilionaceae	Xeroderris stuhlmannii (Taub) Mendonça & E.P. Sousa
988	nph	Pan	Olacaceae	Ximenia americana L.
989	mPh	GC	Annonaceae	Xylopia aethiopica (Dunal) A. Rich.
990	mPh	G	Annonaceae	Xylopia elliotii Engl. & Diels
991	mPh	GC	Annonaceae	Xylopia parviflora (A. Rich.) Benth.
992	Ge	PRA	Xyridaceae	Xyris capensis Thunb.
993	mPh	SG	Sapindaceae	Zanha golungensis Hiern
994	mph	SG	Rutaceae	Zanthoxylum zanthoxyloides (Lam.) Zepernick & Timber
995	Th	Cos	Mimosaceae	Zapoteca portoricensis (Jacq.) H. M. Hern. syn. Calliandra portoricensis (Jacq.) benth.
996	Th	Pan	Poaceae	Zea mays L.
997	Lnph	TA	Cucurbitaceae	Zehneria capillacea (Schumach.) C. Jeffrey syn. Melothria capillacea (Schumach.) Cogn.
998	Lnph	PRA	Cucurbitaceae	Zehneria hallii C. Jeffrey syn. Melothria deltoidea Benth.
999	LTh	_	Cucurbitaceae	Zehneria sp.
1000	Lnph	PRA	Cucurbitaceae	Zehneria thwartesii (Schweinf.) C. Jeffrey syn. Melothria tridactyla Hook. f.
1001	mph	Paleo	Rhamnaceae	Ziziphus mauritiana Lam.
1002	mph	PRA	Rhamnaceae	Ziziphus mucronata Willd. subsp. mucronata
1003	mph	Paleo	Rhamnaceae	Ziziphus spina-cristi (L.) Desf. var. microphylla Hochst. A. ex A. Rich.

Life forms (**LF**) followed Raunkaier (1934), Schnell (1971) and Keay & Hepper (1954-1972). They were:
- Phanerophytes (Ph): mega-phanerophyte (MPh > 30 m), meso-phanerophyte (mPh: 8 to 29 m), micro-phanerophyte (mph: 2 to 7 m) and nano-phanerophyte (nph < 2m);
- Therophytes (Th); - Hemicrytophytes (He); - Chamaephytes (Ch); - Lianas (L); - Geophytes (Ge); - Epiphytes (Ep) and - Parasites (Par).

The **phytogeographic types** (**PT**) were named after White (1986) and Keay & Hepper (1954-1972). They were:
- Species widely distributed in the tropics (Cosmopolitan-Cosmo, Pantropical-Pan, Afro-American-AA and Paleotropical-Paleo).
- Species widely distributed in Africa (Tropical Africa-TA, Pluri Regional in Africa-PRA)
- Regional species in Africa (Sudanian-S, Guinean-G, Sudano-Guinean-SG, Sudano-Zambesian-SZ, Guineo-Congolian-GC).

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