REPUBLIQUE DE COTE D'IVOIRE
Union-Discipline-Travail

Ministère de l'Enseignement Supérieur
et de la Recherche Scientifique

UNIVERSITE FELIX HOUPHOUET-BOIGNY

WASCAL West African Science Service Centre on Climate Change and Adapted Land Use

Sponsored by Federal Ministry of Education and Research

GRADUATE RESEARCH PROGRAMME CLIMATE CHANGE AND BIODIVERSITY

Academic Year: 2024 – 2025 **Order Number:**

THESIS

Submitted in fulfilment of the requirements for the
Doctorate at Félix HOUPHOUËT-BOIGNY University

Speciality: Climate Change and Biodiversity

IMPACT OF CLIMATE CHANGE ON THE CARBON SEQUESTRATION CAPACITY AND DISTRIBUTION AREA OF *Afzelia Africana* Sm. ex Pers AND *Pterocarpus erinaceus* Poir IN COTE D'IVOIRE: CASE OF THE LAMTO SCIENTIFIC RESERVE AND THE BADENOU CLASSIFIED FOREST

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Spécialité : Changement climatique et biodiversité

IMPACT DU CHANGEMENT CLIMATIQUE SUR LA CAPACITE DE SEQUESTRATION DE CARBONE ET L'AIRE DE DISTRIBUTION DE *Afzelia africana* Sm. ex Pers ET DE *Pterocarpus erinaceus* Poir EN COTE D'IVOIRE : CAS DE LA RESERVE SCIENTIFIQUE DE LAMTO ET DE LA FORET CLASSEE DE BADENOU

KOUASSI N'Zibla Roch Ghislaine

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M.OUATTARA Djakalia	**Professeur Titulaire**	**UFHB, Côte d'Ivoire**	**Président**
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DEDICACES

To

my father

KOUASSI Konan Edouard

For showing me the path of perseverance and of surpassing myself. This thesis is the fruit of your confidence in me.

To

my mother

YAO Amoin Olga

For your sacrifices and encouragement, which have been the light that has illuminated my path. This thesis is dedicated to you, who has always believed in me, even at the most difficult times.

To

my friend and brother

KOUAKOU Amani Abell Mike

For being an unwavering support. Your presence by my side has been a source of strength and motivation. We accomplished it!

ACKNOWLEDGEMENTS

I am grateful to the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) and the German Federal Ministry of Education and Research (BMBF) for funding this study. Indeed, we benefited from a fully funded PhD scholarship, and for this I thank Prof KOUASSI Konan Edouard and Dr N'Golo Abdoulaye Koné, respectively Director and Deputy Director of the WASCAL research programme, Climate Change and Biodiversity.
I would like to thank the authorities of the Félix HOUPHOUET-BOIGNY University (UFHB), Abidjan, in particular the President, Professor BALLO Zié, for accepting us into his institution as part of the WASCAL Climate Change and Biodiversity research programme (GRP CC&B). Our special thanks also go to the Institute of Geography at the Friedrich-Alexander University of Erlangen-Nurnberg (FAU), for welcoming us to their institution to carry out our analyses.
I would like to express my sincere gratitude to my research supervisor, Dr DIBI N'Da Hyppolite, Senior Lecturer at Université Félix Houphouët-Boigny, for his valuable guidance, encouragement, and thoughtful advice throughout this work. His patience and support have been instrumental in my academic and personal development. Beyond the professional relationship, I am especially grateful for the fatherly presence he has represented to me. I truly hope to have the opportunity and goodwill to support him in return, whenever he may need it.
I would like to express my sincere thanks to my co-supervisor, Professor Achim BRAEUNING, Director of the Institute of Geography at Friedrich-Alexander University Erlangen-Nuremberg (FAU), Germany, for graciously inviting me to undertake a scientific placement. It was a privilege to benefit from the guidance of such a dedicated co-supervisor. His constant attention to the scientific aspects of my work and his prompt, relevant and constructive suggestions have significantly enhanced the quality of this research.
I would like to express my gratitude to the officials of the Ivorian Office of Parks and Reserves (OIPR) and the Forest Development Corporation of Côte d'Ivoire (SODEFOR) for granting me access to the Lamto Scientific Reserve and the Classified Forest of Badenou for the collection of my thesis data.
I would like to extend my sincere thanks to Dr SILUÉ Pagadjovongo Adama of Péléforo Gbon Coulibaly University in Korhogo, for his valuable support during the data collection phase, particularly for facilitating my introduction to the village chief of Korokaha. I am especially grateful for his regular follow-ups, guidance, dedication, and availability, all of which greatly contributed to the improvement of my final manuscript.

I would also like to express my sincere gratitude to Mr BAIMAN Dagnogo, the current chief of the village of Korokaha, for the warm welcome and kindness he extended to me during

my data collection. I am especially thankful for the remarkable working conditions he facilitated and for the generous hospitality and care he showed, treating me with the same consideration as he would his own children.

I would like to thank Dr YAO N'Guessan Olivier, Research Associate at the National Centre for Floristics, and Dr NANAN Kouassi Kouman Noël, Assistant Lecturer at the University of Bondoukou, for the valuable assistance they provided during the collection of botanical and cartographic data, as well as for sharing their expertise in the field. I am sincerely grateful for their dedicated support during data analysis and thesis writing, and for their constructive feedback, which contributed significantly to the improvement of this work. Their guidance and encouragement have been truly invaluable.

I would like to extend my heartfelt thanks to Dr BOHOUSSOU Crystel Natacha for her valuable contribution to the improvement of my work. I am truly grateful for her recommendations, insightful comments, and encouragement. Her support has played a meaningful role in strengthening this research. Throughout the years, she has been a trusted and invaluable guide, and I am deeply thankful for her presence and assistance.

To Dear Dr. Kouakou Amani Abell Mike, my cherished friend and brother, this thesis is as much yours as it is mine. You are among those rare individuals whom family cannot claim as kin, but whom God gifts to us as lifelong companions. Throughout my academic journey, you have walked beside me at every turn, sharing in my doubts and fears, celebrating my successes, and rejoicing in my moments of joy. I sincerely thank you for guiding and supporting me in my pursuit of becoming a better version of myself through your wise counsel, steadfast encouragement, and unwavering belief in my potential. Here, I express my deepest gratitude to you.

Finally, it is my heartfelt privilege to express my deepest gratitude to both my biological and spiritual family, whose unwavering support, prayers and encouragement have been pivotal in achieving my goals. I wish to convey my profound appreciation, especially to my mother, YAO Amoin Olga, a woman of extraordinary courage and remarkable vision who has been the cornerstone of two theses within our family. Please know that the words "thank you" fall short of capturing the full depth of my gratitude. I am endlessly grateful for your moral, material, and financial support, as well as the patience and understanding that proved indispensable to completing this work. You played an irreplaceable role, not only in initiating this journey but also in bringing it to fruition. Your countless acts of support made this accomplishment possible.

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LIST OF ABBREVIATIONS AND ACRONYMS

1. Biomass and Climate Change

AGB: Above-Ground Biomass

BGB: Below-Ground Biomass

TB: Total Biomass

C: Carbon

CO_2: Carbon Dioxide

GHG: Greenhouse Gas

REDD+: Reducing Emissions from Deforestation and Forest Degradation

DBH: Diameter at Breast Height (The diameter of a tree measured at approximately 1.30 meters (130 cm) above the ground)

p-value: Statistical significance indicator

%: Percentage (used for variation rates)

2. Vegetation Indices and Climate

NDVI: Normalized Difference Vegetation Index

IPCC: Intergovernmental Panel on Climate Change

3. Satellite Data and GIS

LULC: Land Use/Land Cover

GIS: Geographic Information System

GEE: Google Earth Engine

USGS: United States Geological Survey

Landsat Sensors Abbreviations

TM: Thematic Mapper (Landsat 4)

ETM+: Enhanced Thematic Mapper Plus (Landsat 7)

OLI/TIRS: Operational Land Imager/Thermal Infrared Sensor (Landsat 9)

GPS: Global Positioning System

UTM: Universal Transverse Mercator System

5. Forest Types and Habitats

LSR: Lamto Scientific Reserve

BCF: Badenou Classified Forest

LULC: Land Use/Land Cover

GF/DDF: Gallery Forest/Dense Dry Forest

GF/DSF: Gallery Forest/Dense Semi-deciduous Forest

OF/WS: Open Forest/Wooded Savanna

TS: Tree Savanna

SS: Shrub Savanna

LDSS: Low-Density Shrub Savanna

BL/ST: Bare Land/Settlement

WB: Water Body

6. Chorological types

GC: Guinea-Congolese species

GCi: Species endemic to Côte d'Ivoire

GC-SZ: Guinea-Congolese and Sudanian-Zambesian transitional species

GCW: Species endemic to the Western Togo forest block

HG: Species endemic to the Upper Guinea forest block

I: Introduced or cultivated taxon

SZ: Sudanian-Zambesian species

AA: List of rare or important species according to Aké Assi

7. Biological Types of Plants

Ch: Chamaephytes (Perennial plants with buds close to the ground, e.g., small shrubs and cushion plants)

EP: Epiphyte

G: Geophytes (Plants with underground storage organs like bulbs, rhizomes, tubers, e.g., lilies and orchids)

H: Hemicryptophytes (Perennial plants with buds at soil level, e.g., many grasses and forbs)

Hpy: Pyrophytic hemicryptophyte

L: Liane

MP: Megaphanerophytes (Tall trees, >30m, e.g., emergent forest species)

mP: Mesophanerophytes (Medium-sized trees, 8-30 m, e.g., canopy species))

mp: Microphanerophytes (Small trees/shrubs, 2-8 m, e.g., understorey species)

np: Nanophanerophytes (Woody plants <2m, e.g., small shrubs 0.25 et 2 m)

Th: Therophytes (Annual plants completing their life cycle in one season, e.g., grasses and herbs)

9. International Union for Conservation of Nature (IUCN)

IUCN: International Union for Conservation of Nature

IUCN Red List: A global inventory of the conservation status of biological species

CR: Critically Endangered

EN: Endangered

VU: Vulnerable

NT: Near Threatened

LC: Least Concern

DD: Data Deficient

10. Institutions and Organizations

FAO: Food and Agriculture Organization

UNFCCC: United Nations Framework Convention on Climate Change

NASA: National Aeronautics and Space Administration

UN-REDD: United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation

REDD+: Reducing Emissions from Deforestation and Forest Degradation

CCLU: Climate Change and Land Use

SODEFOR : Forest Development Company

UFHB: University of Félix Houphouët-Boigny

UFR: Unité de Formation et de Recherche

CITES : Convention on International Trade in Endangered Species of Wild Fauna and Flora

GBIF: Global Biodiversity Information Fund

CMIP5 : Coupled Model Intercomparison Project - Phase 5

GCM : General Circulation Models

INTRODUCTION

Climate change has become increasingly noticeable over the 21st century. According to the **IPCC (2022)**, climate change refers to an increase in the Earth's surface temperature, characterised by floods, extreme temperatures, heatwaves, cyclones, agricultural and ecological droughts. In addition, it invokes the variations in the parameters of the Earth's climate, both over the long term and on shorter time scales, resulting from natural or anthropogenic factors **(Benarfa, 2021).** These changes may be the result of a variety of factors, including natural processes. However, since the mid-20th century, climate change has been primarily attributed to human activities. These human activities include deforestation, land degradation, slash-and-burn agriculture, bush fires and fossil fuel exploitation.

One of the activities that has a major impact on carbon emissions into the atmosphere is deforestation following the burning of fossil fuels **(N'Guessan, 2016)**, because tropical forests contain 40-50% of the Earth's carbon. As a result, the loss of forest cover due to deforestation and forest degradation contributes around 10-15% of annual global greenhouse gas emissions **(van Breugel *et al.,* 2011)**. According to **IPCC (2021)**, the rate of increase in surface temperature has generally been faster in Africa than the global average. In West Africa, according to **IPCC (2022)**, the monsoon season is expected to start and end later. In addition, these changes have a direct impact on biodiversity, tree growth, forest dynamics, vegetation structure and the carbon sequestration potential of intertropical ecosystems, as demonstrated by studies carried out in various regions of the continent **(UNCBD and UNEP, 2007; Aka *et al.*, 2013)**. Without a reduction in emissions, it will be virtually impossible to keep global warming below 2°C **(REDD+, 2021**).

One of the best ways of meeting this challenge is to implement mitigation measures. In this context, ecosystem conservation seems to be one of the best alternatives, given the carbon sink that forests represent. Forests cover around 30.6% of the world's land surface **(Blaser *et al.,* 2011; FAO, 2015).** They play an important role in the global carbon cycle **(Pan *et al.,* 2011; Houghton *et al.,* 2015)** and are the foundation for mitigating the effects of climate change. In other words, today's forests are true carbon reservoirs, storing an average of 2.1 Gigatonnes of CO_2 each year, compared with 3.1 Gigatonnes for all terrestrial ecosystems **(FAO, 2015)**. All this carbon storage is due to the photosynthetic activity of trees.

In fact, the trees that are the main components of forest ecosystems carry out photosynthesis, intending to create organic matter from atmospheric CO_2 in the presence of light. This natural process of trees is one of the most viable solutions for mitigating the effects of global warming. However, they are affected by the adverse effects of climate change which, by altering the amount and temporal distribution of precipitation, affects crucial climatic factors

and leads to the disruption of tree growth in tropical countries, where temperatures are high. Nonetheless, the trees react differently to the lack of water. They can reduce their growth rate, which has a major impact on carbon sequestration potential. They can also change their rate of flowering and fruiting, which has an impact on crop yields. Finally, they can modify their physiology and the anatomical structure of the wood to mitigate the effects of increasing drought stress. If climatic stress exceeds species-specific thresholds, trees may experience increased mortality rates, leading to changes in their range and in the tree cover of the landscape. While, according to the **IPCC Report (2019)**, more frequent and intense extreme weather events, such as droughts and heat waves, are expected to worsen. Faced with the climatic stress suffered by our best allies, plants, in the fight against climate change, a number of studies around the world and in Africa have been launched to find solutions. It is against this backdrop that people and decision-makers around the world are rushing to plant trees to restore degraded land and enhance biodiversity in order to meet climate change mitigation commitments.

However, the question of what type of trees to plant and in which locations remains the most difficult to answer. Around the world, and especially in temperate countries, many studies have been carried out on the tolerance of species to climatic variability. Similarly, in Africa, particularly in southern and eastern Africa, more and more studies are being carried out on the link between climate change, tree growth and distribution areas **(February and Stock, 1998; February and Gagen, 2003; Bhugeloo, 2014; Slotta *et al.*, 2017; Gebrehiwot Gebregeorgis et al., 2020; Shikangalah *et al.,* 2022).** Also, in West Africa, most of the studies carried out are located in catchment areas or near watercourses **(Tarhule and Hughes, 2002; Boakye, 2016; Sanogo *et al.,* 2016; Condé *et al.*, 2020; Ndiaye, 2020).**

As far as Côte d'Ivoire is concerned, there is a dearth of studies looking at the impact of climate change on trees, and consequently on their carbon sequestration capacity and spatial distribution. Understanding the response of trees to the impact of climatic variations will make it possible to put in place effective strategies for monitoring growth and therefore carbon sequestration, as well as developing a management plan for their conservation. This will also enable the right plant species to be chosen and reduce the cost of reforesting forest ecosystems according to current and future climatic conditions. In Côte d'Ivoire, the predominant approach to assessing carbon sequestration is based on the use of allometric equations. However, this approach is limited when it comes to assessing the dynamics of the carbon sequestered by trees over an extended period, aiming to analyse the influence of climatic parameters on this process. Hence, the need to opt for a methodological approach that will enable us to obtain past data on

the tree species studied in order to gain a clear understanding of the carbon sequestration dynamics.

It is with this in mind that the dendrochronology approach can help as an effective tool for studying forest ecosystems, more specifically their components in the face of the impact of climate change. Dendrochronology is the discipline of dating tree rings back to the year in which they were formed **(Gebrekirstos *et al.*, 2014).** In fact, these precisely dated growth rings provide us with information about the age of the trees, but particularly about the measurement of the diameter of these trees in previous years, which is essential for the calculation of allometric equations. The data collected by dendrochronological analyses will help to fill the data gap for the study of the spatio-temporal dynamics of sequestered carbon, in order to estimate the influence of climatic variables on this. In addition, dendrochronology can be used to determine the resilience index of species in terms of the speed with which they recover from drought episodes and their ability to adapt to climate variability, which will be useful for guiding future restoration (**Worbes *et al.*, 2017**). As a result, dendrochronology is emerging as the tool that will make it possible to truly assess the impact of climate change on carbon sequestration capacity.

In Côte d'Ivoire, however, there is a glaring lack of studies using dendrochronology. At a time when the extensive degradation of vegetation cover is inevitably leading to an increase in the effects of climate change, which could affect the functioning of ecosystem components. Hence, the need for scientific investigations using a more appropriate tool, such as dendrochronology, to assess the influence of climate change on the carbon sequestration capacity of trees. The present study aims to provide some answers to the problem of the impact of climate change on *Afzelia africana* et *Pterocarpus erinaceus*. It is based on the following hypothesis: climate change has a negative impact on the carbon sequestration capacity and distribution range of plant species in Côte d'Ivoire.

Subsidiary hypotheses include:

- climate change has contributed to a densification of plant formations in the different study areas;
- the floristic diversity of the preferred habitats of *Afzelia africana* and *Pterocarpus erinaceus* is determined by the climatic gradient and the level of conservation;
- climatic variability negatively influences the carbon sequestration capacity of *Afzelia africana* and *Pterocarpus erinaceus*;
- the dynamics of climatic variables affect the species' range.

The present study was initiated with a view to verifying these various hypotheses. Its general objective is to improve knowledge of the correlation between the impact of climate change, carbon sequestration capacity and the distribution range of two economically and ecologically important trees namely *Afzelia africana* and *Pterocarpus erinaceus*.

Specifically, the aim will be to:

(1) analyse the influence of climatic variables on the dynamics of land use/cover from 1990 to 2022 in the study areas;

(2) characterise the flora and vegetation of the preferred habitats of *Afzelia africana* and *Pterocarpus erinaceus* species in our two study areas;

(3) assess the impact of climatic variables on the sequestration capacity of the species studied;

(4) to model the spatial distribution of these species.

In addition to the introduction and conclusion, this report is divided into four parts, each structured into chapters. The first part is devoted to a review of the literature and the second to a presentation of the study material and methods. The third part presents the results, which are then discussed in the fourth part.

FIRST PART: LITERATURE REVIEW

CHAPTER 1: GENERAL INFORMATION ON STUDY AREAS

1.1 Geographic location of the study areas

1.1.1 Geographical location of the Lamto Scientific Reserve (LSR)

The Lamto Scientific Reserve (LSR) was established in 1968 by Professor Maxime Lamotte. The acronym LAMTO comes from the first three and two letters of these founders' names, Lamotte (LAM) and Tournier (TO). The reserve houses an ecology station managed by the Centre for Research in Ecology (CRE) of the University of Nangui Abrogoua, as well as a geophysics station integrated into an international network for monitoring earthquakes and weather conditions in the region. This unit is administered by the Félix Houphouët-Boigny University. It is located in the centre of Côte d'Ivoire in the transition zone of pre-forest savannas situated within the dense forest of the Guinean massif at the tip of the V-Baoulé. It is located between the northern latitudes 6°10'53" and 6°15'20" and between the western longitudes 4°58'42" and 5°2'53", about 180 km northwest of Abidjan. The Lamto reserve straddles the departments of Toumodi (Bélier Region) and Taabo (Agnéby-Tiassa Region). It is bordered by traditional lands which are Zougoussi (North-West), Kotiéssou and N'Denou (South-West), and Ahérémou II (East), located respectively 7 km and 15 km from the Lamto Station **(**Error! Reference source not found.**)**. Finally, the Lamto Reserve covers an area of 2617 hectares **(Yassi, 2014).**

1.1.2 Geographical situation of the Badenou Classified Forest (BCF)

The administrative region of Poro is a territorial collectivity in the north of Côte d'Ivoire where the Badenou Classified Forest (BCF) is located. This forest takes its name from the Badénou River, which runs through its central part. The BCF was created by decree No. 3499/SE/5 on November 29, 1937. It straddles four Departments, which are the Departments of Korhogo, M'Bengué, Diawala, and Niofoin **(**Error! Reference source not found.**).** Moreover, it is located between 5° 32' 06" and 5° 49' 67" west longitude and between 9° 41' 63" and 9° 51' 63" north latitude **(Kassé, 2009)** and covers an area of 26,980 hectares. It is located 640 km from Abidjan, 50 km east of Diawala, 40 km south of Korhogo, and 23 km north of M'Bengué. The BCF is made up of the Bandama River and several rivers that form its boundaries. These rivers include, among others, the Badénou, Vaka, Kodjalogo, Loua, and Nafounloho rivers. SODEFOR was designated for the management of the BCF according to decree No. 33/MINAGRA of 02/13/1992.

1.2 Abiotic Factors

1.2.1 Climate of the Study Areas

1.2.1.1 Climate of the Lamto Scientific Reserve

The Lamto reserve is affected by a humid tropical or subequatorial climate, characterised by notable variability, resulting from its intermediate position between the four-season equatorial regime and the two-season tropical regime **(Pagney, 1988).** It is characterised by the fluctuation of monthly precipitation and temperatures, which allows it to define two rainy seasons and two dry seasons. Indeed, as illustrated by the ombrothermic diagram established for the period from 1990 to 2022 **(Figure 2)**, the main rainy season runs from mid-February to July; the short rainy season extends from September to November. The long dry season extends from December to mid-February; the short dry season covers the month of August.

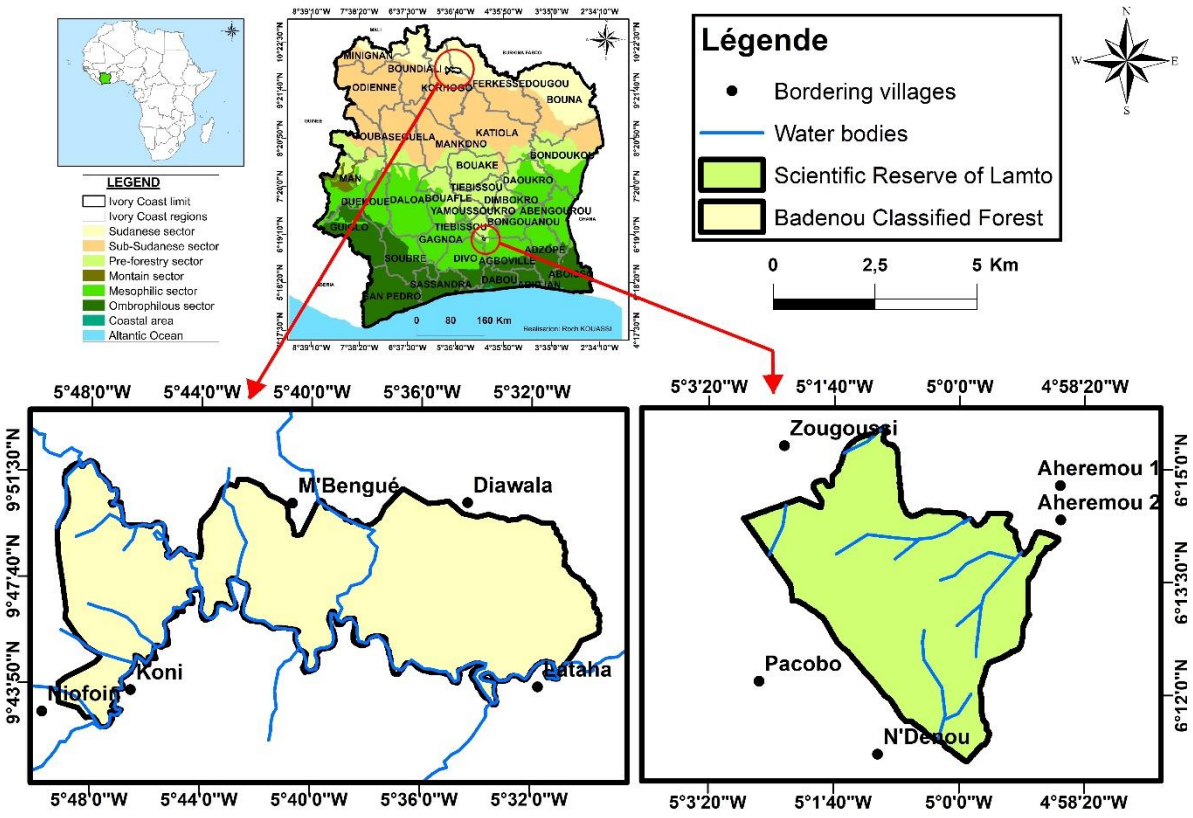

Figure 1: Geographical location of the Lamto Scientific Reserve and Badenou Classified Forest(Roch KOUASSI, 2022)

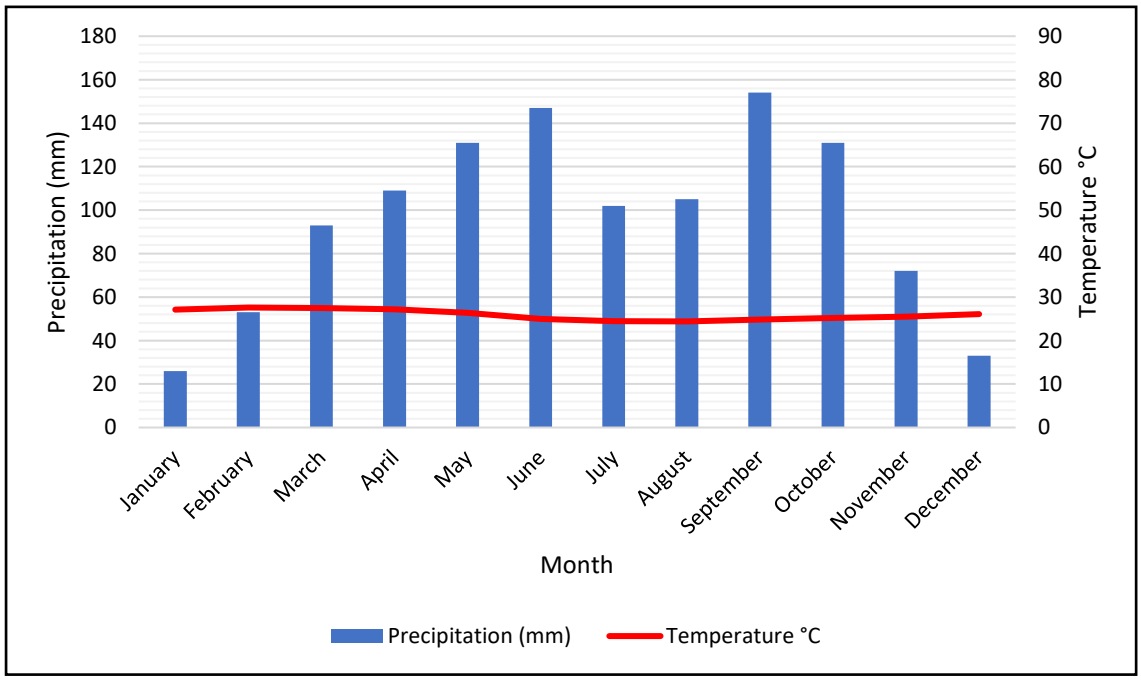

Figure 2: Ombrothermic diagram of the Taabo Department (https://en.climate-data.org/africa/cote-d-ivoire/lagunes/taabo-884044/)

1.2.1.2 Climate of the Badénou Classified Forest

Located in the Subsoudanian sector of the Sudanian domain of Côte d'Ivoire, the BCF is subjected to a subhumid tropical climate of the Sudanian type with two seasons **(Aubréville, 1958).** The ombrothermic diagram **(Figure 3)** highlights these two seasons. A rainy season that extends from April to October, with a maximum of precipitation in August and a dry season spanning from November to March. The dry season is sometimes punctuated by a few low-intensity rainfalls. It is also influenced by the harmattan, a dry and cold wind coming from the Sahel. The cumulative annual water deficit is concentrated from July to September. The average annual temperature is around 27°C. Evapotranspiration (E.T.P) is intense during the dry season **(Kassé, 2009).**

1.2.2 Geomorphology and Soils of the Study Areas

1.2.2.1 Geomorphology and Soils of the Lamto Scientific Reserve

The Lamto Scientific Reserve is located on the Precambrian crystalline basement of West Africa, where the parent rock is predominantly composed of granite and amphibolites in certain areas. Some green rocks outcrop and give rise to black soils or vertisols **(Delmas, 1967; Riou, 1974).** The soils of Lamto are of remoulded impoverished ferrallitic types **(Perraud, 1971).** The presence of hydromorphic soils **(Figure 4),** called gleysols, can also be observed, originating from granite colluvium along watercourses, in depressions, and in areas where drainage is impeded **(Perraud, 1971).** These soils are very sandy (about 80%) and low in clay (7.5-14.5% depending on the strata), with an acidic pH, ranging from 6.5 to 5.5 **(Abbadie *et al.*, 2006).** The sandy fraction plays a crucial role in the seasonal variability of water availability in the soils of Lamto, due to the region's humid climate. The soils of the Lamto savanna generally exhibit low nutrient content, particularly in nitrogen and organic matter **(Abbadie and Lensi, 1990).** This situation of poverty mainly results from the impact of fire and soil erosion caused by heavy rainfall **(Fournier, 1991).**

1.2.2.2 Geomorphology and Soils of the Badenou Classified Forest

The study area, due to its location in the savanna region of northern Côte d'Ivoire in the sub-Saharan sector, is characterised by a parent rock composed of calco-alkaline Precambrian granites **(Adjanohoun, 1964).** The soil map of Côte d'Ivoire by **Monnier (1983),** shows that the soils are of the ferralitic type with low desaturation **(Devineau, 1984).** Hydromorphic soils are also found on the alluvium of river terraces **(Figure 5).**

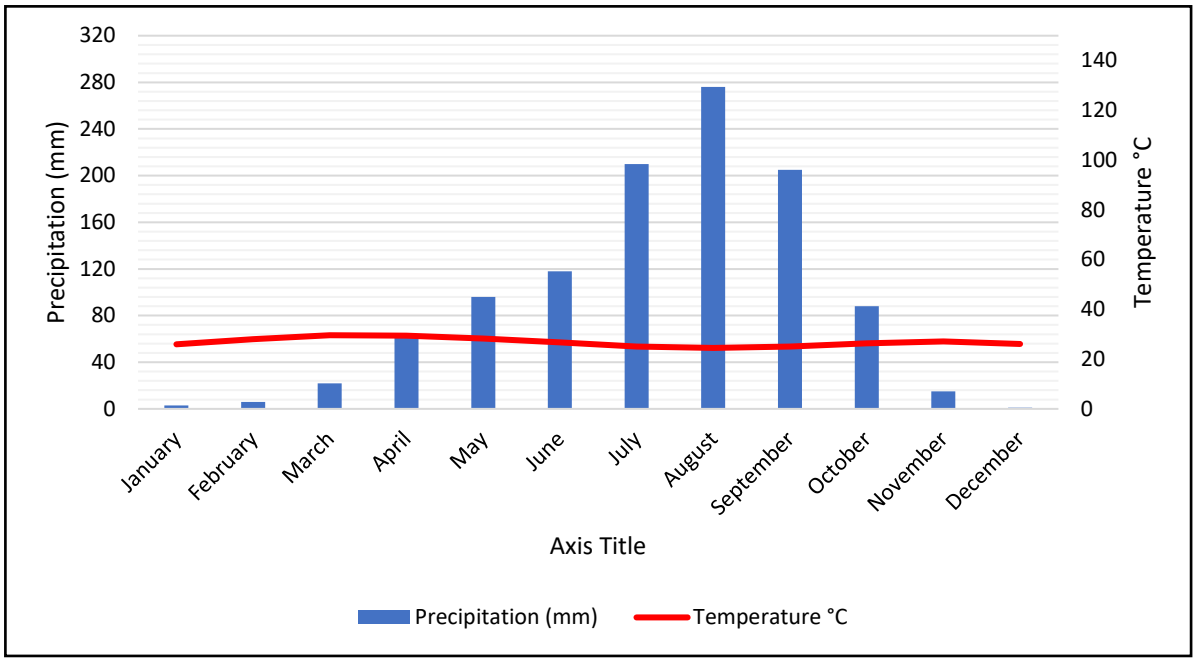

Figure 3: Ombrothermic diagram of the Korhogo Department (https://en.climate-data.org/africa/cote-d-ivoire/lagunes/taabo-884044/)

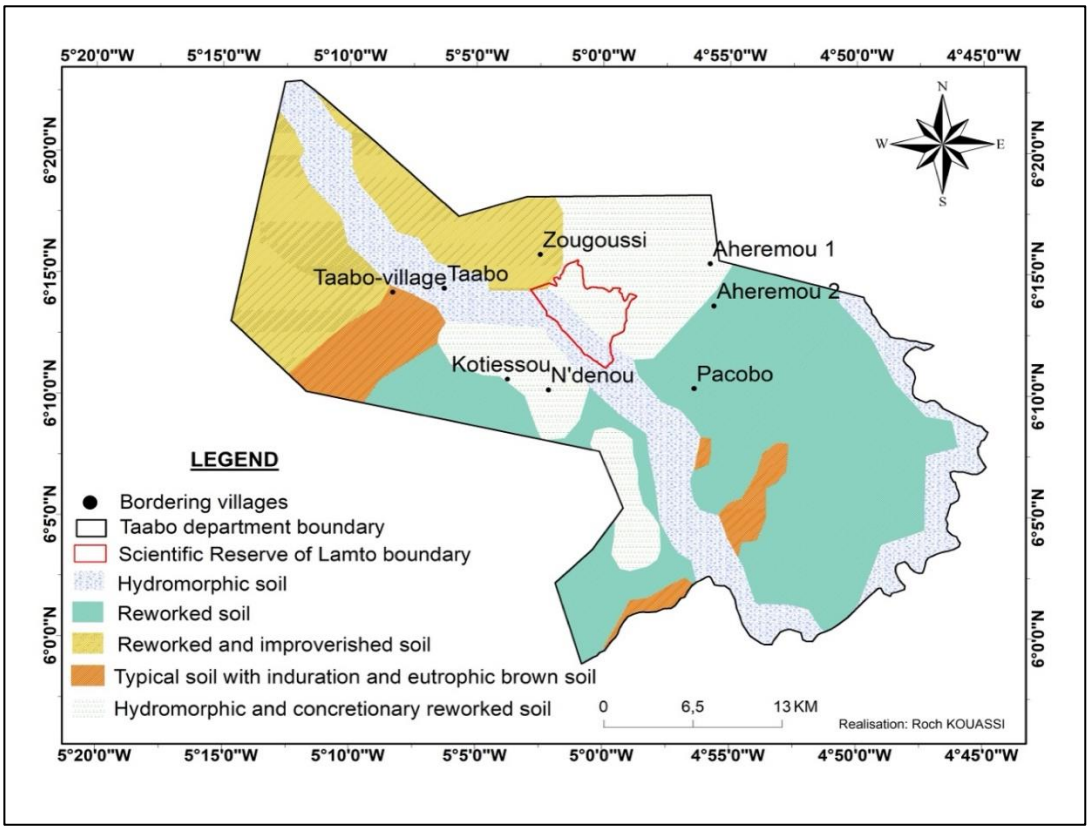

Figure 4: Soil map of the Lamto Scientific Reserve

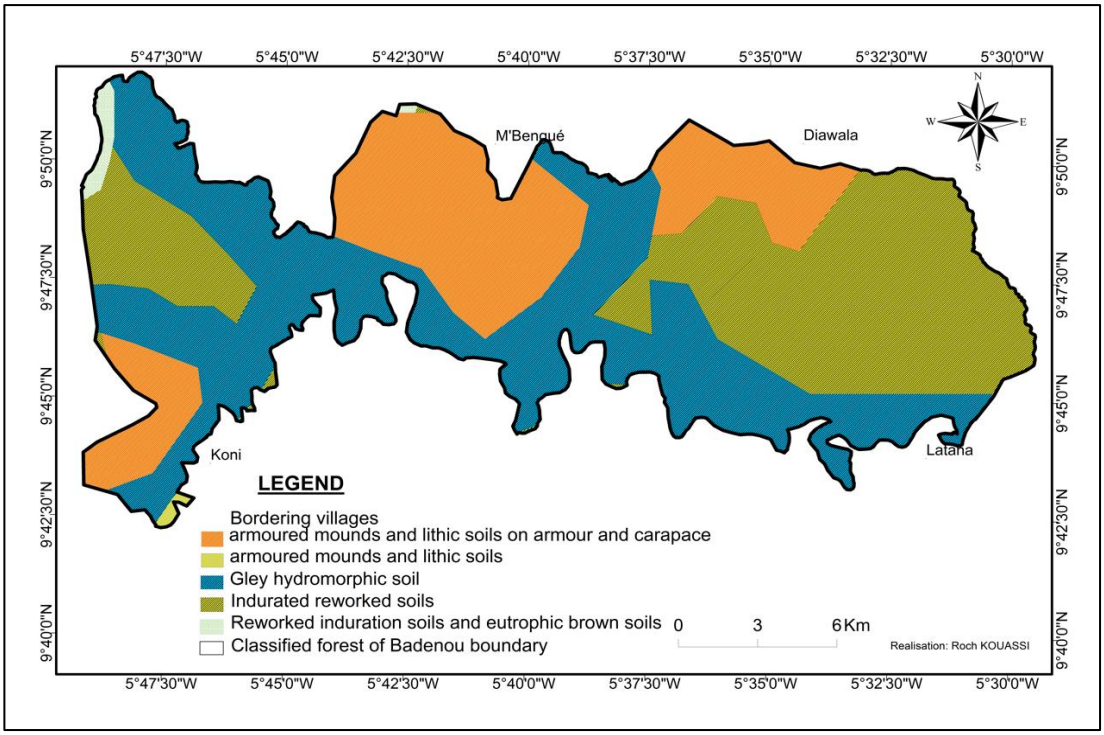

Figure 5: Soil Map of the Classified Forest of Badenou (Roch KOUASSI, 2022)

The topography is gently undulating, with slopes of up to 1%. Generally speaking, the BCF is easy to access. It has a relief of armoured plateaux and interfluves with straight, gently sloping slopes drained by temporary watercourses. The main rocks encountered are granite in the form of large boulders, often found on the mountains, and sandstone, which is predominant on the mountains and often in the form of rolled pebbles on the plains.

1.2.3 Hydrography of the Study Areas

1.2.3.1 Hydrography of the Lamto Scientific Reserve

The hydrographic network of the Department of Taabo is made up of rivers, including the Bandama and its tributary, the N'Zi. In fact, the Lamto reserve is located in an area crossed by the shared hydrological network of these two watersheds: that of the Bandama to the west of the reserve **(Figure 6)**, with a gradient of 7%, and that of the N'Zi, to the east of the reserve, with a gradient of 1% **(Riou, 1974).** Numerous temporary watercourses and marigots, such as the ‘salé’ marigot 500 m to the east of the ecological station and the ‘Assatindrin’ marigot 300 m to the north-west of the geophysical station, are found in closed depressions and talwegs.

1.2.3.2 Hydrography of the Badenou Classified Forest

The BCF is under the influence of the Bandama River and several permanent and temporary watercourses. The Bandama River represents the southern boundary of the classified forest **(Figure 7).** The main tributaries of the Bandama River, located on the left bank, are the Badénou and the Badéni, which partially delineate the northern border. The Bandama River constitutes the main watercourse traversing our study area. The other permanent rivers that cross the Badénou classified forest experience a drop in their water level during the dry season. The temporary rivers that dry up during the dry season are composed of the rivers Kodialani, Vaka, Lokovo, Nafounloho, Zankového, Kobiloho, Kokouho, Loua, Bogro, Kodjalogo, and Nigona.

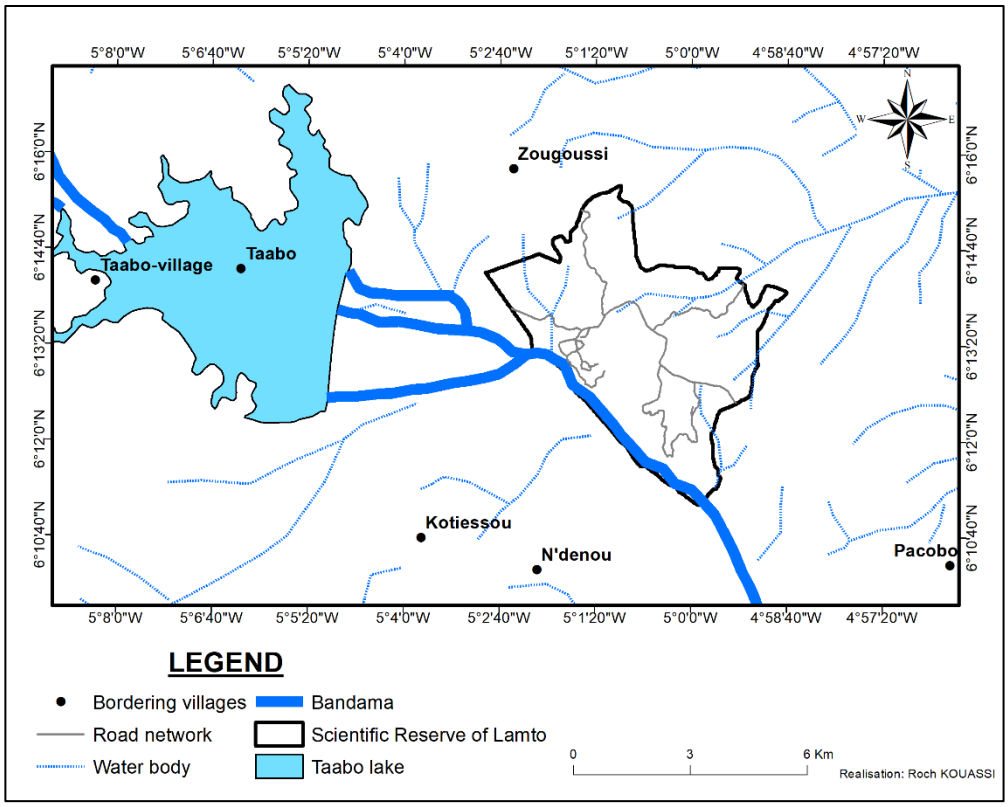

Figure 6: Hydrographic network of the Lamto Scientific Reserve (Roch KOUASSI, 2023)

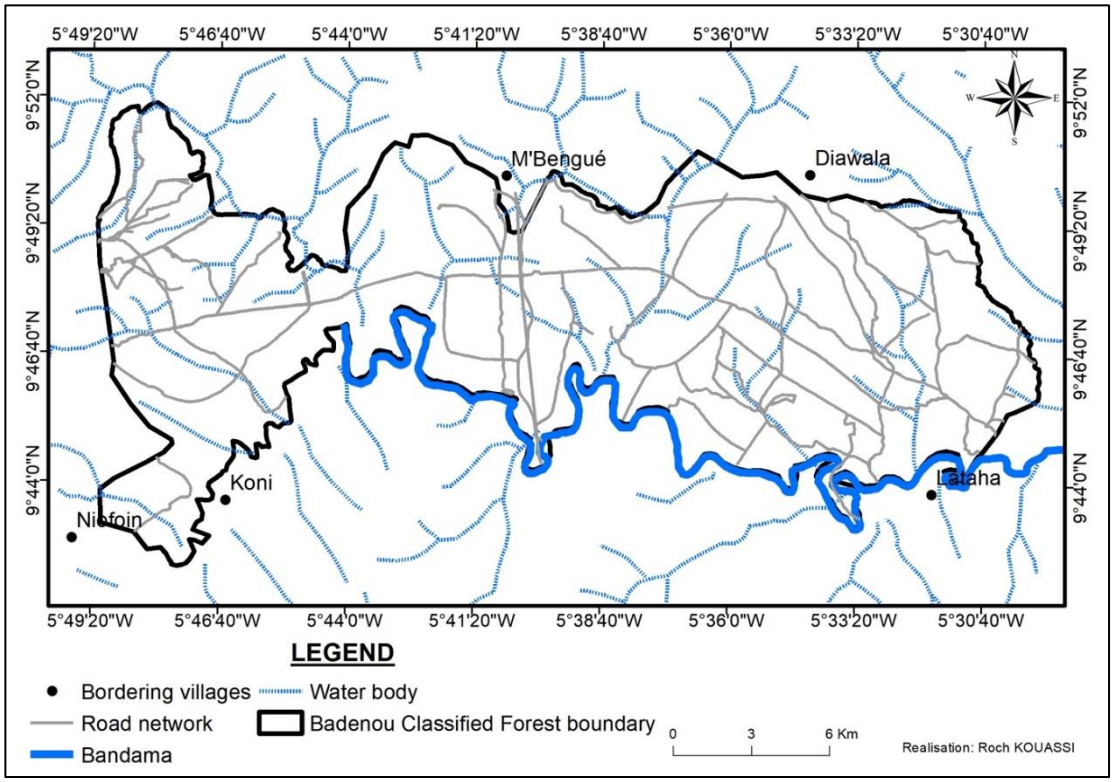

Figure 7: Hydrographic network of the Classified Forest of Badenou (Roch KOUASSI, 2023)

1.3 Biotic Factors

1.3.1 Vegetation of the Study Areas

1.3.1.1 Vegetation of the Lamto Scientific Reserve

The vegetation in Côte d'Ivoire is generally divided between two distinct phytogeographical zones. In the south, we find the Guinean domain, which notably includes a coastal sector located near the sea, with a main climax of dense forest and mangroves, a small mountainous sector (with montane forests), a hygrophilous sector of dense evergreen forest, as well as a mesophilous sector of dense semi-deciduous forest **(Figure 8).** Subsequently, we find the northern Sudanese domain, which is subdivided into sub-Sudanese sectors characterised by dry dense forests, open forests, and expanses of savanna, as well as a Sudanese sector, where open forests and savannas predominate. The Lamto reserve is located in the mesophilic sector of the Guinean domain, in a pre-forest area characterised by the coexistence of a diversity of forests and savannas. This area appears as a savanna-type extension within a dense semi-deciduous forest.

According to **Chatelain *et al.* (2011)**, the plant biodiversity of the Lamto reserve consists of 1309 species of herbaceous and woody plants, out of a total of 1984 species recorded in the preforest savannas of the mesophilic sector. Among these, 74 species are specific to the Guinean savannas. In the Guinean savannas, the presence of the *Borassus aethiopum* Mart. (Arecaceae), constitutes a characteristic element of the landscape **(Vuattoux, 1968).** According to the inventories conducted by **Koulibaly (2010),** the arboreal savanna species in the Lamto reserve are composed of *Bridelia ferruginea* Benth (Phyllantaceae), *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth. (Rubiaceae), *Cussonia arborea* Hochst. ex A. Rich. (Araliaceae) and *Piliostigma thonningii* (Schum.) Milne-Redh. (Fabaceae), *Pterocarpus erinaceus* Poir. (Fabaceae) and *Terminalia schimperiana* Hochst. (Combretaceae). Regarding the herbaceous layer, it is predominantly composed of the species *Loudetia simplex* (Nees) Hubbard. The species appearing in the areas that are more humid and protected from fire include, among others, *Ficus sur* Forssk. (Moraceae), *Zanthoxylum zanthoxyloides* (Lam.) Zepern. & Timler (Rutaceae), *Vitex doniana* Sweet. (Verbenaceae), *Sarcocephalus esculentus* Afzel. (Rubiaceae), *Lannea kerstingii* (Oliver) Engl. (Anacardiaceae). Finally, the forests are characterised by *Triplochiton scleroxylon* K. Schum. (Malvaceae), *Celtis philippensis* Blanco (Cannabaceae), *Dialium guineense* Willd. (Fabaceae), and *Holarrhena floribunda* (G. Don) T. Dur. & Schinz (Apocynaceae) according to **Koulibaly (2010).**

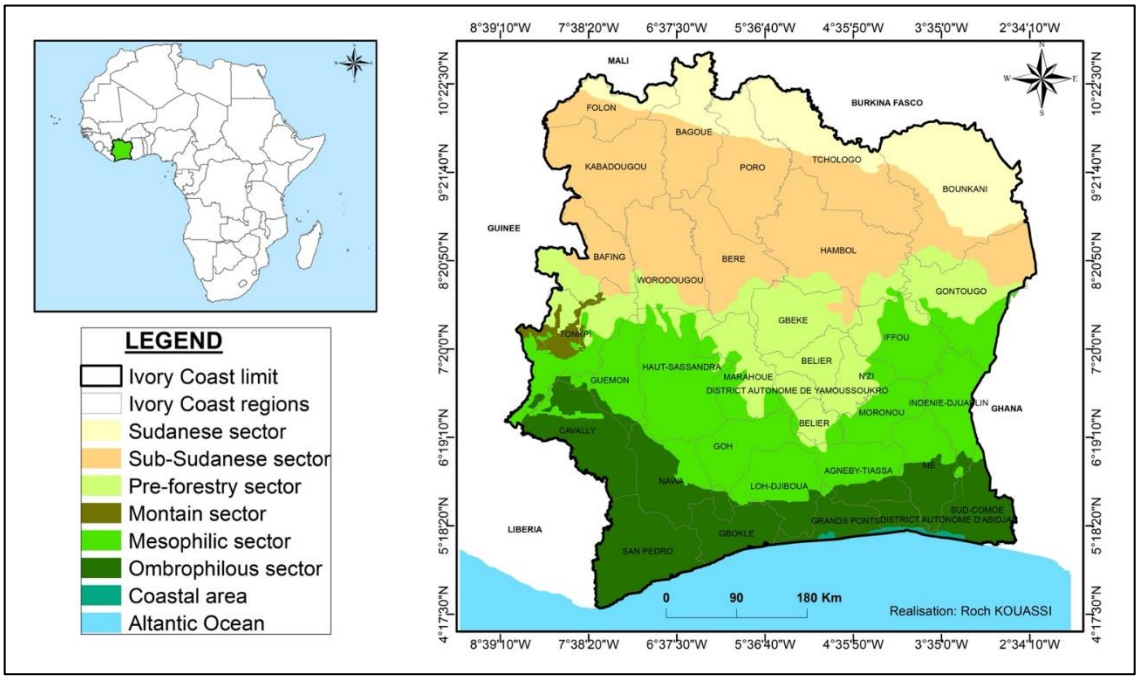

Figure 8: Phytogeogrqphic map of Côte d'Ivoire (Roch KOUASSI, 2023)

1.3.1.2 Vegetation of the Badenou Classified Forest

According to **Kouamé *et al.* (2010)**, the sub-Saharan sector covers a total area of 91,960 km² and is characterised by some patches of dense forests, sometimes humid with *Mimusops kummel* A. DC. (Sapotaceae), sometimes dry with *Anogeissus leiocarpus* (DC.) Guill. & Perr. (Combretaceae), in the savanna, where some individuals of *Burkea africana* Hook. (Caesalpiniaceae), *Daniella oliveri* Hutch. & Dalz (Caesalpiniaceae), *Isoberlinia doka, Parinari* curatellifolia Planch. ex Benth. (Chrysobalanaceae), *Vitellaria paradoxa* C.F. Gaertn. (Sapotaceae), *Khaya senegalensis* (Desr.) A. Juss. (Meliaceae) and *Cola gigantea* var. *glabrescens* Brenanet Keay (Malvaceae) etc., appear. The vegetation in this area also consists of gallery forests and open forests. The classified forest of Badénou belongs to the sub-Saharan phytogeographical zone. This area is composed of several species resistant to bushfires, possesses a high regeneration capacity and its ability to sprout constitutes an important element of the landscape. These forests are composed of two parts: a woody part and a herbaceous part. The woody part consists of mesophanerophytes, microphanerophytes and nanophanerophytes.

1.3.2 Fauna of the Study Areas

1.3.2.1 Fauna of the Lamto Reserve

The Lamto reserve currently exhibits low diversity in terms of large mammal species. It is likely that elephants, *Loxodonta africana* Cuvier (Elephantidae) and hippopotamuses, *Hippopotamus amphibius* Linnaeus (Hippopotamidae) were present in the region at an earlier time. However, it is undeniable that currently, there are few large herbivores in the reserve. The low diversity of animal species in this savanna can be attributed to excessive hunting practised for many years to supply the surrounding villages of Zougoussi, Kotiéssou, N'Denou and Ahérémou II **(Roth *et al.,* 2002).** According to recent observations made by researchers and agents of the Ivorian Office of Parks and Reserves (OIPR), there is currently a herd of about thirty buffaloes, *Syncerus caffer* Sparrman (Bovidae) and a few Buffon kob antelopes, *Kobus kob* Erxleben (Bovidae). As for small mammals, we can mention rodents such as Rudd's rough-haired mouse (*Uranomys ruddi*), the striped mouse (*Lemniscomys striatus*) and the Baoulé's mouse (*Leggada baoulei*), as well as Kemp's gerbil (*Tatera kempi*) as noted **IUCN/BRAO (2008).** Among the 458 bird species recorded in the reserve, there is one particularly rare species, namely the White-headed Picathartes, *Picathartes gymnocephalus* Temminck (Picathartidae), endemic to West Africa and classified as vulnerable on the IUCN Red List (International Union for Conservation of Nature) through the following link (https://www.oipr.ci/index.php/parcs-reserves/reserves-naturelles/reserve-de-lamto). Speaking

of endangered species, we can notably mention the Royal Python (*Python regius*), the Seba's Python (*Python sebae*), the African Forest Buffalo (*Syncerus caffer nanus*), and the Kob (*Kobus kob*) **(IUCN/BRAO, 2008).** The soil macrofauna is composed of a great diversity of invertebrates belonging to the insect group, among which are numerous ants, termites, bees, praying mantises, and earthworms **(Tiho *et al.,* 2015).** While Bees belonging to the genus Trigones are currently present, thus contributing to the pollination of the ron palm **(Lobreau-Callen *et al.,* 1994).**

1.3.2.2 Fauna of the Classified Forest of Badenou

The wildlife in the natural environment of the classified forest of Badenou, whether outside or inside it is greatly impoverished due to habitat degradation and intensive illegal hunting for profit. While small mammals, birds, reptiles and numerous insects are still visible in the classified forests, large mammals such as the Buffon's kob (*Kobus kob kob* Erxleben), the bushbuck (*Tragelaphus scriptus scriptus* Pallas), the hippotragus (*Hippotragus equinus koba* Gray), the leopard (*Panthera pardus* Linnaeus), the warthog (*Phacochoerus porcus porcus* Linnaeus) and the common hippopotamus (*Hippopotamus amphibius amphibius* Linnaeus) have become rare and almost nonexistent. The observations made, as well as the exchanges with the local population, allowed us to confirm the presence of the red monkey (*Erythrocebus patas*), antelopes such as the bushbuck (*Tragelaphus scriptus*) and the red duiker (*Cephalophus natalensis*), the cane rat (*Thyronomys swinderians*), hares (*Lepus sp*), the palm squirrel (*Epixerus ebii*), the ground squirrel (*Xerus erythropus*), the small-scaled pangolin (*Manis tricupis*), the royal python (Python regius), the puff adder (*Bitis arietans*), the grey partridge (*Perdix perdix*), the common guineafowl (*Numida meleagris*), the cattle egret (*Bubulcus ibis*), etc.

1.3.3 Population and Human Activities

1.3.3.1 Population and Human Activities in the Lamto Scientific Reserve

At the beginning of the 19th century, the Department of Taabo was inhabited by the Baoulé, an important ethnic group of the Akan, who had moved from present-day Ghana. The main economic activities of the Taabo Department, which were prevalent in earlier years, include agriculture, canoe making, hunting, tree cutting for charcoal production, carpentry, and firewood. As for agriculture, it consists of the annual cultivation of yam species, *Dioscorea spp.* (Dioscoreaceae), a staple food, in association with secondary crops. Among these secondary crops, they are chili pepper, *Lycopersicon esculentum* Mill. (Solanaceae), okra, *Abelmoschus esculentus* (L.) Moench (Malvaceae), eggplant, *Solanum sp* (Solanaceae) and cassava, *Manihot*

esculenta Crantz (Malvaceae). The search for land to cultivate led to a population shift towards the forest (Blanc-Parmard, 1979), and thus began the cash crop cultivation. Cocoa, *Theobroma cacao* L. (Malvaceae) and rubber, *Hevea brasiliensis* (Willd. Ex A. Juss.) Mull.Arg. (Euphorbiaceae) are the main cash crops in the Taabo Department. These various human activities result in a modification of the natural environment, currently manifested by the impoverishment, weakening, destruction of the original flora and the decline in soil fertility **(Guillaumet and Adjanohoun, 1971).** However, the vegetation in the Lamto reserve does not suffer significant degradation, unlike the surrounding villages in the Taabo Department. Agricultural activity has been recorded within the reserve, and the bushfires that are ignited there are generally controlled fires. The use of fire within the Lamto reserve aims to protect and conserve the Lamto savannas because this area has a climate favourable to the establishment of forests **(Monnier, 1968).** Despite its protection, a significant increase in the density of savanna tree species has been observed. At the same time, a gradual appearance of forest-specific species was noted. After 12 to 15 years, it was observed that the savanna was overrun by these forest species **(Devineau *et al.,* 1984).** Rarely, the collection of fuelwood and plant parts for medicinal purposes in buffer zones has been reported **(Lauginie, 2007).** In order to strengthen the protection of the reserve and to prevent its various extractions, the Ivorian Office of Parks and Reserves (OIPR) is increasingly involving the neighbouring communities in a participatory management approach.

1.3.3.2 Population and Human Activities in the Classified Forest of Badenou

The FCB is traversed by the high-voltage power line that crosses its domain in the eastern part, going from the neighbouring village of Tawara to the Tongon Gold Mine. The inhabitants of the villages located on the outskirts of the Badénou classified forest are mainly composed of Sénoufos and Malinkés, who are indigenous ethnic groups and generally practice animism or Islam. In addition to these locals, there are also newcomers (Attié, Baoulé, Bété, Lobi) and migrants from neighbouring countries (Mali, Burkina Faso, Guinea). The population derives its main economy from agriculture (subsistence crops and cash crops) and traditional livestock farming. The main food crops are cereals such as: *Zea mays* L. (Poaceae), *Oryza spp.* (Poaceae), *Sorghum bicolour* L. (Poaceae), *Pennisetum typhoides* L. (Poaceae), *Arachis hypogea* L. (Fabaceae), and the crop *Dioscorea spp.* (Dioscoreaceae). The main cash crops are *Gossypium hirsutum* L. (Malvaceae) and *Anacardium occidentale* L. (Anacardiaceae). The increase in population is leading to an increasing number of clandestine infiltrations by the inhabitants of neighbouring villages. These residents enter the classified forest to set up camps

CHAPTER 2: BIBLIOGRAPHICAL REVIEW OF SOME CONCEPTS AND TERMS SPECIFIC TO THIS STUDY

2.1. Climate Change

2.1.1. Global Climate Change

In 1979, in response to growing international concern about the threat of climate change caused by human emissions of carbon dioxide, a World Climate Conference was held in Geneva **(WMO, 1979).** It was at this conference that nations began to pay increased attention to natural disasters linked to climate change **(Merle *et al.,* 2014).** In 1988, the Intergovernmental Panel on Climate Change (IPCC) introduced the concept of 'climate change' for the first time **(UNICEF, 2016).** Indeed, climate change refers to a sustained and significant alteration in climate characteristics measured on a global or regional scale.

It is a complex, multifactorial phenomenon that results from the interaction between natural processes and human activities **(IPCC, 2023).** It is mainly caused by disturbances to the Earth's energy balance, generally assessed in terms of radiative forcing. This forcing phenomenon is generated by the accumulation of greenhouse gases (GHGs) in the atmosphere, notably carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These gases have the ability to absorb and re-emit infrared radiation from the Earth's surface, leading to increased heat retention in the climate system **(NASA, 2023).** All these disturbances lead to fluctuations in the Earth's mean temperature, precipitation patterns, ocean currents and winds, characterised by floods, cyclones, droughts, etc., on timescales ranging from several decades to millions of years **(IPCC, 2021).**

As a result, scientific data is multiplying, demonstrating an intensification of the repercussions on ecosystems, economies and human societies. In 2023, various reports and studies highlighted worrying trends, underlining the urgent need for action. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) published in 2023, the global average temperature has already risen by 1.1°C compared to pre-industrial levels. In the event that greenhouse gas (GHG) emissions are not significantly reduced, it is conceivable that the world could reach a temperature rise of 1.5°C as early as the 2030s, a crucial threshold for preventing the most serious climatic consequences **(IPCC, 2023).**

In other words, climate change, a major global phenomenon, is a scientifically proven reality that is impacting our planet in a variety of ways. Faced with this urgent situation, it is imperative that we act collectively and immediately to limit the harmful effects on the environment, biodiversity and human populations. Solutions to this complex problem are available, but their implementation requires a strong political commitment from the various players involved. In addition, close international cooperation is essential to coordinate efforts on a global scale.

Finally, profound structural changes will have to be made to ensure the effectiveness and sustainability of the measures put in place. According to the conclusions of the IPCC in 2023, it is important to take into account every tiny variation in temperature because the choices we make today will have a decisive impact on the future evolution of our planet.

2.1.2 Impacts of Climate Change

The impacts of climate change are mostly ignored or underestimated by political decision-makers, exposing their populations to the harmful effects of extreme weather events. This situation could explain the lack of involvement by governments in implementing concrete measures to reduce greenhouse gas emissions from industry. This represents a major challenge not only for forest-dependent communities but also for downstream regions, which are increasingly affected by devastating floods during the rainy season **(AMCC, 2012).** In reality, 2023 has been characterised by a succession of extreme weather events. Heat waves in Europe, forest fires in Canada and devastating floods in Libya all bear witness to worsening weather patterns.

According to research published in the journal **Nature Climate Change (2023),** these phenomena are closely associated with climate change and are likely to occur more frequently and with greater intensity. Furthermore, Africa, and more specifically West Africa, stands out as one of the regions most exposed to the effects of climate change, due to its heavy dependence on irrigated agriculture and its limited capacity to adapt **(UNEP, 2023).** The consequences include the emergence of extreme climatic phenomena, the deterioration of ecosystems and an increase in socio-economic pressures. This point is illustrated by the reduction in rainfall in subtropical areas and the irregularity of rainfall, which are contributing to the worsening of the water shortage situation. The rainy season, essential for crops such as millet and sorghum, has become increasingly unpredictable. In some regions, rainfall has fallen by around 20% since the 1970s **(UNEP, 2023).** Many coastal flooding, such as those seen in Lagos and Cotonou, poses a threat to infrastructure and surrounding populations.

By 2050, cocoa-growing areas in Côte d'Ivoire and Ghana could be halved, according to a CIAT study **(CIAT, 2021).** Reduced crop yields caused by droughts, floods and locust invasions are a threat to food security. In 2022, according to the **FAO (2023)**, undernourishment will affect 282 million people in Africa. Moreover, the World Bank estimates that 40% of Africa's agricultural land has already been degraded. Finally, climate change acts as an aggravating factor by combining environmental risks, economic fragility and political instability. Solutions

require adaptation, particularly in the areas of resilient agriculture and water management, as well as enhanced regional cooperation, backed by international climate funding.

2.2. Remote Sensing

2.2.1. Definition and Importance of Remote Sensing

Remote sensing is defined as a method which, using one or more sensors, makes it possible to obtain data on an object, an area or a phenomenon on the Earth's surface (including the atmosphere and the oceans) without requiring direct contact with these elements **(N'Da, 2008).** It is the remote use (for example, from an aircraft, spacecraft, satellite or ship) of any type of instrument to acquire information about the environment. It encompasses the entire process of capturing and recording the energy of electromagnetic radiation, whether emitted or reflected, processing and analysing the data, and then practically applying this information **(CCT, 2018).**

Remote sensing is based on the interaction between incident energy and target objects. By processing and analysing the data conveyed by the recorded radiation, it is possible to access certain properties of the target: geometric (position, shape and size), optical (reflection, transmission, absorption, etc.) and physico-chemical (temperature, water content, leaf chlorophyll, plant mass and soil organic matter). In addition, this discipline is fundamental to the effective assessment and regulation of natural resources, to understanding and responding to natural disasters, and to monitoring land use and the impacts of climate change. The process of remote sensing using imagery systems consists of seven distinct stages **(Figure 9).**

A) It is the source of energy (the sun) and is at the origin of all remote sensing processes, allowing the target to be illuminated. This source is the fundamental reference for optical remote sensing.

B) As the radiation propagates from the energy source towards the target, it interacts with the surrounding atmosphere. This interaction is repeated a second time as it travels from the target to the sensor.

C) The interaction with the target surface depends on a number of factors, including its nature, texture and temperature, as well as the characteristics of the incident radiation, such as its wavelength, intensity and angle of incidence. All these factors will influence the way in which the target interacts with the radiation.

D) Energy recording by the sensor

E) The energy recorded by the sensor is transmitted to a receiving station. Here, the formation is processed and converted into digital images.

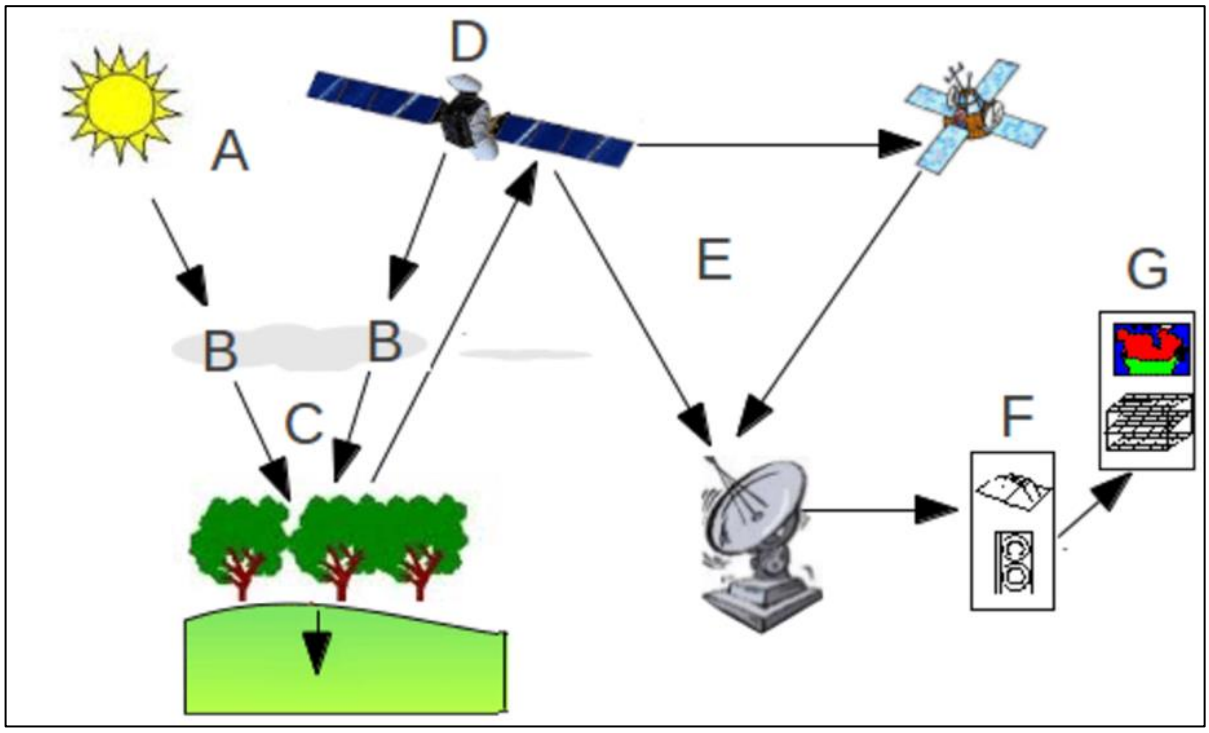

Figure 9: Diagram of the remote sensing process using imaging systems

F) Interpretation and analysis of the digital image involves studying each pixel of the image in detail in order to extract precisely the information required about the target.

G) The final phase of this process involves using the data extracted from the image to gain a deeper understanding of the target. This process brings to light new elements that could contribute to solving a specific problem.

2.2.2 Advantages and Limitations of Remote Sensing

Remote sensing tools have been widely used in landscape analysis since the launch of aerial missions in the 1950s, and the expansion of civilian satellite launch programmes in the 1970s **(Morant, 2000).** For several authors **(Quattrochi and Pelletier, 1990; Bonn and Rochon, 1992; Jensen, 2004),** the application of remote sensing to analyse environmental and cultural properties and the management of natural resources is well known. The main advantages of remote sensing lie in its holistic approach to territorial coverage, the use of sensors covering a wide range of wavelengths, the high frequency of passes, low cost, and the speed with which results can be returned, which is superior to that of traditional information systems **(Tankoano, 2017).**

Because of its global approach and its ability to define geographical boundaries at an administrative level, remote sensing offers valuable information to natural resource managers, making it easier to take decisions about the action to be taken. The ability of sensors to observe beyond the visible range, i.e. in light spectrums not perceptible to the human eye such as infrared or ultraviolet, offers the possibility of acquiring data and details on areas that are normally unreachable or invisible to human beings. The frequency of overflights makes it easier to examine the dynamics of a specific phenomenon by offering a chronological analysis based on the interpretation of data collected at different dates, with the aim of determining the dynamics of land cover. Another significant advantage of remote sensing is its ability to provide data that can be easily combined and integrated with other types of information within Geographic Information Systems (GIS). These systems are particularly interesting tools for resource management, because the various components of the landscape are captured together, in their mutual eco-geographical relationships **(Mikwa, 2010).**

Although it offers many advantages, remote sensing also has certain limitations. These limitations may be due to the phenomena to be observed, the weather conditions, the resolution and the sensitivity of the sensor. One of the most significant limitations of using remote sensing is that resolution is not constant and can vary depending on the sensors and observation conditions. It is important to stress that the reliability of the results obtained is directly linked to the resolution of the type of sensor used. Indeed, the higher the resolution, the better the

quality of the information transmitted, stored and processed (Koua et al., 2017). In tropical forest ecosystems, the application of remote sensing comes up against the specificities of the environment, the saturation of the radiometric signal and the radiometric dominance of the canopy **(Soufouyane et al., 2018).**

It is therefore complex to establish a link between field observation data and remote sensing data, particularly when satellite images have a low resolution, as they do not allow the most subtle details to be discerned. Indeed, when the spatial resolution of an image is low, the small geographical features present in it are overwhelmed by the dominant geographical features. In addition, the extremely heterogeneous nature of tropical forests makes it difficult to discriminate between elements of this landscape in a low spatial resolution satellite image, as one pixel in such an image can cover a whole range of mixed vegetation. What's more, the cost of acquiring data from high-resolution satellite images can be high, so not everyone can afford them.

2.2.3 Satellite Imagery

Remote sensing data is most often provided in digital image format. An image is defined as the two-dimensional representation of an object, produced by the reflectance or refraction of multi-dimensional evidential radiation, or more simply a matrix **(Wiederkehr, 2013).** Satellite imagery is remote sensing imagery collected by artificial satellites (Spot, Landsat, Ikonos, Terra, etc.) orbiting the Earth or other planets. The images exist in certain wavelengths (ultraviolet, visible, infrared, etc.) which can be combined for different interpretations **(Robin, 1998; CCRS, 2018).** Satellite imagery uses vectors and sensors as tools. Vectors are devices (cranes, aircraft, satellites, space shuttles, etc.) that carry detection devices called sensors (cameras, radar, etc.). There are two types of sensors: active and passive. Active sensors, such as radars, operate simultaneously as microwave or hyper-frequency transmitters and receivers. These waves can penetrate cloud formations without modifying the information and are therefore used in areas with heavy cloud cover such as equatorial zones **(Jaeger, 1987).**

The passive sensors used in this study record the energy emitted by the sun after reflection from the Earth's surface. Every object on Earth emits or reflects radiation in the form of electromagnetic waves, classified according to their wavelength. Every object therefore has a ‘spectral signature’ that it emits or reflects in each of the spectral bands in which the sensor operates. However, different objects can have the same spectral signature. For this reason, a large number of spectral bands provides better discrimination. Sensors are characterised by their resolution. Most remote sensing studies of vegetation use high spatial resolution images (2.5 -

10 - 30 m) such as SPOT, SENTINELLE or LANDSAT **(Adjonou *et al.*, 2010; El Garouani *et al.*, 2007; Pain-Orcet *et al.*, 1998).** In our study, Landsat satellite images were used.

LANDSAT (Land Satellite) is the oldest satellite-based earth observation system in the United States. NASA launched the first satellite in the LANDSAT series (originally called ERTS: 'the Earth Resources Technology Satellites') in 1972. Two other satellites (LANDSAT 2 and LANDSAT 3) in the programme were launched the same year with the same type of sensor. From 1982 onwards, the programme introduced a new generation of satellites, the first of which was LANDSAT 4, launched into orbit on 16 July 1982. This first satellite of the new LANDSAT generation was equipped with a Thematic Mapper (TM) sensor in addition to the MSS sensor. This satellite saw a significant improvement in spatial and spectral resolution **(Desjardins, 2000).**

Two other satellites (LANDSAT 5 and LANDSAT 6) using the same technology were launched in 1984 and 1993 respectively. However, the launch of LANDSAT 6 was a failure. In 1999, the programme launched its seventh satellite, LANDSAT 7, equipped with a new multi-band sensor, Enhanced Thematic Mapper Plus (ETM+) **(NASA, 2002).** The most recent in the series is LANDSAT 8, launched in 2013. It features two sensors: Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The TM sensor provides the most detailed approach to radiometric information thanks to its 7 bands, the first 6 of which are used to study vegetation, agriculture and the impact of human activity on the environment, while the seventh is in the mid-infrared. The Enhanced Thematic Mapper Plus (ETM+) sensor is an improvement on the TM sensors. The bands used to study vegetation are bands 4, 3 and 2 in the near infrared, red and green respectively. Band 4 is very important for classifying land cover types.

It differentiates between bare soil and cultivated land, and between land and water. It is highly sensitive to the amount of biomass contained in vegetation. Band 3 corresponds to the wavelength characteristic of the absorption of chlorophyll by green vegetation. It is one of the most important radiometric bands for studying vegetation **(Oszwald, 2005)**. The LANDSAT 8 satellite is completely different from its predecessors and is equipped with two sensors, the main one being OLI (Operational Land Imager). This records images in nine bands ranging from visible to mid-infrared. The study of vegetation using this satellite uses bands 5, 4 and 3 in the near infrared, red and green respectively.

2.2.4. Remote Sensing and Vegetation Dynamics

Vegetation dynamics is the variation in time and space of the structural and functional parameters of the vegetation cover **(Moundzeo *et al.*, 2016)**. This variation occurs following

natural or anthropogenic disturbances leading to a change in the land use of the environment. Natural disturbances include windthrow and volcanic eruptions, while human activities include agriculture, bush fires, grazing, and the collection of wood, wood fodder and medicinal plants **(Koffi, 2016).** Studies on land use change are important because they provide information on current trends in deforestation, degradation, desertification and biodiversity loss in a given region **(Lambin *et al*., 2001).** Remote sensing therefore appears to be an ideal tool for studying vegetation dynamics. Several studies have shown the importance of spatial tools for measuring changes in forest cover. All these studies show that changes in land cover and the regressive dynamics of vegetation cover are due to human activities and the consequences of climate change **(N'Guessan *et al.*, 2006; N'Da 2008; Barima 2009; Diallo *et al.*, 2011; Kouassi *et al.*, 2012; Koumoi *et al*., 2013; Avakoudjo *et al.*, 2014; Kpangui 2015; Sangne *et al.*, 2015 and N'Guessan 2018).**

2.3. Ecological Value

2.3.1 Importance of the Species *Pterocarpus erinaceus*

Since the beginning of man's existence, he has turned to nature, i.e. his immediate environment, to solve the fundamental problems of his life **(Abebe, 1991).** The woody plants of tropical forests play a very important role in the lives of human beings (particularly in rural areas). They provide oxygen, are home to a wide variety of animal and plant species, help to regulate the climate and offer essential resources for local populations, such as food, medicines and building materials. Among the various species that exist, we can identify in particular the *Pterocarpus erinaceus* Poir. species, which is widely appreciated and used by humans. *Pterocarpus erinaceus* Poir. is a species from the Guinean-Sudanese and Sudano-Sahelian zones. It belongs to the large Fabaceae family and the *Pterocarpus* genus. It is a deciduous tree that can reach heights of 15 to 25 metres, with a cylindrical shape and no branches over a height of up to 10 metres. The bark is greyish-brown to reddish-brown, becoming darker with age, and has a fissured appearance. The inside of the bark is red to brownish-red and slightly resinous when freshly cut. Fruiting occurs during leaf loss, and the immature fruits create the illusion that the tree is still leafy **(Figure 10).** In addition, veneer wood has many uses in different fields, including culture, food, medicine, economics and ecology. From a cultural point of view, *Pterocarpus erinaceus* Poir, commonly known as veneer, is used to make traditional musical instruments, masks, ritual objects and decorations **(IUCN, 2018).**

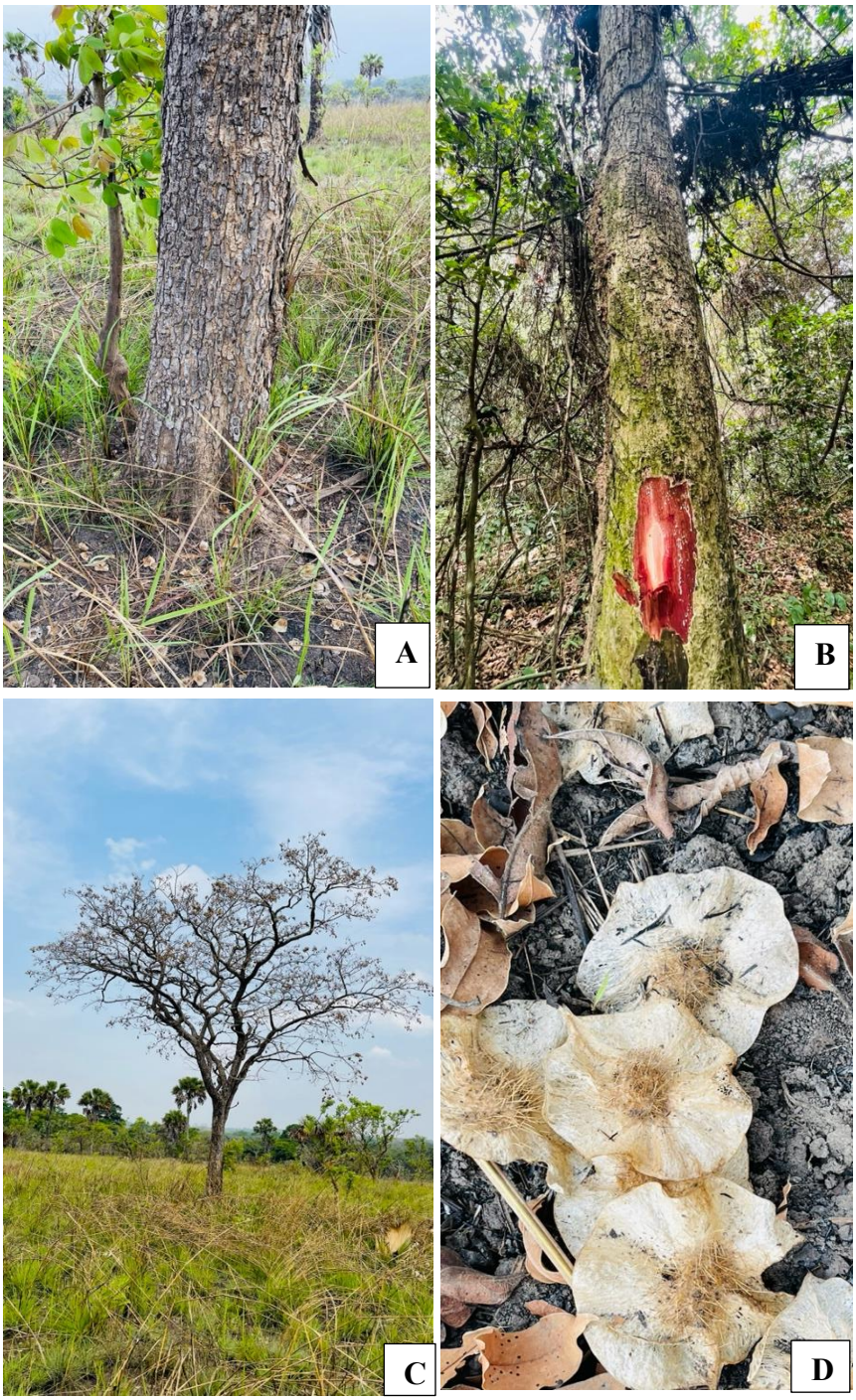

Figure 10: Different parts of *Pterocarpus erinaceus* Poir:

(**A**) : The bark has a greyish-brown colouration
(**B**) : Inner bark with red colouration
(**C**) : Cylindrical in shape and characterized by the absence of branches at a height of up to 10 meters
(**D**) : Immature fruits of *Pterocarpus erinaceus Poir*

In the pastoral sector, research has shown that veneer leaves are used as a source of feed for livestock (Cuny et al., 1997). The young leaves are ingested by ruminants due to their high protein content, making them a high-quality fodder **(Djaouga *et al.*, 2009).** They enable goats, and cattle in particular, to maintain good health and ensure optimum milk production **(Houehanou, 2006).**

In the therapeutic field, the species is mainly recognised for the various pharmacological properties of its leaves, barks and roots. *Pterocarpus erinaceus* treats illnesses such as female sterility, sexual asthenia, ringworm, malaria, haemorrhoids and painful periods. Decoctions or infusions of bark or roots are used to treat bronchial infections, toothache, dysentery, painful menstruation, anaemia, gonorrhoea, post-partum haemorrhage, tapeworm infections, leprosy, wounds, tumours and ulcers **(Rabiou *et al.*, 2017).** Economically, it is mainly independent artisans who harvest it, but in some areas, there are also small- and large-scale timber merchants who harvest and sell it **(Rabiou *et al.*, 2015).** Finally, from an ecological point of view, veneer wood contributes to soil restoration due to its affiliation with the vast Fabaceae family, also known as legumes. Its root system has a significant capacity to fix atmospheric nitrogen, converting it into nitrogen compounds that can be assimilated by the plant to promote its growth, thanks to a symbiotic relationship with Rhizobium bacteria located in its root nodules **(Goba, 2019).** This species can help to restore depleted soils and thus promote the productivity of the crops grown. The species is also used as an insecticide. When millet is sown, the powdered bark is crushed and mixed with the seeds to protect them from predators. Nevertheless, it should be stressed that the importance of this forest resource has made it an endangered species.

2.3.2 Importance of the Species *Afzelia africana*

Afzelia africana Sm. ex Pers. is a species that ranges from savannahs to dense dry forests, gallery forests and dense semi-deciduous forests. It is adapted to the driest habitats. *Afzelia africana* Sm. ex Pers. species are all large, with several buttresses between 1 and 2 m high. The bole is fairly straight, varying in length from 15 to 30 m, with an average diameter at breast height of between 100 and 300 cm. It has paripinnate leaves with 3 to 5 pairs of opposite leaflets **(CTFT, 1980).** The fruits are generally pods, and inside the pods are black oval seeds **(Figure 11).** All these morphological characteristics make *Afzelia africana* Sm. ex Pers. commonly called ‘doussié’ or ‘lingué’ a species highly prized by humans.

Figure 11: Different parts of *Afzelia africana*

E: Fruit of *Afzelia africana*
F: Leaf of *Afzelia africana*
G: Trunk of an *Afzelia africana* tree

In addition to the high quality of its wood, lingué also has interesting medicinal properties, as well as playing a cultural, nutritional and ecological role. Economically speaking, its natural durability against rotting fungi, dry wood insects and termites makes lingué one of the best types of wood. It is used in the manufacture of dugout canoes, kitchen utensils, mortars, drums, firewood, charcoal, etc. Lingué is widely exported in the international timber trade, making it a vulnerable species. Medicinally, the bark and roots are used to treat constipation, fever, vomiting, oedema, tachycardia, hypertension, bronchitis, lung ailments, analgesics and diuretics **(Donkpegan, 2013).** Culturally, Lingué is considered a mystical tree and the wood is used to carve masks **(Houehanou *et al.*, 2011)**. The leaves are also consumed by livestock.

2.4. Dendrochronology

2.4.1. Definition of Dendrochronology

Although Leonardo da Vinci was already interested in tree rings in the 16th century, it was the American physicist and astronomer Andrew Ellicott Douglass who laid the foundations of modern dendrochronology at the beginning of the 20th century. Its etymological definition comes from Greek, where "dendro" means tree, "kronos" means time, and "logos" refers to study **(Worbes, 1995).** Dendrochronology is a scientific discipline that makes it possible to establish the year in which tree rings were formed by measuring the widths of these rings. It uses these precisely dated rings to identify common environmental signals within a population of trees **(Gebrekirstos *et al.*, 2014).**

Initially applied in fields such as archaeology and climatology for the precise dating of fossil trees and the reconstruction of past climates, dendrochronology is now increasingly used to analyse the environment and detect changes in it. It is used in forestry research to assess the impact of climate on tree growth. Tree rings are formed from the periodic cessation of growth caused by extreme fluctuations in environmental conditions **(Schongart *et al.*, 2006; Gebrekirstos *et al.*, 2008).** In temperate zones, ring formation in trees occurs specifically following the winter season. This phenomenon is due to the waking up of the trees' winter dormancy, followed by a period of vegetative activity that extends from spring to early autumn. Annual rings can be distinguished by variations in cell size and cell wall thickness over the growing season. A light initial wood of low density, with large tracheids and thin walls, is formed in spring, and a darker final wood of higher density, with small tracheids and thick walls, is formed in summer and early autumn. In tropical zones, deciduous species are more likely to form growth rings than evergreen species. In conditions where the weather season is

homogeneous, radial growth can occur throughout the year, making the formation of distinct rings unlikely.

2.4.2 Importance of Tree Rings in the Study of Dendrochronology

Tree rings are valuable tools for retrospective bio-indication, providing information on tree growth rates, past climatic conditions, dynamics and carbon sequestration rates of natural forest stands **(Schweingruber, 1996).** Trees have a greater advantage over other natural archives for climate and environmental studies **(Schweingruber *et al*., 1988; McCarroll and Loader, 2004; Gebrekirstos *et al.*, 2011)** because trees are widespread, making it possible to examine geographical variations in environmental conditions. Trees tell us a great deal about the history of climate and ecology, as they are the oldest living things on the planet and can live for up to 4,000 years **(Gebrekirstos *et al.*, 2011).** They can also tell us something about how their specific species coped with the climatic challenges of the past, given that some of them are highly sensitive to drought, failing to respond or even perishing during periods of extreme drought. On the other hand, in a favourable year, these same species can grow significantly, while others manage to thrive even in periods of drought **(Couralet, 2010).**

This means that tree rings contain a wealth of crucial information, particularly relevant for guiding restoration efforts. For example, we can determine the resilience index of species based on how quickly they recover from drought episodes and their ability to adapt to climate variability. Dendrochronology is a fast and cost-effective tool for understanding, quantifying and advising (e.g. on which species are most productive, most resilient, their water and carbon contribution, which compete with crops and which benefit them, the best time to harvest wood, etc.) so that we can plant the right trees in the right places, taking into account future climate projections **(Gebrekirstos *et al.*, 2014).**

However, dendrochronology in the tropics still often struggles with the old, oft-repeated and erroneous assumption that tropical climates are uniform, leading to the equally erroneous assumption that tropical trees do not form annual rings (**Schimper 1898; Whitmore 1984).** In fact, there is overwhelming evidence of distinct climatic seasonality in rainfall patterns in most tropical regions **(Walter; Lieth, 1967).** These seasonal changes induce cambial dormancy and consequently annual rings in the wood. As a result, studies in the tropics have demonstrated the existence of annual rings in tree species from arid zones **(Fichtler et al., 2004; Gebrekirstos *et al*., 2008; Gebrekirstos *et al.*, 2014)** to humid zones **(Trouet *et al.*, 2010)** and riparian zones **(Schongart *et al*., 2006; Boakye, 2016).** Such studies have shown that many tree species in

tropical regions characterised by one severe dry season per year form annual rings with anatomical structures similar to the growth rings of temperate tree species.

2.5. Climate Projections and Modelling

Future climate change will be caused mainly by man-made greenhouse gas (GHG) emissions **(IPCC, 2023).** In order to gain a better understanding of the influence of these various factors on the climate, scientists are using sophisticated models and detailed computer simulations that provide a complex representation of how the climate system works. These climate forecasts, based on complex models and emissions scenarios, make it possible to anticipate the various possible futures linked to human activities. Although these projections are subject to uncertainty, they reveal worrying trends for the planet, highlighting significant risks for ecosystems, economies and societies. Similarly, models are used to make forecasts of the future climate based on possible future scenarios depending on the influence of greenhouse gases **(Voldoire *et al.*, 2020).**

These sophisticated models are meticulously developed by renowned institutions specialising in climate research, and are widely used internationally to study climatic phenomena. As part of the process of adapting to climate change, the use of climate projections, based on scenarios, is essential **(Doffou, 2021).** A climate projection is an estimate of future changes in average or extreme weather conditions **(Nanan, 2024).** The 6th **IPCC report (2023)** chose to assess the climate response to five socio-economic scenarios covering the range of possible future developments in anthropogenic factors. The warming scenarios used previously were the RCPs (Representative Concentration Pathways), which are representative profiles of changes in GHG concentrations.

They have been replaced by the Shared Socioeconomic Pathways (SSP) scenarios, which are more representative of potential socioeconomic trajectories. For these SSP scenarios, forcing models have quantified both future economic parameters (energy use, land use, population, etc.) and future GHG emissions **(Lepousez and Aboukrat, 2022).** Each RCP can therefore be associated with several SSPs **(Table I)**, because a given level of greenhouse gas emissions can correspond to several types of socio-economic development. Climate projections are presented based on scenarios, according to the term:

$$SSP_{X\text{-}Y}$$

SSPx-y is the abbreviation for a scenario, where x is the number (1 to 5) of the socio-economic scenario SSP that has been used to develop the emissions trajectory, and y indicates the approximate value of radiative forcing (in W/m2) achieved by the end of the century.

The IPCC therefore focuses on the five main scenarios (SSP1-1.9; SSP1-2.6; SSP2-4.5; SSP3-7.0; SSP5-8.5) to ensure a certain degree of consistency with the RCP radiative forcing levels at each horizon **(Table II).**

In addition, the SSP (Shared Socio-economic Pathways) scenarios are narratives, translated into sets of socio-economic assumptions (Population, Education, Urbanisation, GDP). These narratives describe alternative developments in future society in the absence of climate change or climate policy **(Lepousez and Aboukrat, 2022).** Five narratives have been constructed by the IPCC, each numbered from 1 to 5:

Both SSP1 and SSP5 envisage relatively optimistic trends for human development, with substantial investment in education and health, rapid economic growth and well-functioning institutions. However, SSP5 assumes an energy-intensive, fossil fuel-based economy, whereas SSP1 predicts an increasing shift towards sustainable practices. SSP3 and SSP4 envisage more pessimistic development trends, with little investment in education or health, rapid population growth and growing inequality. In SSP3, countries prioritise regional security, while in SSP4, large inequalities within and between countries dominate, leading in both cases to societies that are highly vulnerable to climate change. The SSP2 scenario envisages an intermediate trajectory in which trends continue without substantial deviations.

Table I: Correspondence between the SSP and RCP scenarios used by the IPCC in the AR5 and AR6 reports respectively

SSP Scenario	RCP Scenario	Similarity
SSP1-1.9	No RCP scenario equivalent	
SSP1-2.6	RCP2.6	RCP2.6 induces a slightly lower warming.
SSP2-4.5	RCP4.5	. The RCP6.0 scenario is as close as SSP2-4.5, to 2050.
SSP3-7.0	Between RCP6.0 and RCP8.5	In SSP3-7.0, emissions of GHGs other than CO^2 and of aerosols are higher than in any of the RCPs.
SSP5-8.5	RCP8.5	The SSP5 scenario is the only narrative SSP whose emissions are high enough to produce a radiative forcing of 8.5 $W.m^{-2}$ in 2100.

Table II: Levels of warming by scenario and by time horizon in degrees °C

SSP Scenario	Short term: 2021-2040	Medium term: 2041-2060	Long term: 2081-2100
SSP1-1.9	1.5	1.6	1.4
SSP1-2.6	1.5	1.7	1.8
SSP2-4.5	1.5	2.0	2.7
SSP3-7.0	1.5	2.1	3.6
SSP5-8.5	1.6	2.4	4.4

SECOND PART: MATERIALS AND METHODS

CHAPTER 3: MATERIALS

Three types of material were used to carry out this study. These were biological material consisting of the plant species studied and their companion species inventoried on the site, field material and technical material consisting of cartographic data, satellite images and climatic data, and computer tools including software.

3.1 Biological Material

The biological material consisted of the plant species studied, namely *Afzelia africana* and *Pterocarpus erinaceus*, as well as their companion species, samples of which were stored in herbaria for future identification. Herbarium samples from the Centre National de Floristique (CNF) were also used as reference material for the identification of samples collected in the field.

3.2. Field material

A GARMIN GPSMAP 64s model GPS (Global Positioning System) receiver have been used. This equipment was used for orientation within the different study zones, to record the geographical coordinates of the different types of land use and the inventory plots of the different biotopes. It was also used to record the geographical coordinates of individuals of *Afzelia africana* and *Pterocarpus erinaceus* encountered in the field. Data collection sheets were also drawn up. The measuring tape (100 m) was used to measure the contours of the survey areas. The rangefinder was used to estimate the height of woody species. Pruning shears were used to remove twigs for herborisation. Adhesive tapes were also used to number the samples collected. An electric fan heater was used to dry the herbarium. A machete was also used to open the layons, as well as straps, a press and newspapers to make the herbariums. Finally, a digital camera was used to take photos of the vegetation, species, etc.

3.3. Technical material

3.3.1. Cartographic and Climatic Data

The cartographic data consists of the digital contours of the study areas, which are the Lamto Scientific Reserve and the Badenou Classified Forest, and various other layers of vectors (road network, localities, hydrographic network, administrative division) extracted from the BNETD database. Regarding the satellite images, they were downloaded from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov/). The satellite images used date from the 1990s, 2002, 2012, and 2022. An average interval of 10 years was chosen between

the dates, as this is the minimum duration for perceiving changes in vegetation (reference). They are derived from scene 196-56 Lamto and scene 197-53 for Badenou, and from sensors (Landsat TM for the year 1990, Landsat ETM+ for the years 2002 and 2012, and Landsat OLI for the year 2022**(Table III).** These images date from the period of the major dry season, when the cloud cover and cloudiness rates are the lowest **(Chatelain, 1996).** Furthermore, they were acquired during the same period to reduce issues related to solar angles, phenological changes in vegetation, and differences in soil moisture. Moreover, data relating to climatic parameters such as rainfall (monthly and annual) and maximum, minimum and mean temperatures (Tmax, Tmin Tmean) were collected at the Lamto reserve weather station and at the Korhogo weather station for those that were available. Missing data were collected from the Climate Engine website (ClimateEngine.org). Evaluation of the dynamics of climatic variables from 1990 to 2022 in the different study areas. The climatic variables considered in this study are precipitation (monthly and annual), maximum, minimum, and average temperatures (Tmax, Tmin, Tmean). These parameters are generally considered as components of the climate and environment that most influence the behaviour of forest fires and the dynamics of vegetation **(Guiguindibaye *et al.*, 2013; Ago, 2016; Vissin, 2017).** Indeed, temperature is considered one of the main factors influencing the rate of plant development. Higher temperatures predicted by climate change and the risk of more extreme thermal events will impact plant productivity **(Hatfield and Prueger, 2015).** According to **Hatfield and Prueger (2015**), the latter dries them out and weakens them in the face of water stress.

3.3.2. Computer Equipment

The IT equipment included various tools used in different areas. These included a computer and software (World, Excel) for entering the data collected. The statistical software used included XLSTAT, R, and R Studio for comparisons of means and proportions, and for multivariate analysis. MaxEnt software was used for modelling analyses. Software such as ENVI 5.3 were used for images preprocessing, processing, ArcGIS 10.8 for Land Use/Cover mapping, Google Earth Pro for digitisation of roads and tracks within the study areas and dnrgps to extract geographical coordinates from GPS.

Table III: Landsat image data from 1990 to 2022 used for the Land use/cover (LULC) dynamics of FCB and RSL.

ZONE	N°	Date of acquisition	Path/Raw of scenes	Sensor	Resolution
Lamto Scientific Reserve	1	30/12/1990	196/56	Landsat 4 TM	30 m
	2	31/12/2002	196/56	Landsat 7 ETM+	30 m
	3	10/02/2012	196/56	Landsat 7 ETM+	30 m
	4	20/01/2022	196/56	Landsat 9 OLI/TIR	30 m
Badenou Classified Forest	5	29/12/1990	197/53	Landsat 4 TM	30 m
	6	22/12/2002	197/53	Landsat 7 ETM+	30 m
	7	16/01/2012	197/53	Landsat 7 ETM+	30 m
	8	13/12/2022	197/53	Landsat 9 OLI/TIR	30 m

CHAPTER 4: STUDY METHODS

4.1 Choice of Study Areas

The present study was conducted in Côte d'Ivoire, a country located in West Africa. This country is subject to a climatic gradient extending from south to north **(Guillaumet and Adjanohoun, 1971)**, which leads to the formation of two main phytogeographical zones: the Guinean and Sudanian domains. Within this climatic gradient, the vegetation cover gradually evolves from the humid evergreen forest to the savanna **(Aubréville, 1959; Adjanohoun, 1964).** The choice of our study areas was guided by this climatic gradient based on the change in vegetation, but also according to the preferred zone of our studied plant species. In the Sudanian domain, more precisely in the sub-Sudanian sector, the Badenou Classified Forest (BCF) was selected as it is a preferred area for the species *Afzelia africana* and *Pterocarpus erinaceus*. Regarding the Guinean domain, we have chosen the Lamto Scientific Reserve (LSR) located in the pre-forest area, a transition zone between forest and savanna with a strong presence of the studied species.

Furthermore, since the objective of this work is to analyse the impact of climate change on these tree species, the study areas needed to be selected based on distinct climatic gradients as well as varying levels of conservation. Indeed, the Lamto Scientific Reserve presents a bimodal regime with four seasons and is characterised by the existence of two rainy seasons and two dry seasons, while the Badenou Classified Forest is distinguished by two seasons: the dry season and the rainy season. These different seasonal modalities allowed us to highlight which of these climatic zones is more influenced by climate change. Moreover, the choice of a well-preserved area and an anthropised area will allow us to see which zone is more vulnerable to climatic variability.

The methodology adopted for data collection in this work was structured around four (4) complementary axes that required a multidisciplinary approach.

4.2 Land Use/Cover Mapping and Climate Variability

4.2.1 Image Preprocessing

Image preprocessing refers to all the operations required before cartographic classification and validation **(Bonn and Rochon, 1993).** These operations consist of corrections aimed at remedying certain data errors caused by the temporal shift during image acquisition

and the extraction of the study area. These errors include factors such as the sun's elevation angle, the Earth-sun distance, atmospheric conditions, sensor calibration, and viewing geometry, which affect the numerical values of the pixels. The purpose of preprocessing is to improve satellite images for a good spectral discrimination of the different types of land cover in the **l**andscape **(N'Da *et al.,* 2008; Sangne, 2009).** The images from the years 1990, 2002, and 2012, being level 1, the preprocessing carried out focused on radiometric and atmospheric corrections, respectively, pointing to extract information from the signal independent of atmospheric effects and to convert luminance into reflectance **(Caloz and Collet, 2001).**

4.2.2 Radiometric Correction

The radiometric correction method was used on Landsat 4 TM images of 1990; Landsat 7 ETM+ of 2002 and Landsat 7 ETM+ of 2012. The radiometric correction consisted of correcting radiometric distortions or noise due to atmospheric conditions, faulty sensors and data transmission or interpretation problems in order to obtain a good reflectance of the downloaded image **(El Hajj, 2008).** To carry out this operation, the 'Radiometric correction' algorithm was used with 'Radiometric calibration' from ENVI 5.3 software.

4.2.3 Atmospheric Correction

Atmospheric correction makes it possible to obtain signal scattering and absorption effects through the atmosphere **(Cheula *et al.,* 2012).** In reality, the sensors integrated on board Earth observation satellites in the sunlight spectrum are sophisticated instruments called radiometers. Their mission is to quantify the brightness reflected by the Earth-Atmosphere duo, illuminated by the sun's rays. As a result, this correction is essential for obtaining physical quantities relating to the reflection of light by the surfaces studied. To carry out this correction, the FLAASH (Fast Line of Sight Atmospheric Analysis of Spectral Hypercube) tool was used to extract from this signal information that is independent of the effects of the atmosphere, variable in time and space, and relating solely to the Earth's surface, which is the object to be studied **(Pham *et al.,* 2007; Muchsin *et al.,* 2019).**

4.2.4 Study Area Extraction

The purpose of extracting the study area is to restrict the size of the work window and thus reduce the execution time for the various digital processes. Following radiometric and atmospheric corrections, the vector files for the boundary of the Lamto Scientific Reserve and the Badenou Classified Forest were used to extract the study areas.

4.2.5 Image Processing

4.2.5.1 Satellite Image Processing and Analysis for Field Data Collection

Digital processing contributes to the improvement of satellite images in order to provide better spectral discrimination of the various types of land Use/Cover **(N'Da *et al.,* 2008).** Two types of processing have been used at this stage. These are the extraction of information from satellite images by calculating biophysical indices and the extraction of information from satellite images by image enhancement.

4.2.5.2 Normalised Vegetation Index calculating process

The Normalised Vegetation Index (NDVI) is an index widely used in agriculture and forestry because of its ability to provide precise information on the quality and vigour of vegetation. This index can be used to assess plant health, detect water stress and monitor the development of crops and forests. It measures chlorophyll activity **(Rousse *et al.,* 1974)** and is also recognised for characterising the leaf biomass of plant cover over time **(Vancutsem *et al.,* 2006).** It uses the visible red band and the near infrared (NIR). In fact, 90% of the spectral information on the vegetation cover is contained in the red visible and near infrared (NIR) bands, which is why they are used to calculate vegetation indices **(Rouse *et al.,* 1974).** In this study, this index was used to extract the plant formations that are most active in terms of photosynthesis. Its value is between -1 and 1 and is defined by the formula:

NDVI= ((Band NIR - Band red) / (Band NIR + Band red) (1)

4.2.5.3 Tasseled Cap calculating process

The Tasseled cap was calculated using ENVI 5.3 software using the raw strips, which made it possible to generate new images highlighting certain features of the image (enhanced). These are soil gloss, humidity and lushness of vegetation. The Brightness Index (BI) is suitable for characterising bare soil with little vegetation cover. For covered soils, it reflects the level of vegetation cover. The Wetness Index (WI) highlights wet surfaces and the Greenness Index (GI). This index focuses on the health of the vegetation. These three indices were used to discriminate between the different types of habitats in terms of their ground cover, the intensity of their photosynthetic activity, and their humidity or level of water stress during the dry season. These indices are defined by the following formulas:

$$IB = \sqrt{((PIR\ Band)^2 + (Green\ Band)^2)} \quad (2)$$

$$WI = 0.1509 \times B1 + 0.1973 \times B2 + 0.3279 \times B3 + 0.3406 \times B4 - 0.7112 \times B5 - 0.4572 \times B7 \quad (3)$$

Where:

- B1 = Blue band
- B2 = Green band
- B3 = Red band
- B4 = Near Infrared (NIR)
- B5 = Shortwave Infrared 1 (SWIR1)
- B7 = Shortwave Infrared 2 (SWIR2)

$$GI = -0.2848 \times B1 - 0.2435 \times B2 - 0.5436 \times B3 + 0.7243 \times B4 + 0.0840 \times B5 - 0.1800 \times B7 \quad (4)$$

Where the bands are as defined above.

4.2.5.4 Principal Component Analyses Process

Principal component analyses (PCA) were carried out using the raw bands. These analyses aimed to condense the main information contained in the spectral bands while minimising the loss of information, focusing particularly on the first three components. All the processing was carried out using Envi 5.3 software.

4.2.5.5 Processing of Colour Composition of TM, ETM+ and OLI Images

Colour composition involves combining the information contained in three (3) bands, displayed simultaneously in the three primary colours (red, green and blue). This operation aims to obtain a synthesis of information to enable different habitats to be adequately distinguished. Colour compositions were therefore produced from the reduced and/or raw bands, to distinguish those that best discriminate between the different plant formations. The combinations made for each zone and each image are shown in the tables **(Table IV; Table V).** ENVI 5.3 software was used for this processing. The bands used according to the information they provide are as follows:

- ❖ Band 3 (Visible, red) of the TM and ETM+ images or Band 4 (Visible, red) of the OLI images, highlights the chlorophyll activity of plants. It can be used to distinguish between areas where vegetation is present and those where it is absent;
- ❖ Band 4 (Near Infrared) of TM and ETM+ images or Band 5 (Near Infrared) of OLI images is sensitive to the structure of plant cover, making it possible to distinguish between coniferous and deciduous trees and areas where there is fire;
- ❖ Band 5.6 (mid-infrared) of TM and ETM+ images or Band 6.7 (mid-infrared) of OLI images is sensitive to soil and vegetation moisture and detects chlorophyll.

4.2.5.6 Preparing the field mission

The selection of sites for collecting training points was based on the calculations of vegetation indices and colour compositions. In addition to the above, theoretical knowledge of the study area based on the literature review allowed us to identify land uses that could be discriminated. Thus, one hundred (100) points taken from homogeneous environments were selected within the Lamto Scientific Reserve and 327 within the Badénou Classified Forest. This selection was based on physical and biological characteristics, including their homogeneity, size, and location. Each selected plot in vector format was linked to an attribute table containing the point number and geographic coordinates. After entering these various points, they were converted to GPX format and then integrated into a GPS receiver.

Table IV: Bands used for the colour compositions in the Lamto Scientific Reserve

Years	**1990**	**2002**	**2012**	**2022**
Colour composition (Bands)	4/ 7/ 3	4/ 7/ 3	4/ 6/ 3	5/ 7/ 3

Table V: Bands used for the colour compositions in the Badénou Classified Forest

Years	1990	2002	2012	2022
Colour composition	Bands 4/ 7/ 3	Bands 4/ 7/ 3	Bands 4/ 5/ 3	Bands 5/ 7/ 4

4.2.5.7 Field Mission

The field mission, also known as the 'ground truth' phase, was carried out during an observation mission from 19 November 2022 to 04 March 2023, for the Lamto Scientific Reserve and from 29 July to 1 November 2023, for the Badénou Classified Forest. During this stage, two tasks were completed. Each training point was targeted and rallied. The land use corresponding to the point was identified and described. Other points corresponding to the different land uses were then marked for the control stage. A total of 100 training points were rallied and 521 control points were collected for the Lamto Scientific Reserve. In the Badenou Classified Forest, 327 training points were visited and 1,046 control points collected. The training points were used for the actual classification and the control points were used as a basis for validating the future land-use maps produced.

4.2.5.8 Image Classification and Validation of Cartographic Productions

4.2.5.8.1 Formation of Training Plots

The establishment of training plots for the classification of satellite images is a crucial step that involves the meticulous selection of representative samples of different land use classes present in the image. This approach ensures the reliability and accuracy of the subsequent analysis by providing an adequate representation of the diversity of the observed characteristics. These samples are used to train a classification algorithm so that it can learn to distinguish between different classes **(Akoguhi *et al.*, 2022).** The training samples must be carefully selected to ensure an adequate representation of the variability of the classes of interest in the image, to obtain accurate classification results **(Akoguhi *et al.*, 2022).** The establishment of the 100 and 327 training plots was carried out through the identification of the different land use classes. Each plot was assigned a label corresponding to the class to which it belongs **(Aka *et al.*, 2022).** The classes of land use types in the Lamto Scientific Reserve are: Gallery forest_Semi-deciduous dense forest, Open forest_Wooded savanna, Tree savanna, Shrub savanna, Bare soil_Habitat and Water body for the Lamto Scientific Reserve. Regarding the Badenou Classified Forest, the identified land use types are: Gallery Forest, Dense dry forest, Open Forest_Wooded savanna, Tree savanna_Shrb savanna, Low dense shrub savanna, Fallow land, Perennial crop, Bare soil_Rock outcrop_Agricultural development and water body.

4.2.5.8.2 Supervised Classification

Among the classification algorithms, maximum likelihood has been used. This method consists of searching for objects similar to reference objects **(Journaux, 2006).** This algorithm uses training zones to model the distribution of each land-use class according to a normal probability distribution. It is based on a statistical analysis of the distribution of elements in the training zones to define the probability of belonging to each class. The new object is assigned to the class with the highest probability of membership **(Zammit, 2008).** The classifications were first carried out based on the training points that guided the choice of regions of interest (ROIs) for the land cover classes produced on the most recent Landsat 9 OLI/TIRS images from 2022.

4.2.5.8.3 Validation of Classification Results

The validation of classification results consists of examining and evaluating in detail the performance of a classification model to ensure its reliability and accuracy. This crucial stage verifies that the algorithm is capable of classifying the data correctly. Validation of classification results can be carried out in a number of ways, including using measures such as accuracy, precision, recall and F-measure **(Girard and Girard, 1999; Caloz and Collet, 2001).** The classification was validated in two (2) stages: the choice of control plots and the calculation of cartographic precision using the confusion matrix. The control plots corresponded to the points marked during the field mission to serve as a basis for validating the classification. A correspondence was then established between the training plots and the control plots to assess the accuracy of the classification. The second stage of the validation consisted of evaluating the quality of the image classification using the confusion matrix **(Godard, 2005).** The confusion matrix, also known as the error matrix, is a tool often used to assess the performance of classification systems in terms of overall accuracy and the Kappa coefficient **(Girard and Girard, 1999).** Once the classification had been validated by the various performance tests, a 3*3 median filter was applied to reduce intra-class heterogeneity by eliminating isolated pixels **(Congalton, 1991; Blum *et al.*, 1995).** The classifications obtained in raster format were exported to ArcGIS 10.8 software for conversion to vector format. This stage was followed by the production of statistics and cartographic editing.

4.2.5.9. Exploitation of Land Use/Land Cover Cartographic Production

The statistical analyses focused on three (3) aspects:

- calculating the area of Land Use/Cover of each classes

- assessment of the rate of change, which consists of measuring changes in land cover between the different observation dates**;**
- assessment of the spatio-temporal dynamics of land cover.

The rate of change is a parameter commonly used in studies of land-use change**.** In this case, the overall rate of change of land uses was calculated.

It is used to estimate the overall increase in the area of land cover units between two dates (1990 and 2022). This rate is obtained from the following mathematical formula:

Tg = [(S2-S1)/S1] x 100

Tg = overall rate of change (%); S1 = area of the class at date t1 (initial date); S2 = area of the class at date t2 (final date), and t2>t1; t = number of years between the two dates (t2-t1).

Positive values of the overall rate of change indicate 'progression' and negative values indicate 'regression'. Values close to zero constitute the relatively 'stable' classes **(Tankoano *et al.,* 2016).**

Spatio-temporal dynamics were assessed using two parameters: the transition matrix and the transition map. According to **Herrault (2015),** the transition matrix is obtained by crossing two land use/cover maps dating from different periods. It is used to highlight the different forms of conversion that land cover classes have undergone between two given dates **(Sanon, 2019).** Changes are made from rows to columns. The areas of these different classes were calculated in ArcGIS using the 'Overlay-Intersect' tool. The advantage of the transition matrix is that it shows precisely how the reduction in the area of an 'X' class has benefited the other classes, or how the increase in the area of a 'Y' class has been to the detriment of the other classes. It is frequently used to analyse changes in land cover **(Bamba *et al.,* 2008; Mama *et al.,* 2013).** The dynamics map is generated by crossing two land cover maps dating from different periods. It highlights the spatial distribution of three factors: the stability, regression or progression of the different land cover classes in the study area.

4.2.6 Assessment of Climatic Variables dynamics from 1990 to 2022 in the Different study areas

The analysis of climatic data focused on evaluating the dynamics of temperature, precipitation, and assessing drought indices such as the Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI). Hence, a descriptive analysis of the annual fluctuations in maximum, minimum and average temperatures was conducted for the period from 1990 to 2022.

To highlight the periods of water deficit in the study area, the dynamics of precipitation were evaluated from 1990 to 2022, using the Standardized Precipitation Index or Nicholson Index (SPI) and the Palmer Drought Severity Index (PDSI). The Standardized Precipitation Index (SPI) was developed by **McKee *et al.* (1993).** It is a statistical indicator used for the characterisation of local or regional droughts. It therefore allows for the determination of the degree of humidity or dryness of the environment **(Bergaoui and Alouini, 2001).** Based on a long-term precipitation history (minimum 30 years), it quantifies the deviation of precipitation in a period, whether deficit or surplus, compared to the historical average precipitation for that period. This can be normal, wet or dry. It also allows for the interpretation of the dynamics of vegetation cover with the evolution of precipitation **(McKee *et al.*, 1993).** The SPI was evaluated using the following equation:

$$\mathbf{SPI} = \frac{Pi - P_{mean}}{\sigma} \qquad (5)$$

SPI = Rainfall Index for year i; Pi = the total rainfall for year i; Pmean = average annual rainfall observed over the entire series; σ = Standard deviation of the annual rainfall observed for a given series.

The interpretation of the SPI calculation results was made based on the SPI classes and their degree of drought or humidity **(Table VI).** Negative SPI values correspond to a dry year, while positive values indicate wet years.

The PDSI is a drought index that characterises the cumulative deviation of local average soil moisture conditions based on a simplified calculation of the water balance. Thus, it is classified as a meteorological drought index and quantifies the departure of water from the soil surface **(Svoboda and Fuchs, 2016).** It is commonly used worldwide to quantify observed droughts and drought projections **(Ficklin *et al.*, 2016).** The PDSI is calculated based on the parameters of the water balance **(Thornthwaite and Mather, 1955).** The standardised measure of the PDSI **(Table VII)**, ranges from −4 (dry) to +4 (wet), with values below −3 representing severe to extreme drought **(Palmer, 1965).**

Table VI: Classification of drought according to SPI values **(Mckee, Doesken and Kleist, 1993).**

SPI Classes	SPI>2	1.5<SPI<1.99	1.0<SPI<1.49	-0.99<SPI<0.99	-1<SPI<-1.49	-1.5<SPI<-1.99	SPI<-1.99
Level of drought or humidity	Extreme humidity (IL)	High humidity (WH)	Moderate humidity (WM)	Near to the normal	Moderate drought (DM)	High drought (DH)	Extreme drought (DE)

Table VII: PDSI categorisation of drought severity **(Palmer, 1965)**

PDSI Values	**Drought Categories**
4.00 ou more	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Beginning of a wet period
0.49 to -0.49	Close to normal
-0.50 to -0.99	Beginning of drought
-1.00 to -1.99	Slightly drought
-2.00 to -2.99	Moderate drought

Descriptive and trend analyses were evaluated in the same manner monthly over the period (1990-2022) through time series data. The PDSI can be formulated according to the following equation:

$$X_{(i)} = \frac{Z(i)}{\alpha} + \beta X_{(i-1)} \quad (6)$$

$X_{(i)}$ is the PDSI result for the i^{-th} month, $z_{(i)}$ is the moisture anomaly index for the i^{-th} month, $X_{(i-1)}$ is the PDSI amount for the previous month, α and β are the climatic coefficients of the PDSI.

4.2.7 Analysis of the Influence of Climatic Variability on Vegetation Dynamics

A correlation analysis between variables was carried out to assess the influence of climatic parameters (Temp_Min, Temp_Moy, Temp_Maxi, Precipitation (mm), PDSI value, SPI value) on the vegetation dynamics of the LSR and BCF expressed through the areas of each land cover per period (1990-2002;2002-2012;2012-2022), using Spearman's correlation. Spearman's correlation is a statistical measure that evaluates the strength and direction of a monotonic relationship (increasing or decreasing) between two variables **(Sokal *et al*,. 2012).** Spearman correlation does not require the data to be normally distributed. It is calculated using the ranks of the data rather than their raw values. Its ability to work with ordinal and non-normally distributed data makes it a preferred choice in many areas of research, particularly ecology. It was favoured due to its ability to better capture nonlinear relationships, to free itself from the assumption of data normality, and to take into account the effects of critical thresholds, characteristic of interactions between climate and land use/cover. Unlike Pearson's correlation, it is robust to extreme values and allows for the evaluation of monotonic trends, thus providing a more reliable analysis of environmental dynamics.

4.3 Methodology for Studying the Companion Flora and Vegetation of *Afzelia africana* and *Pterocarpus erinaceus*

4.3.1 Floristic and Vegetation Data Collection Methods

The land use/cover maps were used as a basis for selecting the plots to be sampled based on knowledge of the plant formations in which our study species were found. During the first phase of the fieldwork, the GPS coordinates of the individuals of *Afzelia africana* and *Pterocarpus erinaceus* encountered in the study area were recorded. These coordinates were then projected on to the land use/cover maps to select the locations where the plots would be set up for the botanical inventories, taking into account their spatial distribution and Land Use/Cover.

Floristic data were collected using the surface survey method. This method is both quantitative and qualitative, and therefore exhaustive, and has been particularly used in West Africa, where it has remained the main approach to date **(Senterre, 2005).** In each type of land use where individuals of *Afzelia africana* and *Pterocarpus erinaceus* are found, a rectangular plot of 1000 m^2 (50 m x 20 m) was laid out, as shown in Figure 13. The choice of 1000 m² for the inventory plots in this work is based on the recommendations of **Kouamé (2016).** Within the plots, the diameter of all trees with a Diameter at Breast Height (DBH) greater than or equal to 5 cm at 1.30 m above the ground was counted and their circumference measured**.** For individuals with buttresses and stilt roots higher than 1.30 m, the diameter was measured at 30 cm just above the buttresses or stilt roots **(Kouadio, 2007; CTFT, 1989).** In addition, the total height of each individual tree was assessed using a rangefinder **(Figure 12; Figure 13)**.

A total of 46 plots (23 *Afzelia africana* plots and 23 *Pterocarpus erinaceus* plots) were established in each study area, giving a total of 92 plots **(Figure 14; Figure 15;Figure 16)**.

4.3.2.1.1 Characterisation of floristic Richness and Composition data collection

According to **Thurmann (1849),** the flora of a given area is the totality of plant species, listed or not, which grow there, the rare plant occupying no less a place than the common plant'. Thus, according to **Aké Assi (1984),** floristic richness can be defined as simply the number of taxa inventoried in an area. It does not take into account the frequency, abundance, size or productivity of the species encountered. Based on these definitions, we used the term floristic richness to count all the species found in each plot, without taking their abundance into account. The analysis of floristic richness was used to establish the list of species in the Lamto Scientific Reserve and the Badenou Classified Forest. The species inventoried in these two forest blocks enabled the identification of affinities and differences between these environments and facilitated comparisons with data obtained from other areas in Côte d'Ivoire and the surrounding sub-region. In other words, the analysis of the floristic composition consisted of identifying the morphological types, biological types and phytogeographical affinities for each species of DBH greater than or equal to 5 cm encountered in each survey. Species, genus and family names were updated under **APG IV (2016).**

This study was based on the work of **Aké-Assi (2001, 2002)** to determine the biological types of the species inventoried. This group is subdivided into several subgroups according to the height of the aerial axes. These are Megaphanerophytes (MP: trees over 30 m high), Mesophanerophytes (mP: trees 8 to 30 m high), Microphanerophytes (mp: shrubs 2 to 8 m high) and Nanophanerophytes (np: sub-shrubs less than 2 m high).

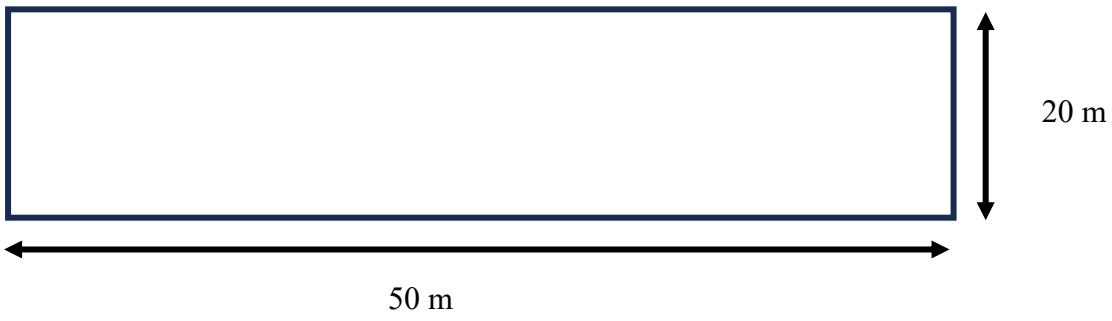

Figure 12: Diagram of the surface survey device

Figure 13: Installation of a plot in the RSL

Figure 14: Plants species recording

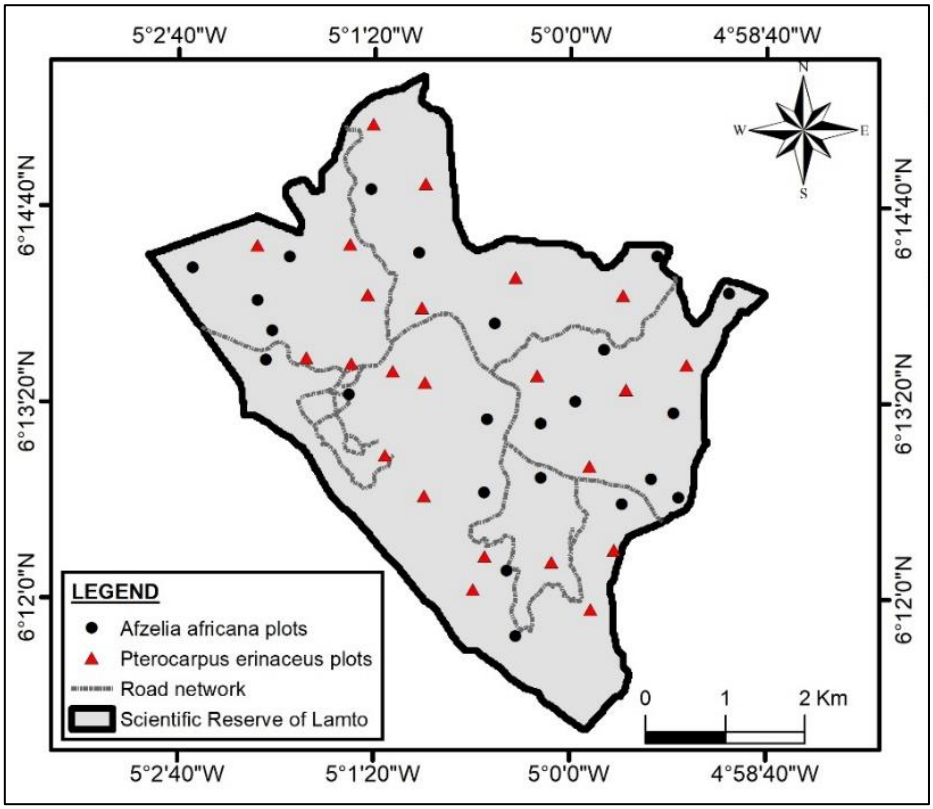

Figure 15: Location of study plots for *Afzelia africana* and *Pterocarpus erinaceus* species in the Lamto Scientific Reserve

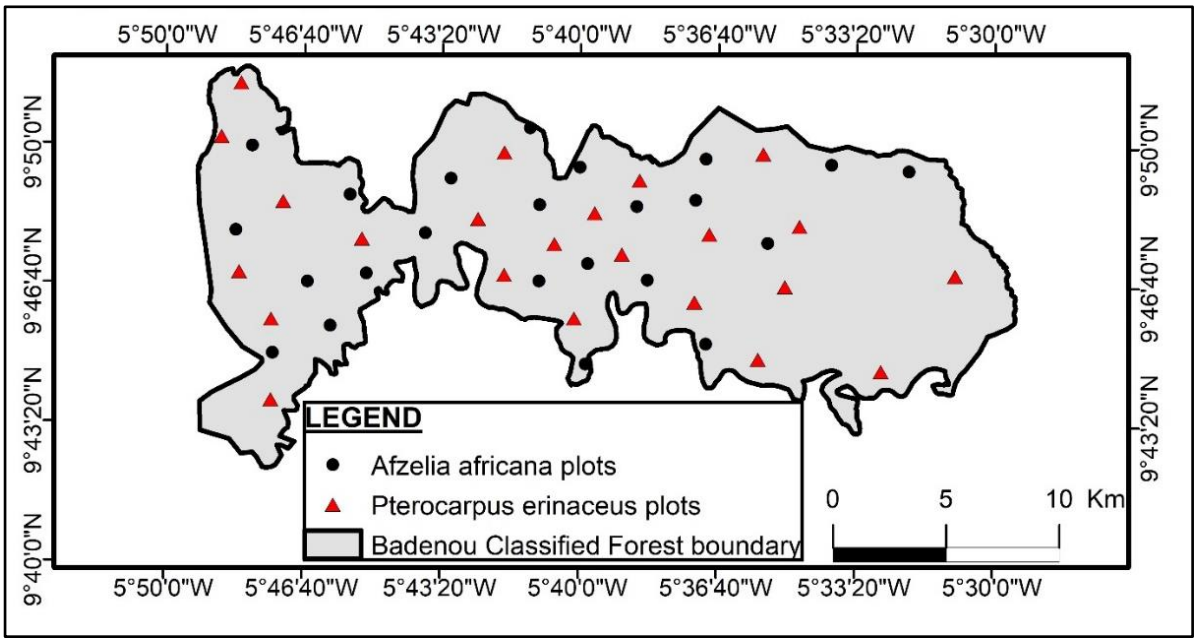

Figure 16: Location of study plots for *Afzelia africana* and *Pterocarpus erinaceus* species in Badenou Classified Forest

Morphological types included trees, shrubs, sarmentaceous plants and lianas. Phytogeographical affinities, defined as the science that studies the delimitation of the geographical distribution areas of species and other taxonomic units, as well as the evolution over time of this distribution and the factors that condition this evolution **(Besancenot and Thibaudon, 2012)**, were used to separate species according to their geographical distribution areas. Within this framework, the phytogeographical distribution of species of the different plant formations was analysed regarding the system proposed by **Lebrun (1960),** which distinguishes between forest species naturally present in the Guinea-Congolian phytogeographical region (GC), savannah species in the Sudan-Zambezian region (SZ), forest-savannah transition species present in both regions (GC-SZ), and introduced species. All these chorological affinities were determined by comparing the list of species studied with those of **Aké-Assi (2001, 2002).**

4.3.2.2 Determination of quantitative Diversity of Flora Assessment

Quantitative species diversity was assessed using the Shannon index **(Shannon-Weaver, 1948**), the Simpson index **(Simpson, 1949),** the Piélou equitability index **(Piélou, 1966)** and the Venn diagram **(Venn, 1880).** This choice is explained by the fact that the ultimate objective of this study is to evaluate and compare the different biotopes.

4.3.2.2.1 Shannon-Weaver diversity index calculating process

Shannon-Weaver's (1948) specific diversity index (H') is one of the criteria commonly used in work in Côte d'Ivoire **(Kouamé, 2016)**. It is used to assess the heterogeneity and diversity of habitats. This diversity index measures the species composition of a stand, considering species' specific richness and relative abundance **(Felfili *et al.*, 2004).** It is used to express the diversity of a site. The values of this index vary from 0 (monospecific stand) to ln (S), which is the maximum diversity (S being the total number of species in the environment). Its value generally varies between 1 and 5. Diversity is low when H’ is less than 3 bits, average if H’ is between 3 bits and 4 bits and high when H' is greater than or equal to 4 bits **(Legendre and Legendre, 1984; Frontier and Piochod-Viale, 1995).**

A high H' value is a sign of good biodiversity, likely to be maintained over the long term **(Adou Yao, 2005)**. The following mathematical expression gives this index:

$$H' = -\Sigma\,(Ni/N)\ln(Ni/N) \qquad (7)$$

In this formula, H' represents the Shannon diversity index, Ni is the number of individuals of species i, and N is the total number of individuals of all species.

4.3.2.2.2 Piélou's Evenness Index calculating process

Piélou's (1966) regularity index J, also known as the equi-partition index, is the ratio between the Shannon index of the sample and the maximum diversity. It is used to assess the distribution of different species in a given habitat **(Adjakpa *et al.*, 2013).** Unaffected by species richness, it is very useful for comparing the potential dominance of species in a habitat. This index varies from 0 to 1. When the value of this index tends towards 0, it means that there are one or very few species that largely dominate, and it is equal to 1 when all the species have the same abundance **(Mehdi, 2010).** Its mathematical expression is as follows:

$$E = H' / \ln S \quad (8)$$

In this formula, E is the Piélou equitability index, H' is the Shannon index and S is the total number of species in the plot or area concerned.

4.3.2.2.3 Simpson's Diversity calculating process

When we have a list of species and their associated frequencies, the Simpson diversity index allows us to evaluate the probability that two individuals randomly selected from a sample belong to the same species. This index therefore, highlights the relative abundance of dominant species within a community. It is particularly sensitive to the presence of rare species, which can strongly influence its value **(Simpson, 1949).** Its mathematical formula is as follows:

$$DS = 1 - \Sigma (Ni (Ni - 1)) / (N (N - 1))) \quad (9)$$

In this formula, D is Simpson's diversity index, Ni is the number of individuals of species i and N is the total number of individuals of all species in each plot. This index will have a value of 0 to indicate maximum diversity and a value of 1 to indicate minimum diversity in a plot. It was calculated to measure the probability of not encountering two individuals of the same species.

4.3.2.2.4 Morisita-Horn (MH) Similarity

The Morisita-Horn (MH) similarity index is a statistical tool designed to quantify the floristic similarity between two ecological communities. It measures β-diversity by taking into account both the presence of species and their relative abundance, which distinguishes it from indices based solely on the presence or absence of species. This dual criterion makes it possible to more accurately assess the real similarity between two sites, particularly when species numbers differ, although the specific composition is similar **(Krebs, 1989)**. The main role of this index is to provide a robust measure of floristic similarity, particularly suited to ecological studies seeking to understand variations in plant communities over space and time.

Several authors have used the Morisita-Horn index in their work on ecology and biogeography. **Kouamé (1998), Kouka (2000)** and **Ouattara *et al.* (2013)** have used it to analyse the similarity between different forest habitats in Côte d'Ivoire, highlighting diversity dynamics and relationships between environments. This approach is also recommended in the scientific literature for its ability to integrate species abundance, making it a relevant choice for in-depth floristic similarity analyses **(Novotny and Weiblen, 2005).** The mathematical expression of this index is:

$$MH_{ij} = \frac{(\sum P_{is}P_{js})}{(\sum P_{is}^2 P_{is}^2)} \quad \textbf{(10)}$$

This index was calculated on the basis of all the species present in each area. In this formula, P_{is} and P_{js} represent respectively the probabilities that species s is from surveys *i* and *j*. The values of this index vary from 0 to 100. The more the two lists have species of similar abundance in common, the more MH tends towards 100. The more the two lists of plants differ in species, the more MH tends towards 0.

4.3.2.2.5 Venn Diagram assessment

The Venn diagram (also known as a logic diagram) has been used to illustrate simple relationships between different habitats **(Vroh *et al.*, 2017).** In this study, we used the **Venn diagram (1880)** to graphically represent the number of species common to habitats. Venn diagrams normally comprise overlapping circles or squares. The intersection between two circles or two squares or two rectangles is the number of common species between two biotopes. The outside of this intercept represents the species that are not common to the different habitats. The Venn diagram can also be used to visualise operations and logical relationships.

4.3.2.3 Analysis of Structural Parameters

In this section, the physiognomy of the vegetation at our study site was highlighted. To characterise the flora and vegetation of the different habitats, an analysis of the horizontal and vertical structure of the stands was carried out. Parameters such as density, basal area of the individuals counted and their distribution by diameter class reflect the horizontal structure **(Vroh, 2013; Kouamé, 2016).** The horizontal structure expresses the arrangement and distribution of individuals in the horizontal plane. It is used to assess the stability of the biotope **(Rollet, 1979; Stutz De Ortega, 1989; Dupuy, 1998; Kouamé, 1998).** Histograms have been drawn up to represent the distribution by diameter class, to analyse the demographic structure of woody stands. The vertical structure of the vegetation indicates the degree of stratification of each plant formation. These are the lower shrub layer (< 4 m in height), the upper shrub layer (4 to 8 m in height), the lower tree layer (8 to 16 m in height), the upper tree layer (16 to 32 m in height), and the emergent layer (> 32 m in height).

4.3.2.3.1 Density calculating process

Density (D) is defined as the number of individuals per unit area **(Rollet, 1979).** It reflects the occupation of the ground by the species. The density of individuals was assessed by counting the number of individuals per plot. The mathematical formula is as follows:

$$D = N / S \quad (11)$$

In this formula, N represent the total number of stems in the plots in the environment considered, and S = total area of the plots in hectares. This formula was used to compare individuals of DBH greater than or equal to 5 cm of all diameter classes in the study plots. It provides information on the number of stems per hectare and makes it possible to define establishment trends.

4.3.2.3.2 Basal Area calculating process

The basal area represents the sum of the horizontal cross-sectional areas of the trunks of all the trees in a survey, assuming that the cut was made 1.30 m above the ground **(Rollet, 1979).** It can therefore be calculated for the stand as a whole, by species or by groups of species. This parameter is closer to the total biomass of individuals **(Jordan and Farnworth, 1980)**

and is important in terms of the stability and spatial occupation of trees in a habitat **(Rollet, 1974).** It is calculated using the following formula:

$$G = \pi D^2/4 \quad (12)$$

In this formula, G is the basal area expressed in m^2 / ha, $\pi = 3.1416$ and D is the diameter determined from the circumference measured during the surveys.

4.3.2.3.3 Distribution of Individuals by Diameter Class

The distribution of individuals by diameter class, also called the 'horizontal structure' by foresters **(Bouko *et al.*, 2007),** was constructed to describe the demographic structure of woody stands to assess their ability to recover. When it is carried out for individual species, it enables their temperaments to be studied **(Adou Yao, 2005).** It can also be used to assess the demographic structure of woody stands through histograms showing the distribution of individuals by diameter class. In this study, the distribution of individuals within DBH classes was analysed to improve the explanation of average DBH values in the plots.

4.3.2.3.4 Distribution of Individuals by Height Class

The distribution of woody plants by height class, also called the 'vertical structure of the vegetation' by **Kouamé (1998),** is an important parameter in determining the degree of stratification indicated in plant formations. This degree of stratification was assessed regarding the work of **Kouamé (1998),** which divides the woody stratum into five (5) levels or strata. These are the lower shrub stratum (< 4 m high), the upper shrub stratum (4 to 8 m high), the lower tree stratum (8 to 16 m high), the upper tree stratum (16 to 32 m high) and the emergent stratum (> 32 m high). The vertical structure of the original formations was assessed to get a glimpse of the variation along the vegetation gradient. Only woody species were taken into account in this stratification.

4.4 Dendrochronological Study

4.4.1 Collection of Dendrochronological Data

The dendrochronological method used involved collecting discs for subsequent analysis. As no dendrochronological studies were identified in Côte d'Ivoire based on the available literature, it was first necessary to determine which woody species produce visible and measurable growth rings. For this purpose, the CITES website (

https://cites.org/fra/search?search_api_fulltext=Afzelia%20africana&f%5B0%5D=content_type%3Atimber_id_material) was consulted. Additional selection criteria included species distribution across multiple ecological zones, and whether the species were deciduous or evergreen. Based on these criteria, two species were selected: *Afzelia africana* Sm. ex Pers. and *Pterocarpus erinaceus* Poir., both belonging to the Fabaceae family. Given their protected status and the specificity of the study areas, disc sampling was carried out in rural zones with authorization from local authorities. During fieldwork, data such as species name, GPS coordinates, DBH (diameter at breast height), total height, vegetation type, felling date, felling site, and specimen ID were recorded.

In each study area, five (5) discs were collected from five (5) individuals of *Afzelia africana* and five (5) individuals of *Pterocarpus erinaceus*, all with DBH ≥ 20 cm **(Boakyé, 2016) (Figure 17).** These discs were labelled with the recorded information, sun-dried, and stored in a dry, uncontaminated space for subsequent sanding and laboratory analysis.

4.4.2 Analysis of Dendrochronological Data

4.4.2.1 Conservation and Preparation of Disc Samples for Dendrochronological Analysis

The analysis of radial growth was based on the collection of discs from five (5) individuals of *Afzelia africana* and five (5) individuals of *Pterocarpus erinaceus* in the two (2) study areas. This number of discs was collected because the representativeness of the average chronology is based on the number of individual series used to construct it. The greater the number, the lower the risk of bias due to individual and station variations **(Morel, 2013).** These discs were taken with a thickness varying from 8 to 10 cm. This thickness should ensure that the wood is still solid when sanded, but also a size that can easily pass under the binocular magnifying glass when read. The information about the wood has been written on the side that will not be read, to avoid clogging the sanding paper during sanding and erasing the inscriptions. The discs were then stored for months in an open-air room to dry gradually, to avoid shrinkage cracks and the appearance of mould. The wood discs were separated to allow air to circulate between them. After drying, the discs were taken to the tree-ring laboratory at Friedrich-Alexander University in Erlangen-Nurnberg, Germany. Standard dendrochronological methods were used to prepare the stem discs for measurement. The first method involved sanding with a circular sander **(Figure 18).** The sanding was started by switching from coarser to finer grit abrasive discs (80, 120, 240, 400, 800, 1200, 2000) as shown in **Figure 19.**

Following sanding, the vessels were unclogged using an air blower to remove all the dust stored. This step was followed by the measurement of the growth rings of the twenty (20) *Afzelia africana* and *Pterocarpus erinaceus* discs. To this end, four (4) to six (6) rays were marked on the various discs. This method makes it possible to detect overlapping rings, false growth rings, discontinuous growth zones and to check the existence of each ring around a disc. The limit of the growth rings was visualised using the ZEISS Smartzoom 5 automated digital microscope **(Figure 20).** Finally, the limit of tree-ring growth determined in this way was followed by marking it on the various radii traced perpendicular to the limits of the growth rings. The rings were measured using a semi-automated device (LINTAB, RINNTECH, Heidelberg, Germany) shown in **Figure 21.** The LINTAB consists of a stereoscope and a mobile board connected to a distance-measuring device and a computer associated with an automatic recorder of the TSAPWin type. This software was used to record the ring measurements taken and also to calculate the average chronology of the different radii of a disc for all the samples of the two species.

Figure 17: Collection of *Afzelia africana* and *Pterocarpus erinaceus* discs

Figure 18: Sanding a disc from an *Afzelia africana* individual

Figure 19: Different sizes of abrasive disc, from the coarsest grain on the left to the finest grain on the right

Figure 20: Semi-automatic device (LINTAB, RINNTECH, Heidelberg, Germany) used to measure rings

Figure 21: ZEISS Smartzoom 5 automated digital microscope used to visualise the limit of growth rings

4.4.2.2 Assessment of Radial Growth of *Afzelia africana* and *Pterocarpus erinaceus* Individuals

Radial growth was assessed by measuring growth rings in the laboratory. The influence of climate on the growth of the two species was assessed using statistical analyses. Average radial growth (ring width) was compared between the different discs of the same species using the Student's T test of the R statistical software. The significance level chosen for these analyses was 5% with $P \leq 0.05$. To assess the relationship between climatic parameters and the radial growth of trees, an average inter-series correlation, i.e. a correlation between all the tree-ring series of the same tree, was used as a measure of the strength of the common growth signal within a chronology using the RWI. The reliability of the chronology was measured using the population signal (EPS). This signal tells us whether the chronology is hypothetically perfect or true. This signal is used to determine whether the chronology is hypothetically perfect or true. The EPS is a function of the inter-series correlation and the replication of the series. The PSE varies from zero (0) to one (1) and is calculated according to the following formula:

$$\mathbf{EPS}(t) = \frac{nr_{bt}}{nr_{bt+(1-r_{bt})}} \quad (13)$$

n = number of correlated trees and rbt = average correlation between all tree-ring series.
In addition, since one ring corresponds to one year of growth, the age of the individuals of the species was assessed by counting the rings.

4.4.2.3.1 Estimation of Carbon Sequestration based on Tree-ring Analysis of the Species Studied

The age and diameter growth rates of the two species studied were assessed on the basis of tree-ring analysis. Consequently, the measurement of the diameter of the various growth rings was used to estimate the above-ground biomass and calculate the carbon stock. In fact, the estimated above-ground biomass (AGB) of each individual *Afzelia africana* and *Pterocarpus erinaceus* species was estimated by replacing D in the equation with its corresponding diameter, derived from the tree rings **(Chave *et al.*, 2014).** Then, the AGB of each tree over its lifetime was divided by the corresponding age, derived from ring analyses, to obtain the annual biomass production **(Worbes and Raschke, 2012).** The carbon stock was estimated to represent 50% of the total biomass. The method used in this study was developed using the mathematical formulae below:

$$D_t = 2 \times \sum_{i=1}^{t} L_i \quad (14)$$

D_t is the diameter at age t in mm, then converted to cm; Li is the ring width for year i in cm; t is the age of the tree in years.

$$AGB = 0.0509 \times \rho \times D^{2.46} \quad (15)$$

AGB is the estimated above-ground biomass in t; ρ: the specific density of the wood (g.cm^{-3}); D is the diameter of the individual derived from the growth rings cm.

Below-ground biomass is generally estimated by applying the stem-root ratio (Tx), depending on the ecological zone **(IPCC, 2006).** In this study, a Tx ratio of 0.37 was used for the biotopes of the Lamto Scientific Reserve and a Tx ratio of 0.56 was used for the biotopes of the Badenou Classified Forest, according to the work of **Fittkau and Klinge (1973).**

$$BGB = 0.37 \times AGB \quad (16) \qquad BGB = 0,56 \times AGB \quad (17)$$

The total carbon biomass is calculated using the following mathematical formula:

$$B_{tot} = BGB + AGB \quad (18)$$

This estimate of total biomass was converted into sequestered carbon stock. The quantity of carbon stored is associated with the biomass according to the following relationship:

$$C = 0.5 \times BT \quad (19)$$

CF is the biomass-to-carbon conversion factor. It has been reported that the carbon contained in the dry biomass of a tree is 50 p.c. **(Malhi *et al.*, 2004).**

The quantity of carbon dioxide sequestered was calculated based on the ratio between the molar masses of carbon and CO_2. The amount of carbon dioxide was determined using the equation below:

$$T_{eq}CO_2 = m_{CO_2} = C \times \frac{44}{12} = C \times \frac{44}{12} \quad (20)$$

4.4.2.3.2 Relationships between Climate and Carbon Sequestration of the Species Studied

A Pearson correlation test was carried out to assess the relationship between the climatic variables of rainfall, temperature (maximum Tmax, minimum Tmin and mean Tmean), the Palmer Drought Severity Index (PDSI) and the Standardised Precipitation Index (SPI) and the amount of carbon sequestered by each individual species (*Pterocarpus erinaceus*, *Afzelia africana*) in each study area. Climatic data were obtained from the Korhogo weather station and the geophysical station in the Lamto scientific reserve. Additional data were downloaded from the Climate Engine platform (ClimateEngine.org). Given the availability of 103 years of climate data (from 1920 onwards), the maximum age was harmonised using a maximum age of 103 years. These various analyses were carried out using R software.

4.5 Methodology for Modelling the Spatial Distribution of *Pterocarpus erinaceus* and *Afzelia africana*

4.5.1 Collection of Occurrence Data and Choice of Variables and Scenarios

4.5.1.1 Collecting Data on the Presence of *Pterocarpus erinaceus* and *Afzelia africana*

The coordinates of the presence of the two species studied were collected during field missions carried out in the various study areas. During these campaigns, the GPS coordinates of all *Pterocarpus erinaceus* and *Afzelia africana* individuals encountered were recorded. During this phase, 698 occurrences of *Afzelia africana* and 1607 of *Pterocarpus erinaceus* were recorded in the two study areas. A further 885 coordinates for *Afzelia africana* and 5090 for *Pterocarpus erinaceus* were then extracted from academic works (theses, dissertations) and from the Global Biodiversity Information Facility (GBIF) database, available at www.gbif.org. All this data was compiled to form a database of georeferenced occurrences of the two species. In addition, environmental variables were collected, including physical data such as the hydrographic network, the Digital Terrain Model (DTM) and bioclimatic variables, as well as socio-economic variables, in particular the road network.

4.5.1.2 Choice of Environmental Variables and Climate Scenarios

To design potential distribution models, 21 environmental variables were downloaded from the AfriClim online platform (https://webfiles.york.ac.uk/KITE/AfriClim/). The 'AfriClim 3.0' model is a tool for generating accurate climate projections for the African continent **(Platts and Marchant, 2015).** This model is particularly suitable for analysing the impact of climate change on the African continent, due to the correlation of its bioclimatic variables with temperature and humidity **(Platts and Marchant, 2015)** (**Table VIII)**. The

climate conditions cover the current period (1950-2000) and the future period between 2000-2060 and (2060-2100). Two scenarios SSP2-4.5 in 2060 (2041-2060) and SSP5-8.5 in 2100 (2081-2100) were used for future projections. SSP2-4.5 projects intermediate greenhouse gas emissions, and then its emissions trajectory projects warming of around 2°C by 2060. SSP5-8.5, on the other hand, involves a higher increase, and its emissions trajectory predicts warming of around 4.4°C by 2100 **(Lepousez, 2022).**

4.5.2 Modelling Data Processing

The points of occurrence, which are the geographical coordinates of the species studied, were recorded using a latitude/longitude coordinate system. These coordinates are in a precise and organised order: Species, Longitude and Latitude. The Excel sheet was then converted to CSV format (*.csv), which stands for Coma Separated Values, adapted to the Maximum Entropy (MaxEnt) software programme. The bioclimatic variables were extracted from the compressed file mbio_tbio_wc30s.zip to a directory on the computer in ASC (Action Script) format. To carry out this task, it was necessary to open the raster layer using ArcGIS software. The following functions were then applied: Arctool Box / Conversion tools / From a raster / Raster to Ascii then request an Ascii file as output. Bioclimatic variables were then processed at the Côte d'Ivoire scale using the Côte d'Ivoire boundary Shape file, using the following functions: Arctool Box / Spatial Analysis Tools / Extraction / Extract by Mash.

The correlation tests were then converted into Decimal Degrees before calling them up on an Excel sheet, performed on the 21 environmental variables using R software to select the least correlated ($r < 0.80$), to avoid bias on future predictions **(Elith *et al.,* 2011**). Pearson's method was used to examine the correlation between the different bioclimatic variables. The correlation coefficient varies between -1 and +1, with 0 reflecting a zero relationship between the two variables, a negative value (negative correlation) meaning that when one of the variables increases, the other decreases, while a positive value (positive correlation) indicates that the two variables vary in the same direction. The Jackknife test was then performed on the bioclimatic variables (from the current projection) to identify the variables that contributed most to the modelling.

Table VIII: Bioclimatic variables used for modelling

Code	Bioclimatic variables
BIO1	Mean annual temperature
BIO2	Mean diurnal temperature variation
BIO3	Isothermy
BIO4	Seasonality of temperatures
BIO5	Maximum temperature in the warmest month
BIO6	Minimum temperature in the coldest month
BIO7	Annual temperature variation
BIO10	Mean temperature in the warmest quarter
BIO11	Mean temperature for the coldest quarter
PET	Potential evapotranspiration
BIO12	Mean annual precipitation
BIO13	Precipitation during the wettest period
BIO14	Precipitation during the driest period
BIO15	Rainfall seasonality (coefficient of variation)
BIO16	Precipitation in the wettest quarter
BIO17	Precipitation in the warmest and driest quarter
MI	Annual moisture index
MIMQ	Moisture Index of the Moist Quarter
MIAQ	Moisture Index of the Arid Quarter
DM	Number of Dry Months
LLDS	Length of the Longest Dry Season

4.5.3 Modelling the Distribution Range of *Pterocarpus erinaceus* and *Afzelia africana*

The model was calibrated and validated using points obtained from literature reviews. Model validation was carried out repeatedly to obtain more accurate and reliable estimates of model performance **(Phillips *et al.*, 2006).** This repetition is an essential method for ensuring the reliability and representativeness of the results obtained, guaranteeing that the model's performance is indeed achieved. In addition, by increasing the number of validation iterations performed, it is possible to obtain a more accurate estimate of the model's performance. This approach also reduces the potential biases that could arise from using a single sample of data to evaluate the model. The reliability of the Maximum Entropy (MaxEnt) prediction was validated using the AUC (Area Under the Curve) statistical receiver as recommended by **Phillips *et al.* (2006).**

The AUC value reflects a model's ability to distinguish between existing data and context. For the interpretation of the AUC, the work of **Araújo *et al.* (2005)** was used as a reference **(Table IX).** Then, when it came to analysing the results of the logistic probabilities concerning the occurrence of the different species, it was decided to use the raw output of the model instead of the logistic transformations traditionally used **(Delsuc and Tramesel, 2006).** The logistic probability of occurrence of a species is considered to be an indicator of the quality of the species' habitats **(Nanan, 2024).** The logistic probability of occurrence can be used to determine the probability of presence of *Pterocarpus erinaceus* and *Afzelia africana*, and therefore of areas that are favourable or unfavourable for their proliferation.

It is obtained in the cumulative format between 0 and 1 and divided into 5 classes defined as follows:

- When the value of the logistic probability of occurrence is less than 0.19, the probability of presence of the model species is very low.
- When the value of the logistic probability of occurrence is between [0.19 - 0.339[, the probability of the presence of the model species is low.
- When the value of the logistic probability of occurrence is between [0.339 -0.479[, the probability of presence of the model species is moderate.
- When the value of the logistic probability of occurrence is between [0.479 - 0.62[, the probability of presence of the model species is high.
- When the value of the logistic probability of occurrence is greater than 0.62, the probability of the presence of the model species is very high.

To estimate the rate of change (Tc) for each climate model from the 'potentially favourable' current habitat to the 'potentially unfavourable' future habitat, the following formula was used: (10) Tc = ((A2-A1)/A1) x 100).

A1 and A2 are respectively areas of existing climatic conditions and the possible existence (future climatic conditions) of this species **(Toyi *et al.*, 2013).** A positive rate of change (Tc) indicates an expansion of the species' range, while a negative rate indicates a reduction in the species' range.

Table IX: Validity of the MaXent test according to AU values

Values	**Interpretations**
0.90 < AUC < 1. 00	Excellent
0.80 < AUC < 0. 90	Good
0.70 < AUC < 0. 80	Acceptable
0.60 < AUC < 0. 70	Poor
0.50 < AUC < 0. 60	Invalid

PART THREE: RESULTS

CHAPTER 5: IMPACT OF CLIMATIC VARIABLES ON THE DYNAMICS OF LAND USE TYPES IN THE STUDY AREAS

5.1. Mapping of Vegetation Cover in Study Areas

5.1.1 Description of the Different Types of Land Use/Cover in the Study Areas

The plant formations identified in the Lamto Scientific Reserve are: gallery forests, semi-deciduous dense forests, open forests, wooded savannas, tree savannas and shrub savannas. Regarding the Classified Forest of Badenou, in addition to the natural vegetation formations which are: gallery forests, dry dense forests, open forests, wooded savannas, tree savannas, shrub savannas and low density shrub savannas, there are anthropogenic formations such as: fallow land, perennial crops and annual crops. Furthermore, other types of land use/cover include bare soil, rock outcrops and agricultural development, followed by water bodies.

5.1.2.1 Gallery Forests

Present in the Sudanese savannas in the north and in the Guinean savannas in the forest-savanna transition zone in the centre of Côte d'Ivoire, gallery forests are plant formations that form a strip of about 100 meters in width, following the course of the rivers (**Figure 22**). They appear as closed vegetation in which epiphytes and vines can be found. These two types of forest gallery are composed of 3 strata and have a coverage rate of 60 to 70%, with a superior stratum having a height of 20 to 35 m. The upper stratum consists of species such as: *Nesogordonia papaverifera*, *Cleistopholis patens*, *Morus mesozygia*, *Cola gigantea*, *Cola cordifolia* (Cav.) R.Br., *Berlinia grandiflora* (Vahl) Hutch. & Dalz., *Ceiba pentandra* (L.) Gaertn, and *Khaya senegalensis* (Desv.) A. Juss., *Manilkara obovata* (Sabine & G. Don) J.H. Hemsl., *Cassipourea congoensis* DC., *Mimusops kummel* A. DC., *Pterocarpus santalinoides* DC., *Anthostema senegalense* A. Juss. A. Juss.. The woody plants of the middle stratum have a height of 8 to 15 meters and a coverage rate of 20 to 50%. They are composed of species such as *Cola laurifolia* Mast., *Phoenix reclinata* Jacq., *Olax subscorpioides* Oliv., *Argocoffeopsis afzelii* (Hiern) Robbr. The undergrowth exhibits the presence of *Psychotria calceata* Petit, *Stylochaeton hypogaeus* Lepr., *Scleria boivinii* Steud., *Oplismenus hirtellus* (L.) P. Beauv., and *Urena lobata* L., with a coverage rate ranging from 15% to 25%.

5.1.2.2 Semi-deciduous Dense Forest

The dense semi-deciduous forest is found in Lamto SR, mainly on deep soils, where the hydric conditions favour dense vegetation (**Figure 23**).

Figure 22: Overview of the undergrowth of a forest gallery at Lamto RS (Photo taken in 2022 by KOUASSI Roch)

Figure 23: Overview of a dense semi-deciduous forest at Lamto SR (Photo taken in 2022 by KOUASSI Roch)

This habitat is characterised by a pronounced seasonality, with a dry period during which some of the trees lose their leaves. This formation comprises four woody strata: the upper tree savanna (20 to 30 m) dominated by *Ceiba pentandra* (Linn.) Gaertn, *Triplochiton scleroxylon* K. Schum., *Entandrophragma angolense* (Welw.) C.DC. and *Cola grandifolia*; the lower tree layer (8 to 15 m) featuring *Diospyros heudelotii* Hiern, *Chrysophyllum albidum* G.Don, *Pseudospondias microcarpa* (A.Rich.) Engl., and *Pterocarpus soyauxii* Taub.; and the shrub savanna (2 to 8 m), which consists of shrub species and juvenile tree individuals. Species such as *Cola nitida* (Vent.) Schott & Endl., *Anthonotha fragrans* (Baker f.) Exell & Hillc., *Annickia polycarpa* (DC.) Setten & Maas, *Bridelia micrantha* (Hochst.) Baill. and *Erythroxylum emarginatum* Thonn. can be found. The woodland cover frequently surpasses 70%, creating a dense canopy, while the undergrowth is abundant and varied, including woody plants and herbaceous species such as *Psychotria calceata* E.M.A.Petit, *Urena lobata* L. and *Oplismenus hirtellus* (L.) P.Beauv. This forest serves a fundamental ecological function as a transitional area between savanna and forest ecosystems, regulates climate, protects soil, and supports remarkable biodiversity.

5.1.2.3. Dry Dense Forests

The dense dry forests are the forest islands of the savannas in the Sudanese domain that occupy the northern half of Côte d'Ivoire (**Figure 24**). The dense dry forests of the Badenou Classified Forest are very scarce throughout the savannas and are affected by extensive livestock farming and transhumance. Indeed, these practices have significant consequences on the woody vegetation because grazing, trampling and the pruning of treetops for fodder production result in a degraded appearance of these forests. These islets of dense dry forest are subdivided into three strata: the upper woody stratum, the middle woody stratum and the lower woody stratum. The upper woody stratum is dominated by species such as *Bombax buonopozense*, *Terminalia superba*, *Triplochiton scleroxylon*, *Afzelia africana* Sm., *Ceiba pentandra* (Linn.) Gaerth., *Anthonotha crassifolia* (Baill.) J. Léonard, *Cola caricaefolia.* (G. Don) K. Schum., Antiaris toxicaria (Engl.) Corner, *Khaya senegalensis* (Desv.) A. Juss., *Cola gigantea* A.Chev., *Pentadesma butyrecea* Sabine, *Samanea dinklagei* (Harrns) Keay, etc., with a height ranging from 20 to 32m and a cover of 50 to 60%. At the level of the middle woody stratum, the height of the trees ranges between 5 and 15 meters; we can mention species such as: *Blighia sapida*, *Sterculia tragacantha*, *Trichilia prieureana*, etc.

Figure 24: Overview of a dry dense forest at CF Badenou photo (KOUASSI Roch, 2023)

Finally, the lower woody stratum is sparse and consists of species such as *Anchomanes difformis* (Blume) Engl., *Amorphophallus accrensis* N.E. Br., *Cleidion gabonicum* Baill., *Nervilia bicarinata* (Blume) Schltr., *Olyra latifolia* Linn. with a height ranging from 0 to 2 m and a cover of 10 to 15%.

5.1.2.4 Open Forests and Wooded Savannas

The open forests and wooded savannas of RS Lamto and FC Badenou are open woody stands, where the tree canopies are more or less contiguous, but still allow light to penetrate. At the undergrowth level, the grassy layer is relatively sparse or mixed with other herbaceous vegetation **(Figure 25; Figure 26).** The open forests and wooded savannas have three types of woody strata and one herbaceous stratum. Its height varies from 15 to 20 m with a coverage of 20 to 50% for the tall woody layer, which has a canopy of very variable density and relatively small, deciduous, and hard leaves. A height of 10 to 15m with a coverage rate of 30 to 40% for the mid-story layer and a height of less than 8m for the lower layer with a coverage rate of 10 to 20%. The species that are frequently found in the woody layer include, among others: *Pterocarpus erinaceus* Poir., *Prosopis africana* (Guill. & Perr.) Taub., *Isoberlinia doka* Craib & Stapf, *Uapaca togoensis* Pax, *Daniellia oliveri* Hutch. & Dalz., *Cussonia arborea* Hochst. ex A.Rich., *Vitex doniana* Sweet, *Crossopteryx febrifuga* (G.Don) Benth. The herbaceous layer, on the other hand, is dominated by: *Andropogon tectorum* Schum. & Thonn.

5.1.2.5. Trees Savannas

Tree or arboreal savannas are formations characterised by a continuous grass layer composed of various species. This habitat is present both within the RS Lamto and the FC Badenou. These are plant formations with a high occurrence of fire. This biotope features two woody layers and one herbaceous layer, then is distinguished by the presence of trees and shrubs scattered within a grassy mat **(Figure 27).** The upper layer, composed of trees, has a height ranging from 8 to 15 meters. The middle layer, composed of shrubs, is between 2 and 8 meters, while the lower layer, formed by herbaceous plants, ranges from 0 to 2 meters. The coverage rate of the woody layer is estimated to be between 20 and 30%. *Daniellia oliveri* Hutch. & *Dalz, Lophira lanceolata* Tiegh. ex Keay, *Khaya senegalensis* (Desv.) A. Juss, *Combretum nigricans* var. *elliotii* (Engl. & Diels) Aubrév,., *Pericopsis laxiflora* (Benth) Meeuv and *Terminalia avicennioides* Guill. & Perr. are the species found in the tree layer. The shrub layer includes several species such as *Gardenia ternifolia* Schum. & Thon, *Annona senegalensis* Pers, *Bridelia ferruginea* Benth, *Parinari curatellifolia* Planch. ex Benth.

Figure 25: Overview of an open forest (Photo taken in 2022 by KOUASSI Roch)

Figure 26: View of a wooded savanna crossed by fire (Photo taken in 2022 by KOUASSI Roch)

Figure 27: Overview of a dense tree savanna photo (KOUASSI Roch, 2023)

Antidesma venosum Tul. The herbaceous vegetation, dominated by grasses, is very dense and heterogeneous, with 45 to 90% cover. It is made up of species such as *Andropogon gayanus* Kunth, Andropogon tectorum Schum. *Aframomum sceptrum* (Oliv. & Hanb.) K.Schum, *Clausena anisata* (Willd.) Benth.

5.1.2.6. Shrub Savannas

Shrub savannas are characterised by the abundant presence of shrubs. In the field, a difference between Sudanese shrub savannas and Guinean shrub savannas has been observed. This habitat generally has a woody stratum and a herbaceous stratum, and is then distinguished by a woody stratum dominated by shrubs scattered within a graminaceous mat **(Figure 28)**. This stratum covers between 10 and 20% and is dominated by juvenile trees and shrubs such as *Parinari curatellifolia* Planch. ex Benth, *Piliostigma thonningii* (Schumach.), *Bridelia ferruginea* Benth, *Annona senegalensis* Pers, *Crossopteryx febrifuga* (G. Don) Benth, *Pericopsis laxiflora* (Benth) Meeuv, *Vitellaria paradoxa* C. F. Gaertn, *Vitex doniana* Sweet. The herbaceous stratum varies in cover from 50 to 90%, with the same floristic richness as that of tree savannas, but with greater density and height.

5.1.2.7. Low-density Shrub Savanna

The low-density shrub savannas found at the CF Badenou are either of edaphic origin or anthropogenic origin (resulting from cultivated areas). Regardless of their origin, they are found on hydromorphic soil near watercourses and form a strip of intercalary vegetation between gallery forests and other plant formations on one hand (**Figure 29**). Moreover, they can also be observed on hilltops, far from watercourses, and in areas characterised by the presence of ferruginous soils and rocky outcrops. They are mainly composed of grassy formations interspersed with rare woody plants generally found on termite mounds. You can find species such as *Cynodon dactylon* (Linn.) Pers., *Cyperus sphacelatus* Rottb, *Andropogon gayanus* Kunth, *Digitaria horizontalis* Willd., *Fimbristylis ferruginea* (Linn.) Vahl, *Kyllinga erecta* Schumach, *Panicum repens* Linn., *Sida acuta* Burm.f., *Cassia kirkii* Oliv., *Annona senegalensis* Pers, *Acacia sieberiana* A. Chev, and *Piliostigma thonningii* (Schumach.).

5.1.2.8 Fallow Lands

Fallow land was found only in Badenou FC. These are plots of land set aside after cultivation. They are former plots of annual or perennial crops grown in the study area **(Figure 30).** The most commonly encountered emergent species are: *Terminalia glaucescens*, *Piliostigma thonningii*, *Ficus vallis-choudae*, *Nauclea latifolia*, etc. The herbaceous layer is

Figure 28: Overview of a shrub savanna photo at SR Lamto (KOUASSI Roch, 2022)

Figure 29: Overview of a low-density shrub savanna photo (KOUASSI Roch, 2023)

Figure 30: Overview of a fallow land at CF Badenou photo (KOUASSI Roch, 2023)

largely dominated by *Chromolaena odorata*, *Cassia tora*, Hyptis suaveolens, *Andropogon gayanus* and *Imperata cylindrica*, etc.

5.1.2.9 Cultures

Agricultural activities were only encountered in the Classified Forest of Badenou.

5.1.2.9.1. Perennial Crops

Cashew plantations represent the main perennial and sustainable agricultural activity in the northern region of Côte d'Ivoire. This is a shrubby plant formation whose density and cover vary according to the age of the crop **(Figure 31).** This biotope has a tree structure that is generally monostratified. However, it is possible that there is a second tree layer made up of local species preserved by the farmers during cultivation. These include useful woody species such as *Tamarindus indica* Linn, *Parkia biglobosa* (Jacq.) Benth, *Daniellia oliveri* Hutch. & Dalz, *Adansonia digitata* Linn.

5.1.2.9.2 Annual Crops

Annual crops grown in the FC Badenou region mainly include rice, cotton, maize and groundnuts, and to a lesser extent yams and cassava. These crops are grown alternately or in association on the same plots. The first crops planted after land clearance are generally cotton and yam, followed by other crops in subsequent years**.** Alternate cropping, especially with cotton, means that the same plots of land can be used for up to 10 years **(Figure 32)**. The rice crop, which was traditionally cultivated in wooded areas such as dense forests, clear forests and wooded savannahs, is now being grown in the lowlands.

5.1.2.10 Bare Soils and Habitats

This class is represented within the RS Lamto by habitats and rocky outcrops, whereas in the FC Badenou, it generally consists of areas developed for agriculture or clandestine gold mining sites and camps (**Figure 33**).

5.1.2.11 Water Body

The water body of the study sites includes the Bandama River, rivers (tributaries) with a permanent regime, rivers with a non-permanent regime, and ponds (**Figure 34)**.

Figure 31: Overview of a cashew plantation within CF Badenou (KOUASSI Roch, 2023)

Figure 32: Overview of a gold mining area within CF Badenou photo (KOUASSI Roch, 2023)

Figure 33: Overview of a habitat within the ecological station of LSR photo (KOUASSI Roch, 2023)

Figure 34: Overview of the Bandama River of LSR Photo (KOUASSI Roch, 2023)

5.1.2. Cartographic Performances and Land Use/Cover Types

Land use/cover mapping of the vegetation in the Lamto scientific reserve identified 6 classes, these are the gallery forest/dense semi-deciduous forest (GF/SDF), open forest/wooded savannah (OF/WS), tree savannah (TS) and shrub savannah (SS) classes for the Lamto RS(**Figure 35**). Mapping of the Badenou classified forest identified 8 classes for the years 1990, 2002, 2012 and 2022 (**Figure 36**). Then the gallery forest/dense dry forest (GF/DSF), open forest/wooded savannah (OF/WS), tree savannah/shrub savannah (TS/SS), sparsely populated shrub savannah (LDSS), fallow (FL), perennial crop (PC), bare land/rock outcrop/ Agricultural development (BL/RO/AD) and water bodies (WB) classes for FC Badenou.
The overall accuracies of the various classifications for the 1990, 2002, 2012 and 2022 images are 98.66%, 99.83%, 99.27% and 98.32% respectively for RS Lamto (**Appendix 1**; **Appendix 2**; **Appendix 3**; **Appendix 4).** For FC Badenou, they are 95.98%, 95.60%, 92.65% and 94.39% respectively **(Appendix 5; Appendix 6; Appendix 7; Appendix 8).** For all the treatments carried out, minor confusion was observed between certain land use classes. The highest confusion value for SR Lamto was observed in 2022 between the semi-deciduous dense forest and open forest/wooded savannah classes. It was 2.58%. For FC Badenou, the highest confusion value was observed in 2022 between the fallow (FL) and open forest/wooded savannah (OF/WS) classes (19.95%). For the year 2012, the highest confusion (8.04%) was observed between the fallow (FL) and tree savannah/shrub savannah (TS/SS) classes. Then, for the year 2002, the highest level of confusion (3.01%) was observed between the gallery forest/dense dry forest (GF/DDF) classes and the open forest/wooded savannah (OF/WS) classes. Finally, for the year 1990, the most significant confusion value (3.87) was recorded between the different classes of open forest/wooded savannah (OF/WS) and gallery forest/dry dense forest (GF/DSF).

5.1.3. Evolution of Land Use/Cover Between 1990 and 2022 in the study areas

The spectra of proportions (%) and areas in hectares of land use/cover in the LSR vary from year to year **(Figure 37).** In 1990, the vegetation of the Lamto Scientific Reserve was dominated by shrub savannas, which accounted for 46% of the reserve's area, or 1,289.46 ha. This class is followed in order of importance by gallery forest/dense semi-deciduous forest (23%) and open forest/wooded savannah (23%). Wooded savannahs and bare ground/habitats are the least represented habitats. The trends for this date show a slight dominance of savannah formations over forest formations. In 2002, the trend was the same for the dominant habitats in terms of surface area.

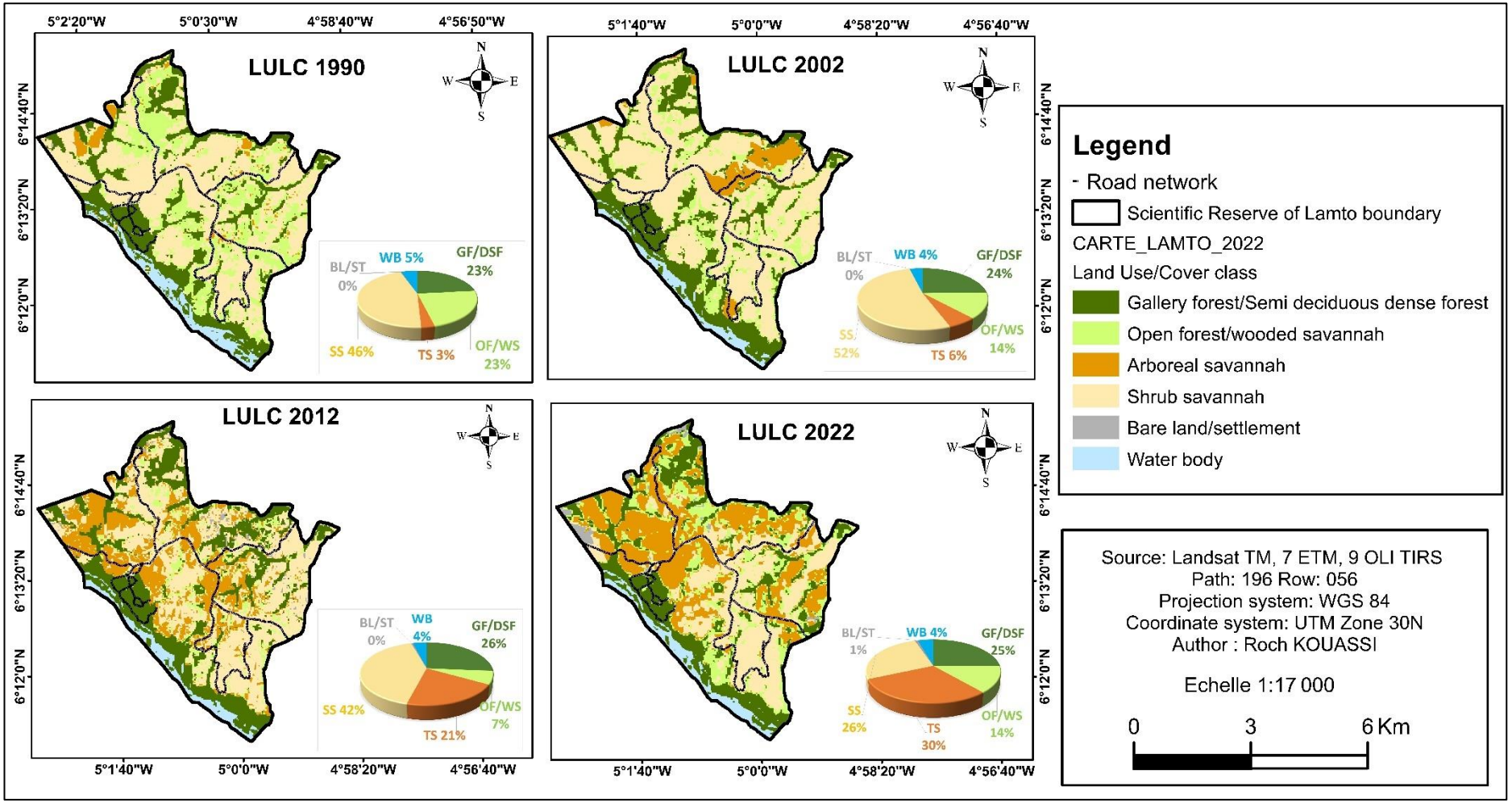

Figure 35: Land use/cover classification map of LSR from 1990 to 2022

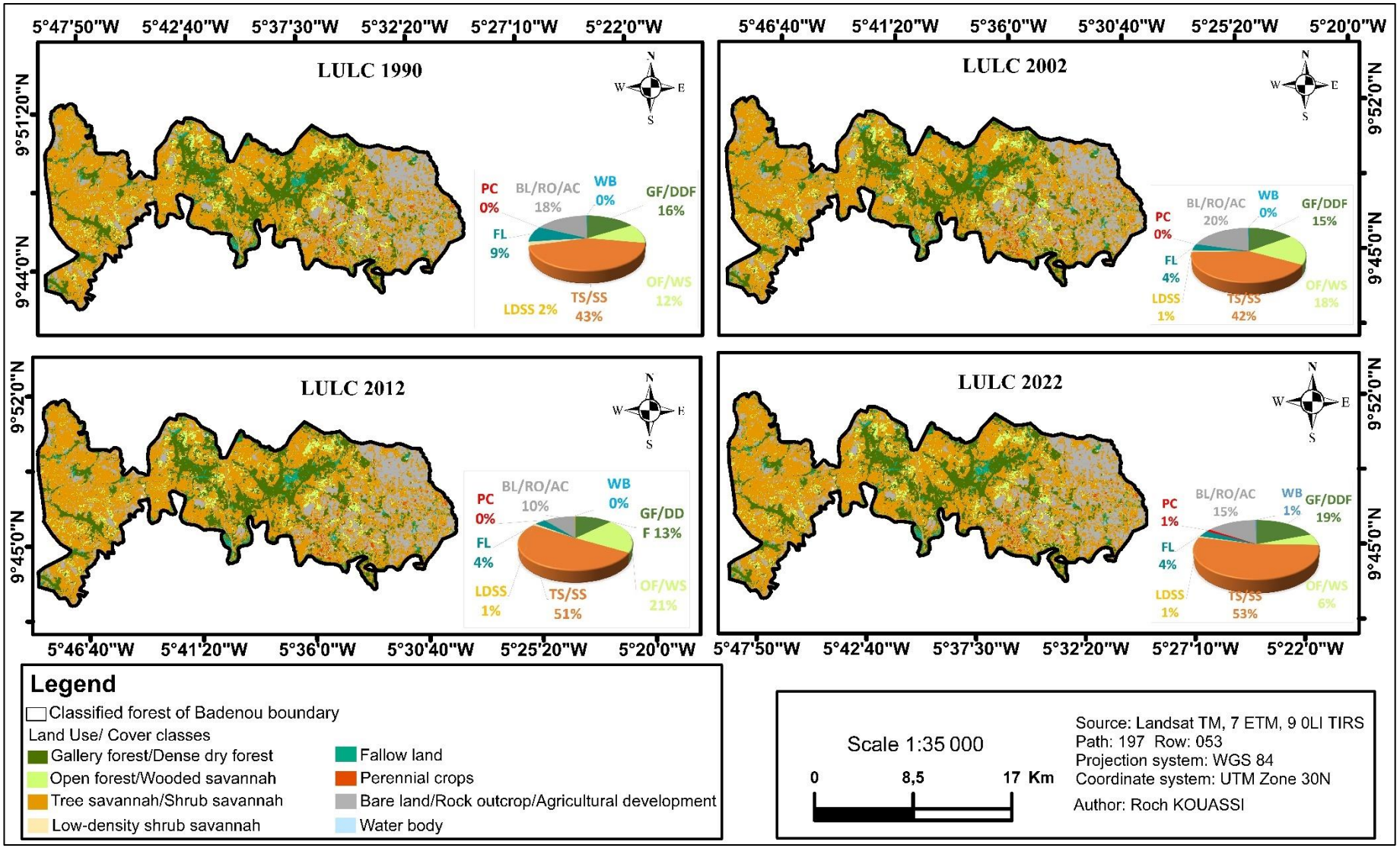

Figure 36: Land use/cover classification map of BCF from 1990 to 2022

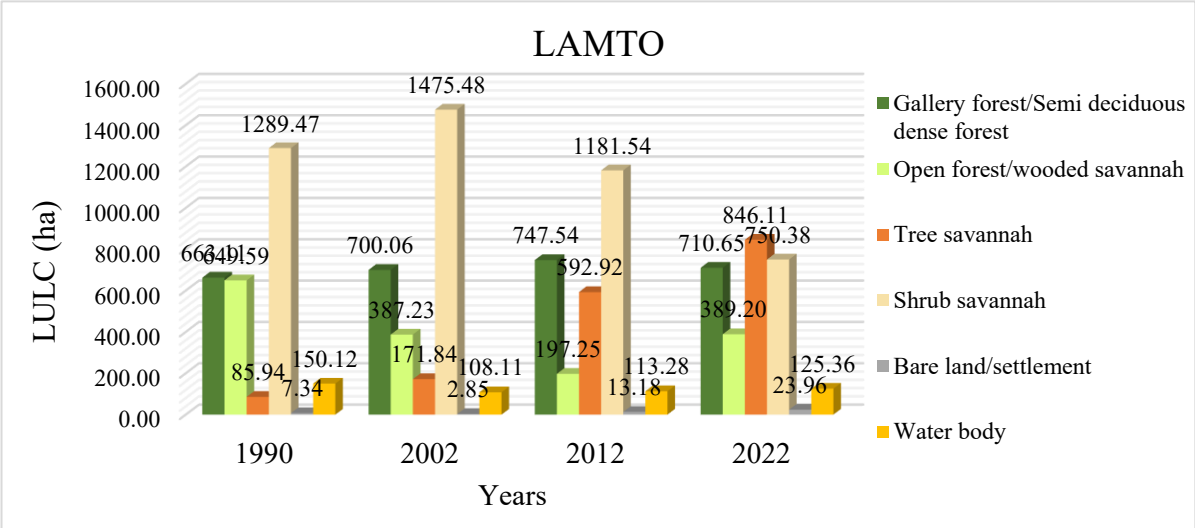

Figure 37: Histograms of the evolution of land use/cover classes in the LSR from 1990 to 2022

However, there was an increase in the surface area of shrub savannahs, which rose from 46% to 52%, and a reduction in that of the open forest savannah woodland class, which fell from 23% to 14%. At the same time, the dominance of savannah formations increased from 49% to 58% of the reserve's surface area.

In 2012, wooded savannahs increased in size from 6%, equivalent to 171.84 ha, to 21%, or 592.92 ha, and occupy 3rd place in terms of surface proportion, after shrub savannahs and gallery forests/dense semi-deciduous forests. The open forest/wooded savannah class lost half its surface area, falling from 14%, corresponding to 387.23 ha, to 7%, or 197.25 ha, at that date. Savannahs (shrubs and trees) still dominate the vegetation and have still increased in area at this date. In 2022, the trend is marked by the dominance of wooded savannahs, which will occupy 30% of the reserve by that date, i.e. an area of 846.11 ha. The open forest/wooded savannah class, which is still in 4th place, has, however, increased its area by almost 10% of the reserve. The dominance of savannah formations is declining slightly, from 62% (in 2012) to 55% (in 2022).

In 1990, the BCF was characterised by a strong predominance of arboreal savannah/shrub savannah, occupying 43% or 14121.73 ha of the total area **(Figure 38)**. Forests, comprising the classes gallery forest/dense dry forest (16%) and open forest/wooded savannah (12%), account for around 28% of the cover. Then, there is a relatively high proportion of bare soil/rock outcrops/agricultural land (18%). Fallow land accounts for only 9% of the surface area of the study area.

In 2002, the landscape was still characterised by a predominance of savannah environments, with the tree savannah/shrub savannah class covering 42% equivalent to 13641.77 ha of the total area. At the same time, the forest cover shows a notable reorganisation. The gallery forest/dense dry forest class fell by 16% to 15%, while the open forest/wooded savannah class rose significantly to 18%, equivalent to 5,950.55 ha. The area of bare land/rock outcrops/agricultural land development, meanwhile, increased to 20%, equivalent to 6,715.04 ha. Finally, fallow land has been drastically reduced, occupying just 4% of the surface area. Overall, the proportions and surface areas in 2002 reflect a changing landscape, where the predominance of savannahs is combined with a reorganisation of forest cover and an intensification of land use, particularly in terms of areas dedicated to agricultural development.

In 2012, a significant change in vegetation cover was observed, with a marked increase in the tree or arboreal savannah/shrub savannah class, covering 51% or 1,686.12 ha of the total area. Gallery forests/dense dry forests continue to decline, now accounting for 13%, while open forests/wooded savannahs have increased significantly to 21%. There has been a marked

reduction in the area of bare soil/rock outcrops/agricultural land, which has fallen to 10% compared with previous higher values, potentially suggesting the abandonment of certain plots. At the same time, fallow land remained relatively constant at around 4%.

In 2022, the landscape is characterised by the marked predominance of wooded savannah/shrub savannah, which occupies more than 53%, equivalent to 17555.26 ha of the study area. In terms of gallery forest/dense dry forest, we note a slight increase, accounting for around 19% of the surface area, while open forest/wooded savannah fell from 21% to 6%. When these two categories are combined, total forest cover stands at around 25%. Fallow land remains relatively stable at around 4%. At the same time, bare land/rock outcrops/agricultural developments occupy almost 15% of the area, i.e. 5006.63 ha.

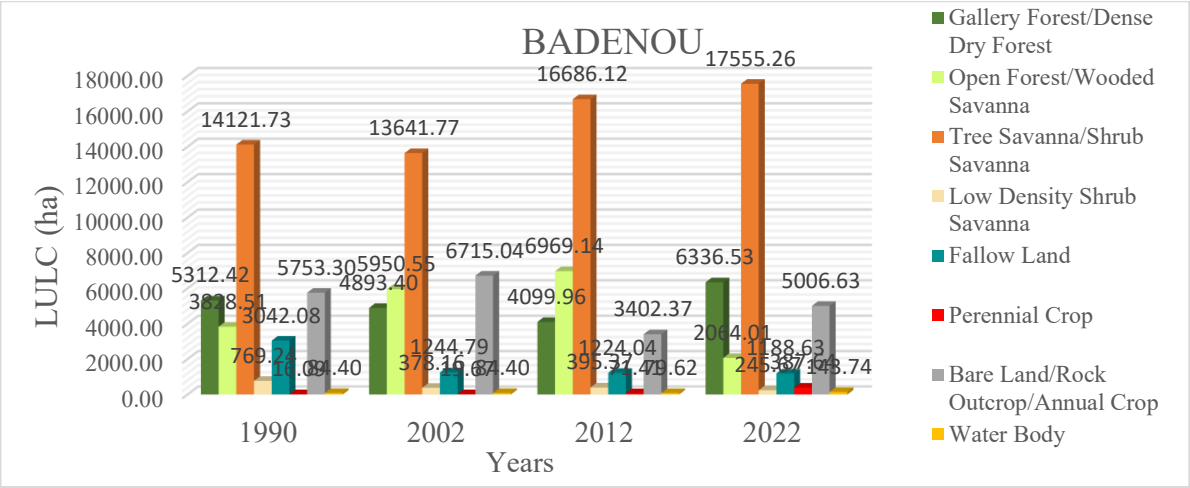

Figure 38: Histograms of the evolution of land use/cover classes in BCF from 1990 to 2022

5.1.4. Overall Rate of Change in Land Use/Cover Types

The changes in land use/cover types were characterised using the overall rate of change (Tg). **Figure 39** shows the overall rates of change in land use/cover in the Lamto between 1990-2002, 2002-2012, 2012-2022 and finally between 1990-2022. These histograms show that the Lamto Scientific Reserve has undergone a process of natural reforestation of certain plant formations. These are gallery forests/dense semi-deciduous forests and arboreal savannahs. The gallery forests/semi-deciduous dense forests showed increasing rates of overall change from 1990 to 2022, rising from 663.11 ha (23%) to 710.65 ha (25%), i.e. a total gain of +7.17%. Next, the tree savannah class, which is the mainstay of this reforestation within the study area, recorded the highest rate of overall change, rising from 85.94 ha (3%) in 1990 to 846.11 ha (30%) in 2022, i.e. a total gain of +884.55%. The shrub savannah, on the other hand, experienced an overall loss of -41.81%. On the other hand, the open forest/wooded savannah class underwent a sharp decline during the first two decades (1990-2002; 2002-2012) -40.39% and -49.06 respectively before showing a significant recovery +97.31% for the third decade (2012-2022). Despite this recovery, there was a net loss of -40.08% over the entire study period. Bare land/settlement classes increased from 7.34 ha in 1990 to 23.96 ha in 2022. Although the surface area of water bodies has decreased slightly, it remains stable overall.

In Badenou , significant rates of overall change between land use/cover classes were observed during the study period (1990-2022). The class that recorded the greatest expansion was perennial cropping **(Figure 40).** In fact, this land cover, which in the 1990s was 16.09 ha, has increased to 387.64 ha in 2022, i.e. an overall rate of change of +2309.51%. The second class with the most significant rate of change is tree savannas/shrub savannas. It should be noted, however, that this plant formation has always dominated the landscape of Badenou FC. Despite the loss recorded in 2002, tree savannas/shrub savannas led the gains in the overall rate of change in natural formations, corresponding to +24.31% over the entire study period.

However, low density shrub savannahs have seen a significant reduction in the corresponding overall rate of change a (-68.06%) over the period from 1990 to 2022. In other words, this class has declined drastically, especially between 1990-2002 (-50.84%) and 2012-2022 (-37.86%). In terms of forest formations, gallery forests/dense dry forests saw an overall rate of change of +19.28 between 1990-2022. In fact, this class shows an overall increase over the entire study period, despite a sharp decline between 1990-2002 (-7.89%) and 2002-2012 (-16.21%). Open forests/wooded savannas, which are buffer forest formations between gallery forests/dense dry

forests and tree savannas/shrub savannas, experienced a significant decrease (-46.09%) in their overall rate of change from 1990 to 2022. Yet, the third decade (2012-2022) recorded the most significant loss (-70.38%). In terms of fallow land, the first decade (1990-2002) recorded the most drastic overall rate of change (-59.08%) before stabilising at the level of the last two decades. The bare land/rock outcrops/agricultural development class showed a complex dynamic in terms of its overall rate of change, but ultimately experienced a loss of -12.98 over the entire study period. Although the overall rate of change for water bodies decreased slightly in 2002-2012 (-5.66), it remained stable overall throughout the study period.

5.1.5. Transition in Land Use/Cover in the Study Areas

The transition matrices show a contrasting evolution of land use/cover classes in the Lamto Scientific Reserve and in the Badenou Classified Forest. Analysis of land cover transitions over 32 years in the Lamto Scientific Reserve shows progressive afforestation, marked by afforestation of savanna formations, particularly tree savannas, to the detriment of shrub savannas. On the other hand, the Badenou Classified Forest shows a regression or even a degradation of forest formations towards savannah formations. However, the Badenou FC is also undergoing a similar phase of savannah densification. The work made it possible to understand the dynamics that took place between the different types of land use/cover during the study period within the LSR. During the period 1990-2002, the open forest/wooded savannah class lost 59.62% of its surface area, mainly in favour of tree savannas (36.63%) and shrub savannas (14.62%). The tree savannas class lost 24.85% of its area to shrub savannas. Bare soil/habitats is the class that recorded the highest rate of transfer. In fact, it retained only 25.29% of its surface area. Most of this loss was to shrub savannas (73.48%) according to **(Appendix 9).** On the other hand, gallery forests/dense semi-deciduous forests and shrub savannas recorded the lowest rate of transfer. During the second period (2002-2012), it was the open forest/wooded savannah class that lost 52.73% of its area specifically to gallery forests/dense semi-deciduous forests (22.52%), tree savannas (13.58%) and shrub savannas (16.63%). The tree savannas class was also affected by this change, retaining only 51.55% of its area. A further 23.88% of its area was converted to shrub savannah and 13.85% to open forest/wooded savannah. However, this same tree savannas class gained 32.19% of its area from shrub savannas. Compared with the previous year, the bare land/settlement, gallery forest/dense semi-deciduous forest and water body classes remained stable **(Appendix 10)**.

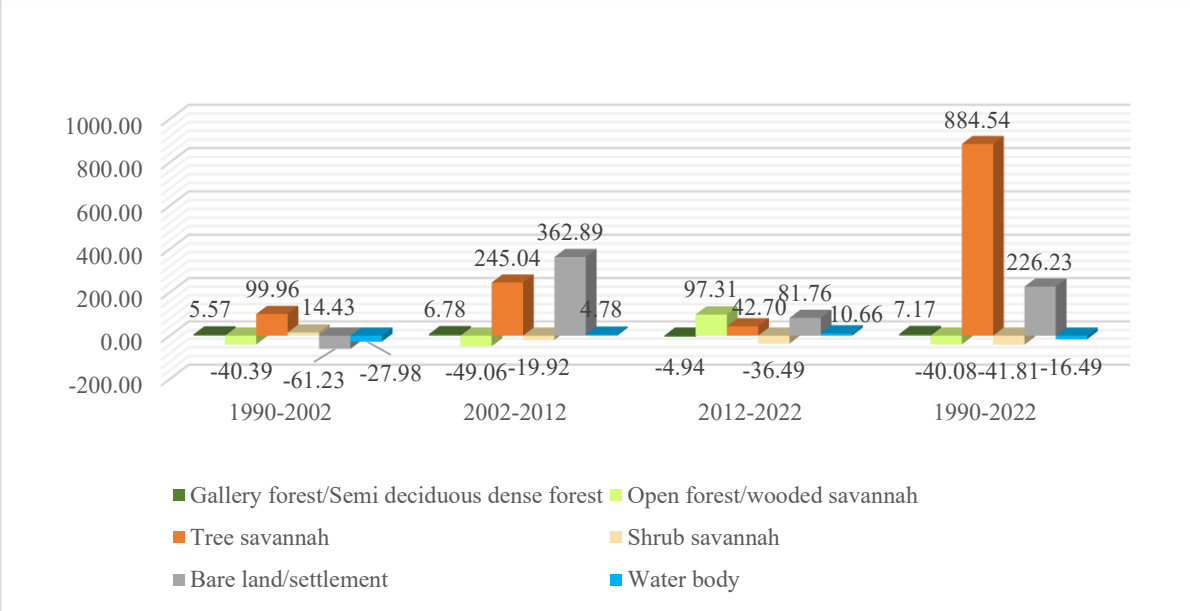

Figure 39: Histograms of the overall evolution rate of land use classes from 1990 to 2022 at RS Lamto

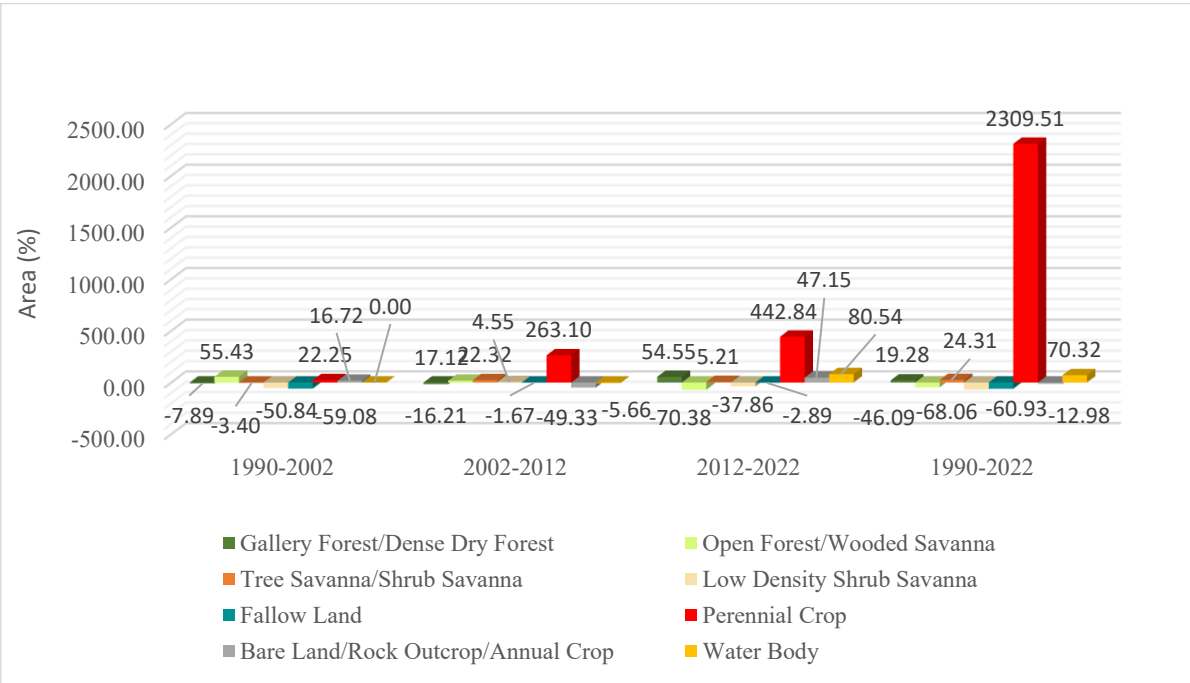

Figure 40: Histograms of the overall evolution rate of land use/cover classes from 1990 to 2022 at CF Badenou

For the period 2012-2022, the shrub savannah and bare land/settlement classes lost most of their area. Shrub savannah lost 37.03% of its area to tree savannah. Bare soil/habitats transferred 25.69% of their area to shrub savannas and 49.28% to tree savannas. The other classes remained practically stable **(Appendix 11).** Overall, over the entire study period (1990-2022), the open forest/wooded savannah class and the shrub savannah class are the natural formations that have experienced a regressive dynamic. Tree savannas are the only class to have gained more surface area from other land uses, specifically open forest/wooded savannas and tree savannas. The other formations have retained most of their surface area **(Appendix 12).**

Talking about the transition in land use in Badenou FC. Between 1990 and 2002, gallery forest/dense dry forest lost 32.19% of its surface area to open forest/wooded savannas (16.53%) and tree savannas/shrub savannas (15.66%). Open forests/wooded savannas also lost 33.10% of their area to tree savannas/shrub savannas (19.34%) and gallery forests/dense dry forests (13.76%). The tree savannas/shrub savannas class is the class that received the most area transfer from natural plant formations (73.85%) and man-made formations (79.13%). However, fallow land is the class that lost most of its area, retaining only 8.32% **(Appendix 13).** The second decade (2002-2012) saw virtually the same trends. However, in contrast to the previous decade, sparse shrub savannah (79.40%) and fallow land (89%) recorded the greatest loss **(Appendix 14).** During the third decade (2002-2012), the open forest/wooded savannah class lost 68.35% of its area, mainly to tree savannas/shrub savannas (47.97%) and open forest/wooded savannah (20.38%). This is followed by sparsely populated shrub savannas, which lost 98% of their area to tree savannas/shrub savannas (47.45%) and bare land/rock outcrops/agricultural development (13.54%). Finally, this same bare land/rock outcrops/agricultural development class and tree savannah/shrubby savannah are the classes that recorded the greatest increase in area from other plant formations

Appendix *15*).

Overall, over the entire study period (1990-2022), in terms of natural plant formations, it was gallery forests/dense dry forests and tree savannas/shrub savannas that experienced a progressive dynamic. Most of the area of the open forest/wooded savannah and sparsely wooded savannah classes has been converted to tree savannas/shrub savannas. Man-made formations (fallow and perennial crops) have lost most of their area to tree savannas/shrub savannas. Finally, bare land/rock outcrops/agricultural developments also gave up 50.91% of their area to tree savannas/shrub savannas **(Appendix 16).**

5.2. Climate Variability of the Study Areas from 1990 to 2022

5.2.1. Temperature Fluctuation at Study Sites from 1990 to 2022

The average minimum, and maximum temperatures of SR Lamto exhibit various trends during the study period (**Figure 41**). Talking about the mean temperature, the curve shows an increase along the chronosequence, marked by occasional upward or downward fluctuations. We thus went from 24.5° in 1992 to 27° in 2021, which is a global increase of 2.5° over 30 years. This chronological sequence is marked by two decisive dates, namely the years 1992 and 2021. The year 1992 recorded the lowest average temperature (24.38°C), while the year 2021 experienced the highest warming with an average value of 27°. However, a discontinuity in the temperature dynamics is observed. Thus, the period from 1992 to 2002 is marked by an increase in mean temperature from 24.5° to 26°, representing a warming of 1.5°.

The period from 2002 to 2015, on the other hand, is marked by very weak overall growth. The average temperatures fluctuated between 25° and 25.5°. From 2015 to 2021, the average temperature increased from 25.5° to 27°. During this period, we witnessed a global warming of 1.5°. The maximum and minimum temperatures show the same dynamics as the mean temperature during the study period. They have generally experienced an increase in their average value. The year 1998 presents a particularity regarding the three temperature variables. We witnessed a simultaneous increase in these three variables by about 0.5° during this year. By analysing the temperatures within CF Badenou, it is observed that the average, minimum, and maximum temperatures display varied but relatively similar trends over the studied period (**Figure 42**). The evolution of mean temperatures shows interannual fluctuations with periods of increases and decreases. The mean annual temperatures between 1990 and 2022 range from 26.07°C (1992) to 28.60°C (2021), corresponding to an overall increase of 2.5°C over the 30 years. The increase in the overall mean temperature of 2.5°C observed during the study period at CF Badenou is similar to that recorded at SR Lamto. However, a more pronounced variability is observed after the year 2000, with several years exceeding the general average. The year 2021 recorded the highest temperature in the series, while the years 1992 and 2012 showed values below the mean. The analysis of minimum temperatures from 1990 to 2022 reveals significant interannual variability, with fluctuations around an average of 20.89°C. The lowest values were recorded in 1992. maximum temperatures from 1990 to 2022 show marked interannual variability, with notable fluctuations over time. The average maximum temperature over this period is 35.69°C, indicated by a reference line on the graph.

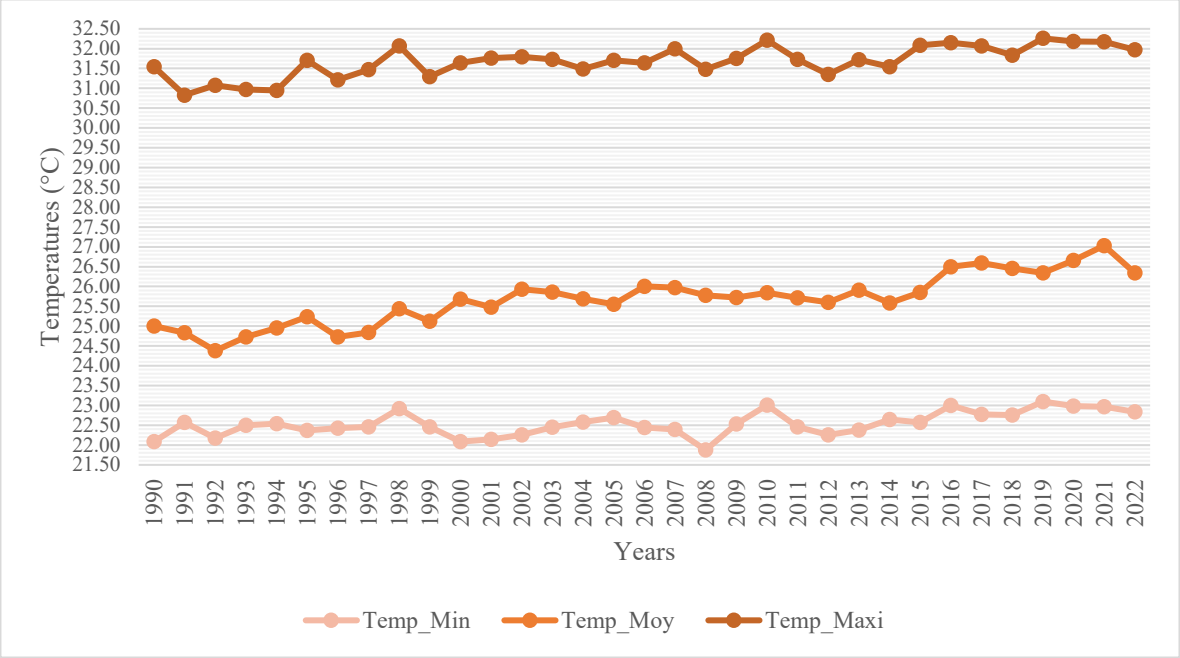

Figure 41: Trend curves of temperature variables in the Scientific Reserve of Lamto, from 1990 to 2022

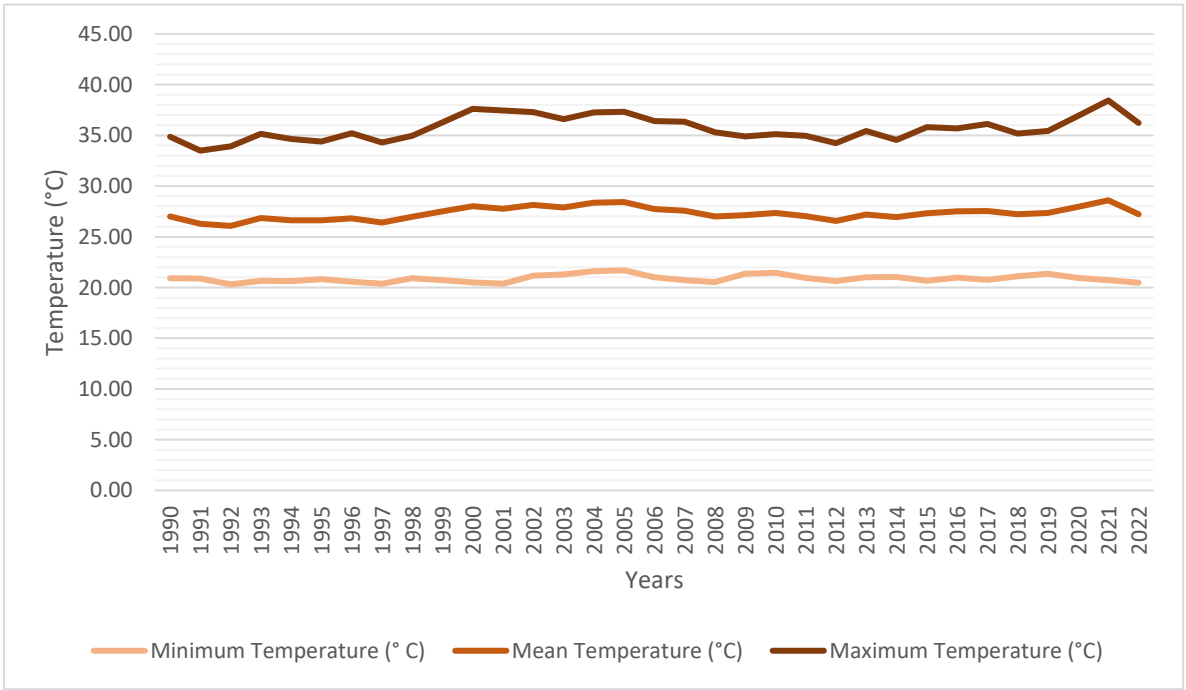

Figure 42: Trend curves of temperature variables in the Classified Forest of Badenou, from 1990 to 2022

5.2.2. Dynamics of Precipitation at the Study Areas from 1990 to 2022

The precipitation values for the three decades of study at SR Lamto range between 900 mm and 1687 mm, respectively for the years 1992 (907 mm), which corresponds to the least rainy year, and 2021 (1687 mm), which corresponds to the year with the most rainfall (**Figure 43**). The years 1990, 1992 and 1997 correspond to those that recorded the lowest amounts of rainfall, with respective values of 1100 mm, 907 mm and 1040 mm. On the contrary, the years 2003, 2010, and 2021 recorded the highest amounts of rainfall with respective values of 1638 mm, 1676 mm and 1687 mm. The analysis of annual precipitation between 1990 and 2022, highlights significant interannual variability in the Classified Forest of Badenou region (**Figure 44**). The recorded values range from 888.8 mm in 2015, the driest year, to 1410.9 mm in 2003, which represents one of the highest rainfall peaks. The mean precipitation over the entire studied period is 1178 mm, with a standard deviation of 111.8 mm, indicating a humid tropical climate. Some years stand out for particularly low levels of precipitation, such as 2015 and 2017, with 888.8 mm and 976.3 mm, respectively. Conversely, the years 2003 and 2018 recorded precipitation levels significantly above the mean, reaching 1410.9 mm and 1334.6 mm, respectively. These fluctuations reflect an alternation between periods of high humidity and episodes of water deficit. Over the entire 32 years analysed, no clear trend of increasing or decreasing precipitation appears. The alternation of wet and dry periods remains a notable characteristic of the regional rainfall regime.

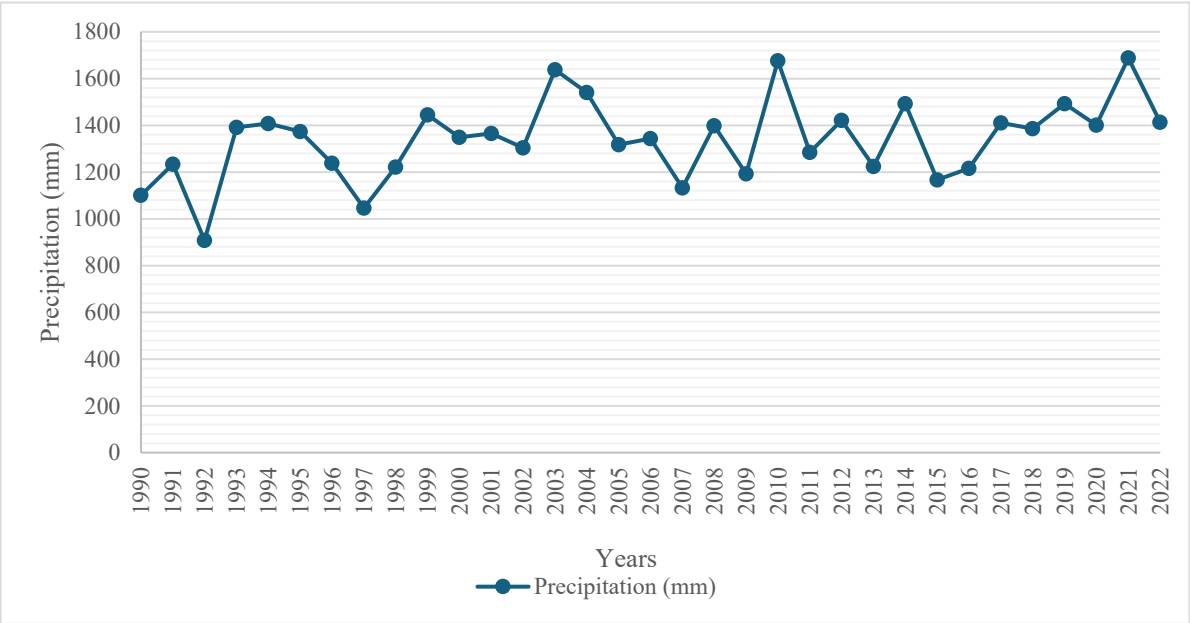

Figure 43: Curve of precipitation fluctuations in the Scientific Reserve of Lamto, from 1990 to 2022

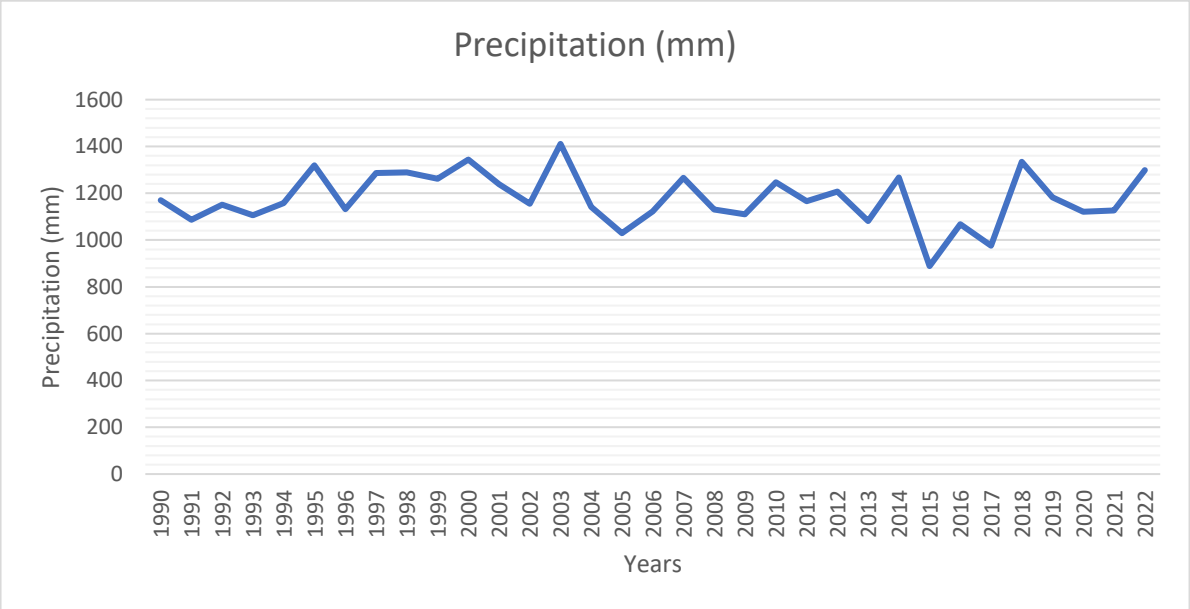

Figure 44: Curve of precipitation fluctuations in the Classified Forest of Badenou, from 1990 to 2022

5.2.3. Periods of Humidity and Drought

The standardised precipitation index (SPI) allowed for the assessment of wet periods (SPI > 0) and dry periods (SPI < 0) during the study period. For the SPI, at the SR Lamto, the study period (1990-2022) shows two trends, namely dry periods and wet periods (**Figure 45**). Thus, the years 1990 (SPI= -1.38), 2007 (SPI= -1.20) and 2015 (SPI= -1) were characterised by moderate drought, while 1997 (SPI= -1.70) experienced severe drought and 1992 (SPI= -2.50), extreme drought. In contrast to these dates, the year 2004 (SPI= 1.16) experienced a moderate humidity episode, the years 2003 (SPI= 1.73) and 2010 (SPI= 1.95) high humidity, and the year 2021 (SPI= 2.01) extreme humidity.

In terms of the standardised precipitation index (SPI) at CF Badenou, the SPI values fluctuate regularly, illustrating climatic cycles where some years are characterised by a water deficit while others record a precipitation surplus (**Figure 46**). This dynamic is observable throughout the studied period, with sequences of several consecutive years in the same trend before a reversal. The years 2005 (SPI = -1.33, moderate drought), 2015 (SPI = -2.59, extreme drought), and 2017 (SPI = -1.80, severe drought) are distinguished by strongly negative indices, indicating periods of marked drought. While 2000 (SPI = 1.48, moderate humidity), 2003 (SPI = 2.08, extreme humidity), 2018 (SPI = 1.40, moderate humidity) and 2022 (SPI = 1.08, moderate humidity) show distinctly positive values, indicating episodes of excessive precipitation. The distribution of extreme values shows an intensification of rainfall variability after the 2000s, with more pronounced alternations between droughts and water surpluses.

Moreover, some transitions appear gradually, while others show abrupt changes, where a very dry year can be immediately followed by an excess year.

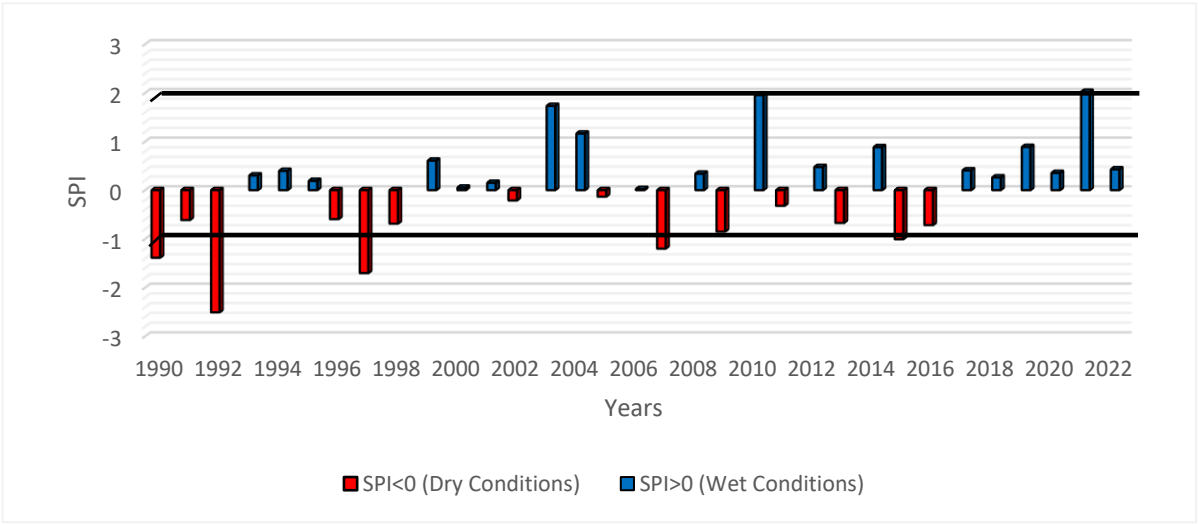

Figure 45: Trend curve of the SPI of the Scientific Reserve of Lamto, from 1990 to 2022

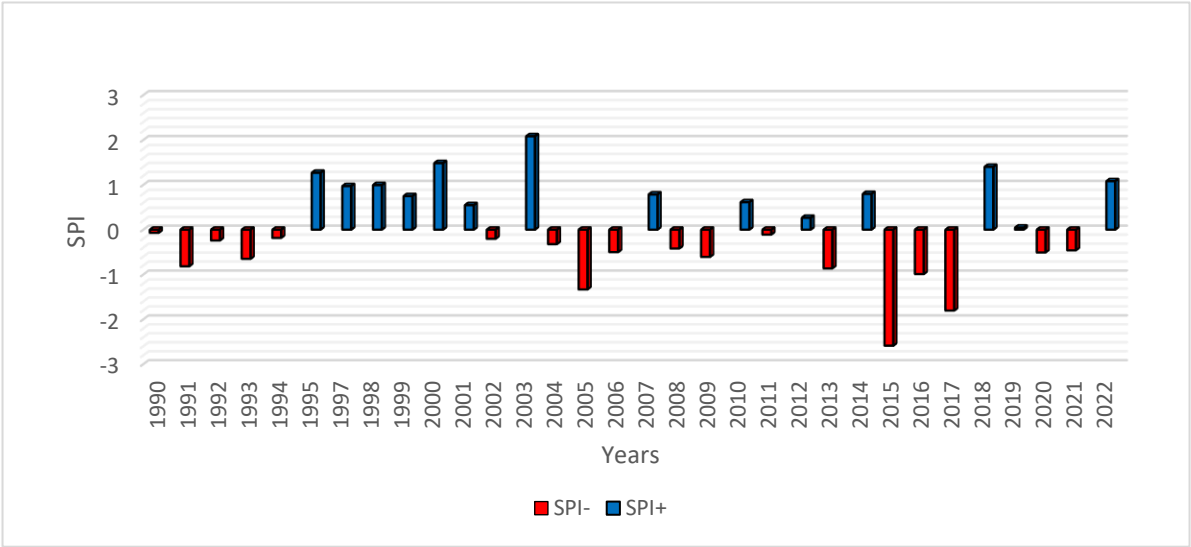

Figure 46: Trend curve of the SPI of the Classified Forest of Badenou, from 1990 to 2022

5.2.3.2. Palmer Drought Severity Index (PDSI)

At the level of the Palmer Drought Severity Index (PDSI), both trends were observed at the SR Lamto (**Figure 47**). However, a dominance of the drought episode is noted during the study period (**Table X**). Nearly 67% of the study period is marked by a drought episode. For these dry years, moderate drought (1990, 1993, 1999, 2000, 2006, 2012) and mild drought (2002, 2007, 2009, 2014, 2015, 2018) were more frequently observed. They each account for 18% of the study years. They are followed by severe drought (1992, 1997, 2013, 2017, 2020) and then extreme drought (1998, 2016, 2021, 2022) with 15% and 12% of the study years, respectively. The years marked by the onset of drought represent only 3% (2019) of the study period. On the contrary, humidity only covers 12% of the study period. The most predominant humidity category is light humidity (1991, 1995, 2010), which occurred over 9% of the study period. In summary, the Lamto reserve was essentially marked by drought during the 32 years of study.

The evolution of the Palmer Drought Severity Index (PDSI) at CF Badenou between 1990 and 2022, highlights significant fluctuations between periods of drought and humidity. Before 2015, the values oscillated around zero, with a relatively balanced alternation between drier and wetter phases (**Figure 48**). However, the PDSI classification table (**Table XI**) highlights a predominance of drought periods, representing 63.63% of the years studied, with a notable distribution between mild droughts (18.18%), moderate droughts (18.18%), severe droughts (15.15%) and extreme droughts (12.12%). Next, the year 2011 is isolated in the category of drought onset, signalling a transition to drier conditions. Starting from 2016, a marked trend towards drought appears, with strongly negative values reaching minima in 2017 (-3.56), 2020 (-3.99) and 2021 (-3.84). This period is characterised by an increased recurrence of dry years, contrasting with the variability observed previously. Thus, the results show a gradual evolution of climatic conditions over more than three decades, with an increase in dry episodes in recent years. The most frequent category is that of conditions close to normal (21.21%), indicating years without major anomalies. In contrast, wet periods are much rarer, with only 9.09% of the years classified as light humidity and 3.03% corresponding to the beginning of a wet period (2019). Indeed, certain years stand out with positive indices, notably 1995 (1.64), 2010 (1.23), and 2014 (1.70), indicating wetter periods.

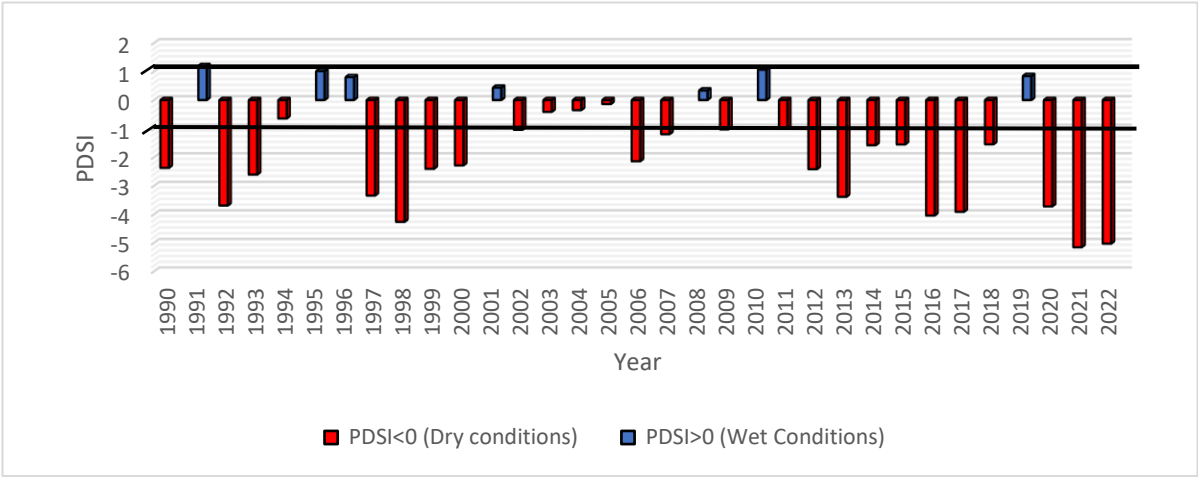

Figure 47: Trend curve of the PDSI of the Scientific Reserve of Lamto from 1990 to 2022

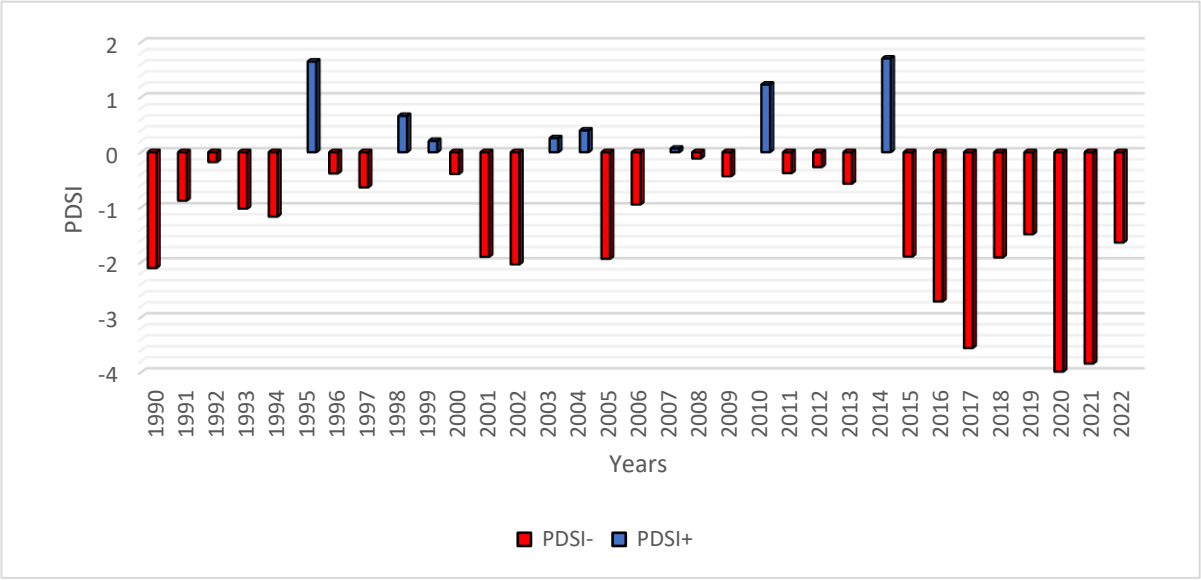

Figure 48: Trend curve of the PDSI of the Classified Forest of Badenou from 1990 to 2022

Table X: Distribution of years of study according to PDSI categories at SR Lamto

PDSI Value	Slight wet	Incipient wet spell	Near normal	Incipient dry spell	Mild drought	Moderate drought	Severe drought	Extreme drought
Years	1991 1995 2010	2019	1994 1996 2001 2003 2004 2005 2008	2011	2002 2007 2009 2014 2015 2018	1990 1993 1999 2000 2006 2012	1992 1997 2013 2017 2020	1998 2016 2021 2022
Number of years	3	1	7	1	6	6	5	4
Proportion	9.09	3.03	21.21	3.03	18.18	18.18	15.15	12.12

Table XI: Distribution of years of study according to PDSI categories at FC Badenou

PDSI Categories	Light Humidity	Beginning of Humid Period	Near Normal	Beginning of Drought	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Light Humidity
Years	1991, 1995, 2010	2019	1994, 1996, 2001, 2003, 2004, 2005, 2008	2011	2002, 2007, 2009, 2014, 2015, 2018	1990, 1993, 1999, 2000, 2006, 2012	1992, 1997, 2013, 2017, 2020	1998, 2016, 2021, 2022	1991, 1995, 2010
Number of Years	3	1	7	1	6	6	5	4	3
Proportion (%)	9.09	3.03	21.21	3.03	18.18	18.18	15.15	12.12	9.09

An alternation between periods of normalcy and phases of drought, which become more pronounced after 2015, while periods of humidity remain exceptional.

5.3 Influence of Climate Variability on the Dynamics of Vegetation at the Study Areas, from 1990 to 2022

The correlation conducted through the Spearman test shows that there are links between the dynamics of certain land uses/cover and climatic variables. Thus, the results from the Spearman correlation test show that climatic variables, particularly precipitation, temperatures, as well as the PDSI (Palmer Drought Severity Index) and SPI (Standardized Precipitation Index) drought indices, significantly influence land use/cover dynamics. The variables that significantly explain the dynamics of the different land uses/cover at SR Lamto are: the severity index the Palmer Drought Severity Index (PDSI), the mean and minimum temperatures (**Figure 49**). However, the mean temperature is the most influential variable.

- **Influences of the Palmer Drought Severity Index (PDSI)**

The PDSI shows a positive and moderate correlation (0.48) with gallery forests and dense semi-deciduous forests. In other words, gallery forests/semi-deciduous dense forests manage to thrive even in the case of intense drought. In contrast to this observation, the PDSI index is negatively correlated with the open forest/wooded savanna class. This implies that drought has a negative impact on the development and even the regression of open forests/wooded savannas (**Table XII**).

- **Influences of the mean temperature**

The mean temperature is one of the climatic variables that has a significant influence on land use dynamics. Thus, the increase in temperature strongly promotes the expansion of tree savannas and those near watercourses, with respective correlation values of 0.816 and 0.699. Unlike these land uses/cover, the mean temperature, with a correlation value of -0.811, very negatively influences the expansion of shrub savannas.

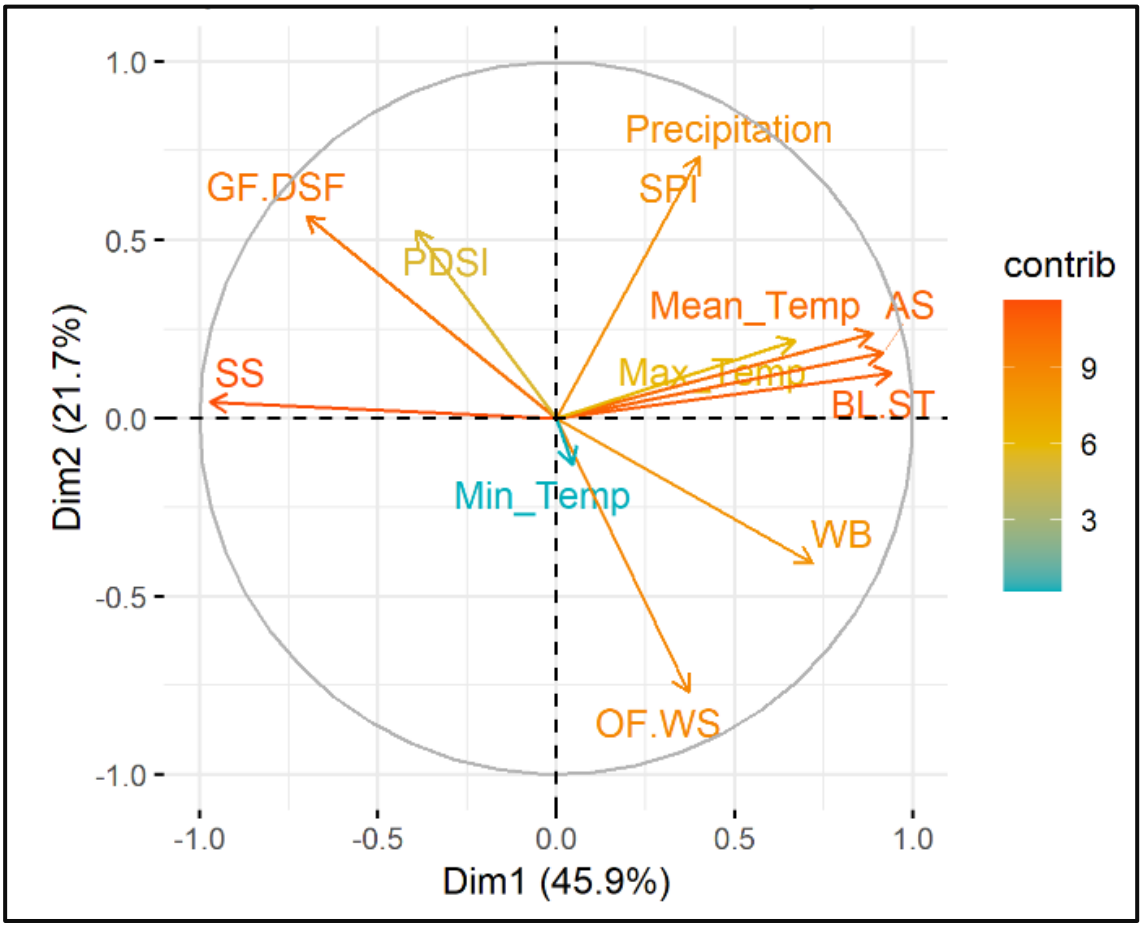

Figure 49: Correlation circle between climatic variables and land uses in the Scientific Reserve of Lamto

Table XII: Summary of Spearman's test correlations between climatic variables and land uses, in the Scientific Reserve of Lamto

Variables		Gallery forest/ Semi deciduous _dense forest	Open forest/ wooded savanna	tree savanna	Shrub savanna	Bare_land/ settlement	Water body
Precipitation	**Correlation value**	-0.018	-0.043	0.343	-0.297	0.297	0.180
	P-Value	*0.923*	*0.813*	*0.051*	*0.093*	*0.093*	*0.314*
	Coefficient of Determination	0.000	0.002	0.118	0.088	0.088	0.033
PDSI Value	**Correlation value**	0.478	-0.470	-0.256	0.278	-0.278	-0.302
	P-Value	*0.005*	*0.006*	*0.150*	*0.117*	*0.117*	*0.087*
	Coefficient of Determination	0.228	0.221	0.065	0.077	0.077	0.091
SPI Value	**Correlation value**	-0.018	-0.043	0.343	-0.297	0.297	0.180
	P-Value	*0.923*	*0.813*	*0.051*	*0.093*	*0.093*	*0.314*
	Coefficient of Determination	0.000	0.002	0.118	0.088	0.088	0.033
Minimum Temperature	**Correlation value**	-0.253	0.241	-0.084	0.106	-0.106	-0.107
	P-Value	*0.155*	*0.177*	*0.641*	*0.556*	*0.556*	*0.551*
	Coefficient of Determination	0.064	0.058	0.007	0.011	0.011	0.012
Mean Temperature	**Correlation value**	-0.314	0.245	0.816	-0.811	0.811	0.699
	P-Value	*0,075*	*0,170*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
	Coefficient of Determination	0.099	0.060	0.665	0.657	0.657	0.489
Maximum Temperature	**Correlation value**	-0.079	0.041	0.591	-0.602	0.602	0.533
	P-Value	*0.662*	*0.822*	*0.000*	*0.000*	*0.000*	*0.002*
	Coefficient of Determination	0.006	0.002	0.349	0.363	0.363	0.284

- **Influences of the minimum temperature**

Just like the mean temperature, the minimum temperature has the same effects on vegetation dynamics, but with a lesser influence. To this effect, the increase in minimum temperature moderately promotes the expansion of tree savannas, bare soils, and watercourses. The correlation values are 0.591, 0.602, and 0.533. On the other hand, the increase of this variable hinders the expansion of shrub savannas. The value of this link is -0.602.

Regarding CF Badenou, the variables that significantly explain the dynamics of different land uses are: mean and maximum temperatures, the Palmer Drought Severity Index (PDSI), and the Standardized Precipitation Index (SPI) (**Figure 50**).

- **Influences of the mean temperature and the maximum temperature**

The analysis of the correlations between temperature and land use/cover highlights significant and non-significant interactions, revealing the influence of thermal variations on the distribution and evolution of different land use/cover classes. Temperatures have a significant impact on several land use/cover categories, particularly the Low Density Shrub Savanna (LDSS) and fallow lands (FL). Indeed, the mean and maximum temperatures are strongly and negatively correlated with Low Density Shrub Savanna (LDSS) (-0.597, $p < 0.0001$; -0.613, $p < 0.0001$), which means that as the temperature increases, Low Density Shrub Savannas (LDSS) tend to decrease. Similarly, Fallow Lands (FL) are negatively correlated with mean temperature (-0.427, $p = 0.014$) and maximum temperature (-0.413, $p = 0.017$), which means that the increase in temperatures leads to a reduction of these changing areas. At the same time, the Perennial Crop (PC) shows a positive correlation with the mean temperature (0.427, $p = 0.014$) and the maximum temperature (0.413, $p = 0.017$), suggesting that these cultivated areas could be favoured in warmer conditions, potentially due to better resistance to high temperatures or adaptation of the cultivated species (**Table XIII**).

- **Influences of the Palmer Drought Severity Index (PDSI)**

The analysis of the correlations between the drought index (PDSI) and land use/cover reveals significant and non-significant interactions, highlighting the impact of drought conditions on the distribution and evolution of different land use/cover classes. In particular, the PDSI drought index is significantly, negatively correlated with several land use/cover categories, highlighting the impact of drought periods on vegetation and water bodies. Indeed, the negative correlation between the Gallery Forest/Dry Dense Forest (GF/DDF) and the PDSI (-0.502, $p = 0.003$) shows that droughts do not affect this forest formation due to its location along watercourses, which ensures a permanent water supply.

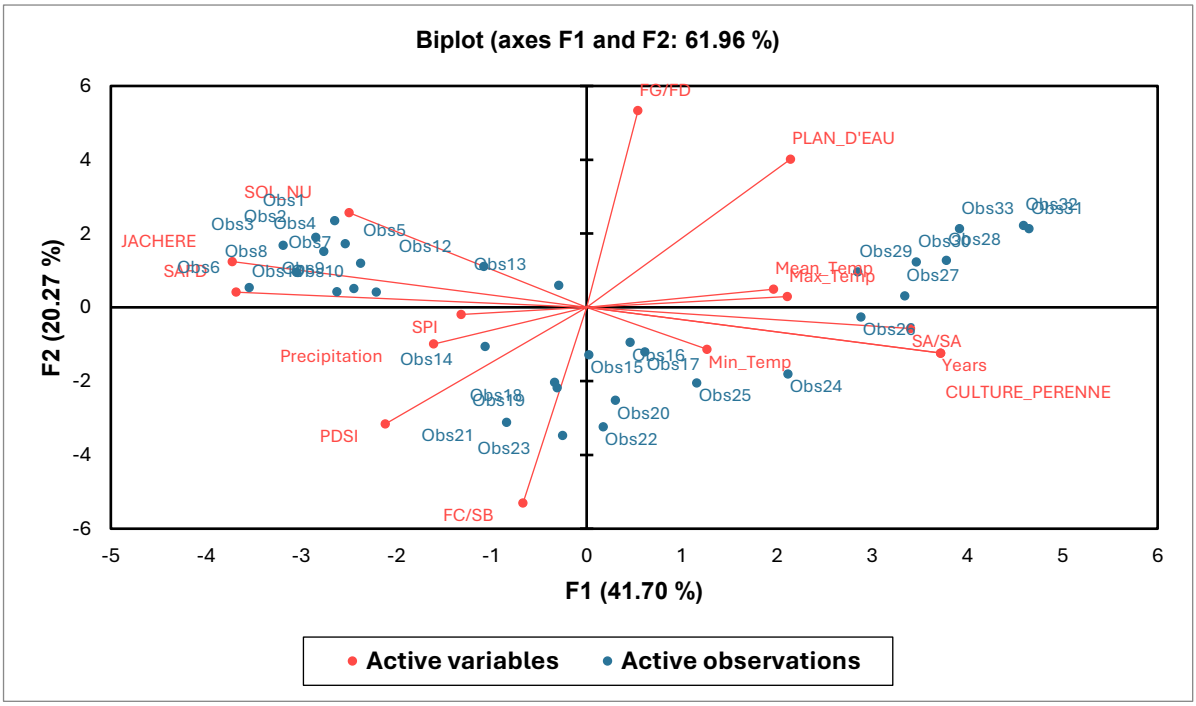

Figure 50: Correlation Circle between Climatic Variables and land uses/cover, in the Classified Forest of Badenou

Table XIII: Spearman's test correlations between climatic variables and land uses/cover in the Classified Forest of Badenou

Variables		Gallery forest/ Dense Dry Forest (GF/DDF)	Open Forest/ Wooded Savannah (OF/WS)	Tree Savanna/Shrub Savanna (TS/SS)	Low Density Shrub Savanna (LDSS)	Perennial Crop (PC)	Fallow Land (FL)	Bare Land/ Settlement (BL/ST)	Water Body (WB)
Precipitation	Correlation value	-0.091	0.113	-0.264	0.245	-0.241	0.241	0.171	-0.224
	P-Value	*0.614*	*0.531*	*0.137*	*0.168*	*0.176*	*0.176*	*0.339*	*0.210*
	Coefficient of Determination	0.008	0.013	0.070	0.060	0.058	0.058	0.029	0.050
PDSI Value	Correlation value	-0.502	0.510	-0.348	0.384	-0.316	0.316	0.109	-0.545
	P-Value	*0.003*	*0.003*	*0.048*	*0.028*	*0.073*	*0.073*	*0.545*	*0.001*
	Coefficient of Determination	0.252	0.260	0.121	0.148	0.100	0.100	0.012	0.297
SPI Value	Correlation value	0.057	-0.002	-0.304	0.126	-0.136	0.136	0.362	-0.076
	P-Value	*0.753*	*0.992*	*0.086*	*0.483*	*0.448*	*0.448*	*0.039*	*0.674*
	Coefficient of Determination	0.003	0.000	0.092	0.016	0.019	0.019	0.131	0.006
Minimum Temperature	Correlation value	-0.130	0.135	0.195	-0.393	0.231	-0.231	-0.167	0.009
	P-Value	*0.468*	*0.452*	*0.276*	*0.025*	*0.196*	*0.196*	*0.352*	*0.959*
	Coefficient of Determination	0.017	0.018	0.038	0.154	0.053	0.053	0.028	0.000

Mean Temperature	Correlation value	0.063	-0.031	0.132	-0.597	0.427	-0.427	0.123	0.266
	P-Value	*0.729*	*0.862*	*0.461*	*0.000*	*0.014*	*0.014*	*0.494*	*0.135*
	Coefficient of Determination	0.004	0.001	0.018	0.356	0.182	0.182	0.015	0.071
Maximum Temperature	Correlation value	0.011	0.018	0.178	-0.613	0.413	-0.413	0.082	0.170
	P-Value	*0.953*	*0.919*	*0.321*	*0.000*	*0.017*	*0.017*	*0.649*	*0.342*
	Coefficient of Determination	0.000	0.000	0.032	0.376	0.171	0.171	0.007	0.029

Moreover, the surface area of Water Bodies (WB) significantly decreases during periods of drought, as shown by the negative and significant correlation between Water Bodies and the PDSI (-0.545, $p = 0.001$). This confirms that periods of drought have a direct impact on the availability of surface water. On the other hand, some positive correlations are observed. Thus, the Low Density Shrub Savanna (LDSS) shows a positive correlation with the PDSI (0.384, $p = 0.028$), suggesting that this vegetation formation tends to increase with the intensification of droughts.

- **Influences of the Standardised Precipitation Index (SPI)**

The SPI index, which measures precipitation anomalies, establishes several significant and non-significant relationships with land use/cover categories, highlighting the influence of precipitation variations on ecosystem dynamics and the distribution of different types of land use/cover. As a result, a positive and significant correlation is observed between the SPI index and precipitation (0.665, $p < 0.0001$), confirming that this index accurately reflects rainfall variability. Another significant relationship concerns Bare Soil/Habitat (BL/ST), which is positively correlated with SPI (0.362, $p = 0.039$), suggesting that wetter conditions could promote an increase in these surfaces, possibly due to stronger erosion or a modification of vegetation regeneration processes. Other correlations, on the other hand, are not significant. In this regard, the Low Density Shrub Savanna (LDSS) shows a weak positive correlation with SPI (0.126, $p = 0.483$), indicating that relative humidity conditions do not have a significant influence on this vegetation formation. Moreover, the relationship between Water Bodies (WB) and SPI (-0.076, $p = 0.674$) is negative but not significant, which means that an increase in humidity does not necessarily result in an expansion of water bodies, probably due to other hydrological factors at play.

CHAPTER 6: PLANT DIVERSITY IN THE HABITATS OF *Afzelia africana* AND *Pterocapus erinaceus* IN THE LAMTO SCIENTIFIC RESERVE AND THE BADENOU CLASSIFIED FOREST

6.1. Qualitative Diversity of *Afzelia africana* and *Pterocarpus erinaceus* Habitats

6.1.1. Specific Richness

The inventory identified a total of 424 species in 81 families belonging to 233 genera on the two sites. The richness per site is estimated at 294 species divided into 179 genera within 66 families for the Lamto reserve, while the Badenou Classified Forest has a floristic richness of 242 species divided into 55 botanical families within 137 genera **(Table XIV).**

The study of the family spectrum of the two sites reveals a notable dominance of Fabaceae, which represent 17% of the recorded species. The Rubiaceae occupy the second position with 8%, followed by the Poaceae and Malvaceae, each contributing 5% to the overall plant diversity **(Figure 51).**

The comparison between the sites highlights distinct variations. At Lamto, the Fabaceae remain predominant with 14%, followed by the Rubiaceae (9%), the Poaceae (8%), the Apocynaceae (5%), the Moraceae (4%) and the Malvaceae (3%). In contrast, at Badenou, the predominance of Fabaceae is more pronounced, reaching 21% of the species. The Malvaceae are better represented there than at Lamto (7%), while the Combretaceae and Rubiaceae each share 5%, followed by the Moraceae at 4% **(Figure 52;Figure 53).**

The species richness varies both according to sites and habitat types. Thus, in the Badenou Classified Forest, the A*fzelia* habitats exhibit a higher species diversity than those under *Pterocarpus*. The wooded savanna (138 species) and the open forest (134 species) are the richest in companion species, while the dry dense forest follows with 118 species. In contrast, the shrub savanna shows the lowest diversity with only 50 species. For *Pterocarpus*, the wooded savanna remains the richest habitat (105 species), followed by the open forest (85 species) and the dry dense forest (68 species). The shrub savanna, with 28 species, is the least diverse habitat. In all types of vegetation, habitats under *Afzelia* host a greater number of species on average than those under *Pterocarpus*. In contrast, in the Lamto Scientific Reserve, species richness is higher, particularly in habitats under *Afzelia*. The dense semi-deciduous forest stands out with particularly high richness, featuring 224 species, followed by the gallery forest with 78 species **(Table XV).**

Table XIV: Floristic richness of Badenou Classified Forest and Lamto Scientific Reserve

Sites	Habitats	Number of Species	Number of genera	Number of botanical families
Badenou Classified Forest	Habitats of *Afzelia*	218	129	52
	Habitats of *Pterocarpus*	131	98	42
	Total Badenou	**242**	**137**	**55**
Lamto Scientific Reserve	Habitats of *Afzelia*	244	148	62
	Habitats of *Pterocarpus*	109	83	35
	Total Lamto	**294**	**179**	**66**
Total inventory		**424**	**233**	**81**

Table XV: Floristic richness of *Afzelia africana* and *Pterocarpus erinaceus* habitats

Sites	Target species	Habitats	Number of plots	Number of Species	Number of genera	Number of botanical families
Badenou Classified Forest	*Afzelia*	Open Forest	8	134	95	41
		Dense Dry Forest	3	118	78	36
		Gallery Forest	2	69	57	28
		Tree Savanna	9	138	91	39
		Shrub Savanna	1	50	41	21
	Pterocarpus	Open Forest	5	85	68	29
		Dense Dry Forest	3	68	57	31
		Gallery Forest	4	59	49	24
		Tree Savanna	9	105	82	36
		Shrub Savanna	2	28	27	15
Lamto Scientific Reserve	*Afzelia*	Dense Semi-deciduous Forest	22	224	139	61
		Gallery Forest	3	78	74	34
	Pterocarpus	Open Forest	2	37	33	20
		Dense Semi-deciduous Forest	1	34	33	21
		Wooded Savanna	17	39	37	21
		Tree Savanna	1	90	72	31
		Shrub Savanna	2	27	24	11

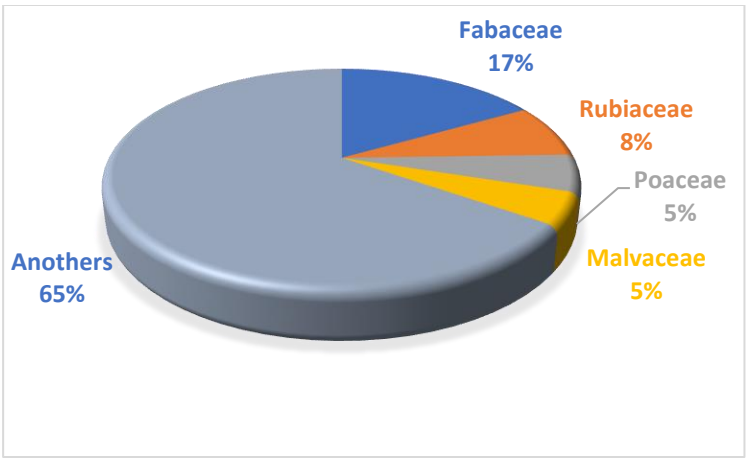

Figure 51: Spectrum of dominant families of all the flora inventoried

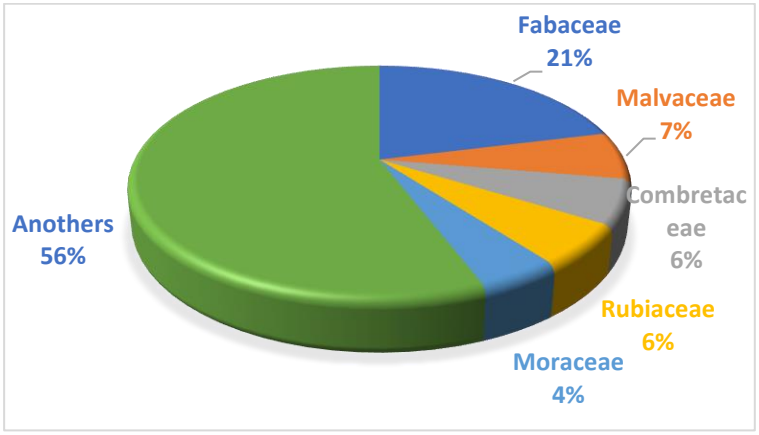

Figure 52: Spectrum of dominant families in the Badenou Classified Forest

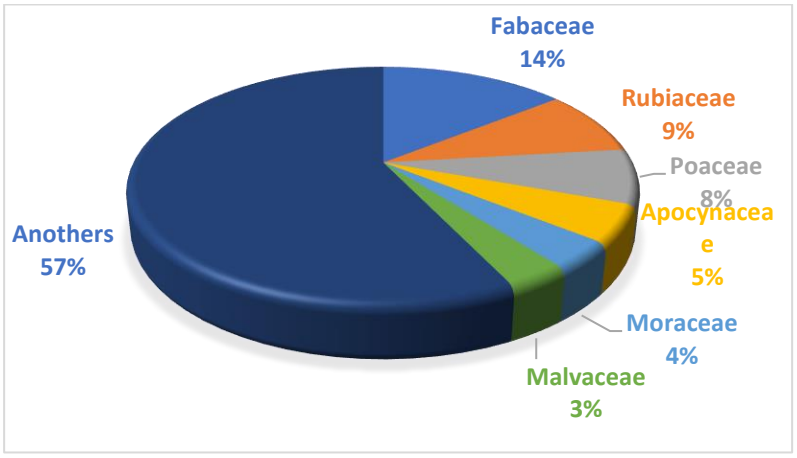

Figure 53: Spectrum of dominant families in the Lamto Scientific Reserve

In comparison, *Pterocarpus* is associated with lower diversity, with a maximum of 90 species in the wooded savanna. Shrub savanna remains the least diverse habitat for this species, with only 27 species recorded. As at Badenou, *Afzelia* is systematically associated with greater species diversity than *Pterocarpus*.

Comparing the two sites, the Lamto Scientific Reserve stands out for having a higher total species richness than the Badenou Classified Forest, particularly in the dense semi-deciduous forest. In general, habitats under *Afzelia* have a higher species richness than those under *Pterocarpus*, regardless of the site studied. In addition, forest formations have a higher biodiversity than savanna formations.

6.1.2. Floristic Composition

6.1.2.1. Biological Types

A total of ten (10) biological or adaptive types were identified in the plant communities studied **(Figure 54; Figure 55; Figure 56).** These are Microphanerophytes (MicroP), Nanophanerophytes (NanoP), Mesophanerophytes (MesoP), Megaphanerophytes (MegaP), Chamephytes (Ch), Geophytes (G), Therophytes (Th), Rhizomatous Geophytes (Gr), Hydrophytic Hemicryptophytes (Hpy), Epiphytes (Ep) and Rheophytes (rh).

The general distribution of the biological types reveals a clear dominance of Microphanerophytes (MicroP), representing around 53% (129 species) of the total numbers in the Badenou Classified Forest and almost 56% (128 species) in the Lamto Scientific Reserve. The two sites are distinguished by their biological types according to the Microphanerophytes (MicroP). At Badenou, the nanophanerophytes (NanoP) predominate the flora, followed by the MesoP with 20% and 17% respectively, whereas at Lamto, the opposite is true. Here, the mesophanerophytes (MesoP) dominate the flora with 29%, followed by NanoP with 21%.

The other biological types remain very much in the minority, each representing less than 5% of the total numbers on the two sites**.** For all the habitats of the two target species, the trends are the same for each site, whatever the target species**.** At Badenou, MicroP dominated, followed by NanoP and then MesoP, for both *Afzelia* and *Pterocarpus* habitats. At Lamto, on the other hand, MicroP is followed by MesoP and then NanoP in *Afzelia* habitats. The trend is the same for woody plants in *Pterocarpus* plots, but with a marked proportion of Hemicriptophytes (H).

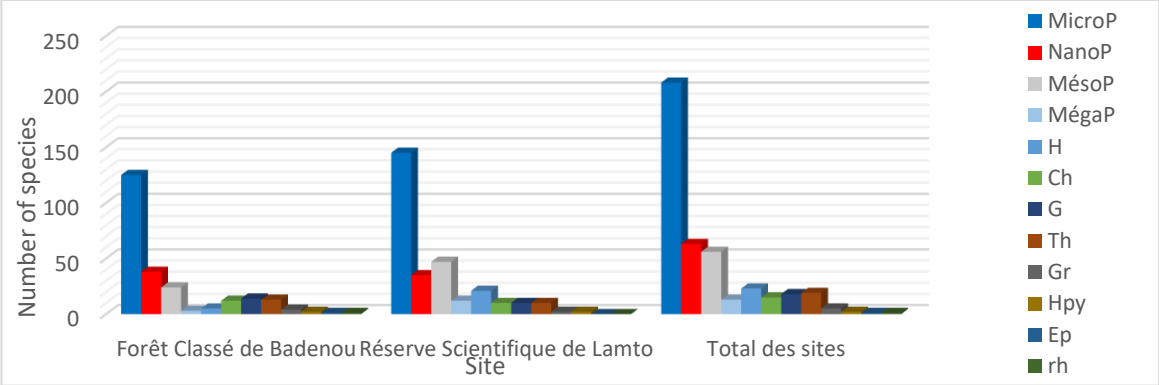

Figure 54: Spectrum of biological types for all the sites surveyed

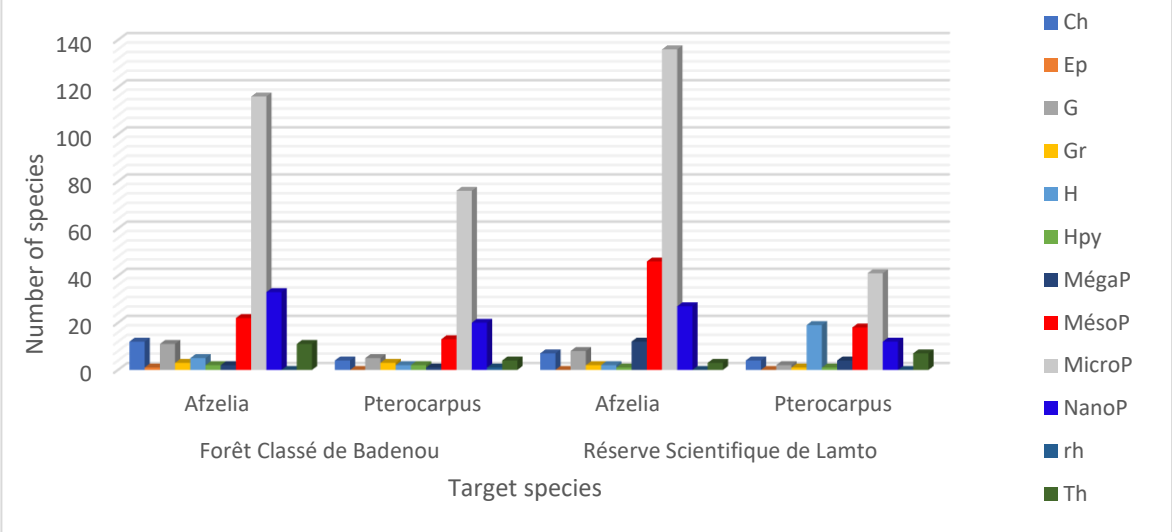

Figure 55: Spectrum of biological types of *Afzelia* and *Pterocarpus* habitats by site

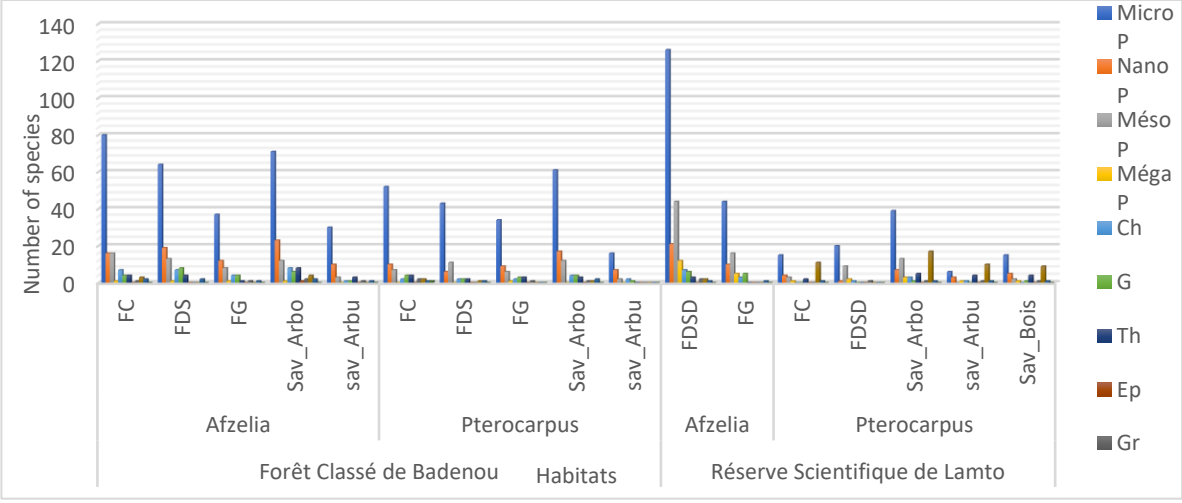

Figure 56: Biology by target species habitat for each site

By habitat, the high representation of Microphanerophytes (MicroP) is clearly confirmed. It peaks in the Semi-deciduous Dense Forest at Lamto with *Afzelia africana* (126 species, around 75% of the habitat). Significant values are also observed at Badenou, in the Open Forest (75 species, 55%) and the Tree Savannah (71 species, around 60%). Other biological types, such as Mesophanerophytes (MesoP), Nanophanerophytes (NanoP), Chamephytes (Ch) or Geophytes (G), generally do not exceed 20% per habitat. Specialised biological categories remain very poorly represented, with proportions of less than 5%.

6.1.2.2. Chorological Types

The analysis of the chorological types associated with *Afzelia africana* and *Pterocarpus erinaceus,* shows clear differences between the two sites studied **(Figure 57; Figure 58; Figure 59).**

In the Badenou Classified Forest, the two species are mainly accompanied by Guinea-Congolese-Sudan-Zambezian transition species (GC-SZ), followed by Sudan-Zambezian species and forest species (CG), across all their habitats. Conversely, in the Lamto Scientific Reserve, the trends differ according to species**.** *Afzelia africana* is mainly associated with Guinea-Congolese (GC) species, particularly in forest formations (Semi-deciduous Dense Forest with 102 species, around 63%, and Gallery Forest with 29 species); conversely, Pterocarpus erinaceus remains mainly associated with GC-SZ species, in both forest and savannah formations, although the GC group is also well represented. The other types (GCW and GCi) remain very poorly represented in all habitats.

6.1.2.3. Phytogeographical Types

A total of thirteen (13) phytogeographical types were identified within the plant formations studied. These are the intertropical African taxon (A), the taxon common to Africa and the Comoros Archipelago (ACo), the Afro-Eurasian taxon (AEAs), the Afro-Malagasy taxon (AM), the taxon common to Africa, Madagascar and the Comoros Archipelago (AMCo), the Afro-Neotropical taxon (AN), the Asian taxon or taxon common to Africa and Asia (As), the colonising taxon of American origin (COAm), the cosmopolitan taxon (Cosm), the Neotropical taxon (N), the Palaeotropical taxon (PaléoT), the Pantropical taxon (PanT), as well as the taxon common to Africa and the Mascarene Islands (Mc), as well as the and the Mascarene Islands (Mc).

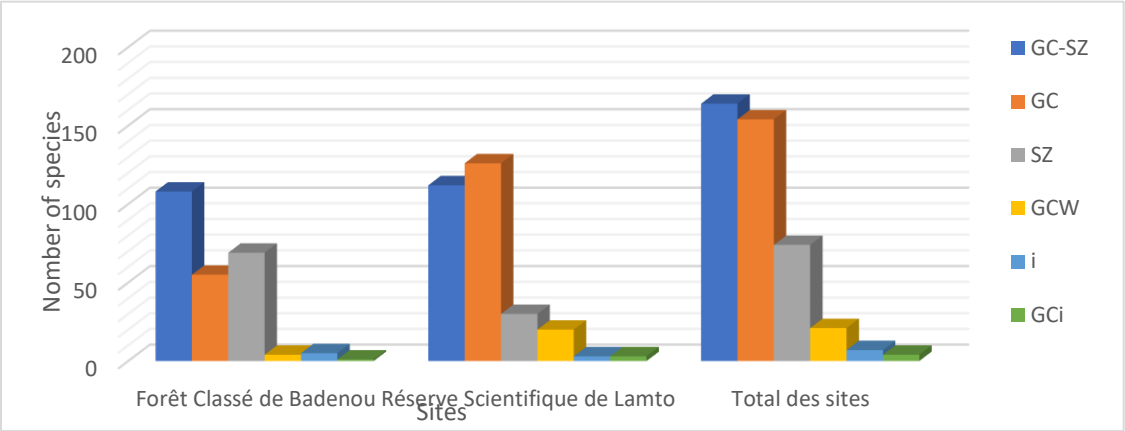

Figure 57: Chorological types by site

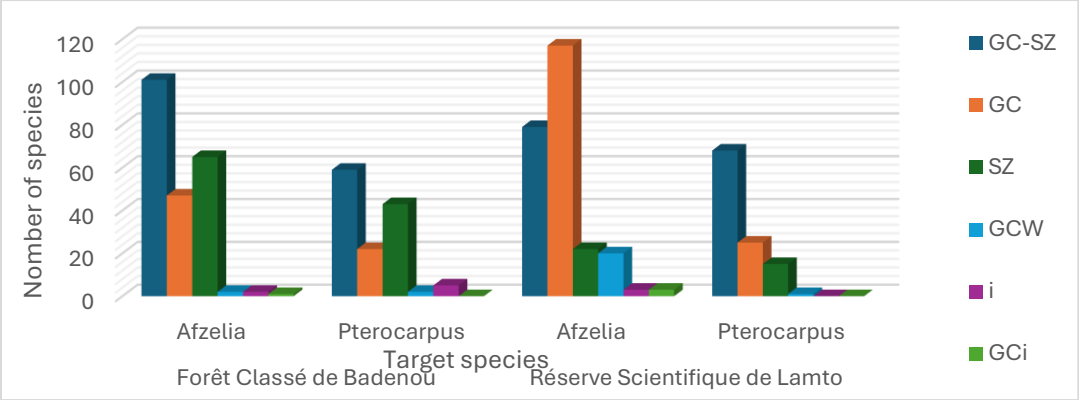

Figure 58: Type Chorology of target species per site

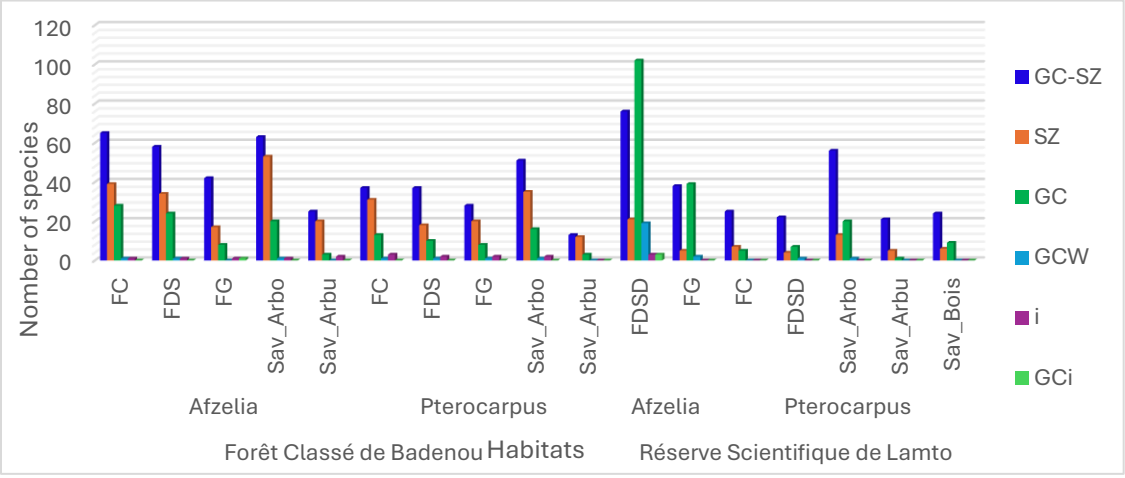

Figure 59: Spectrum of chorological types by target species' habitat for each site

The phytogeographical distribution of species associated with *Afzelia africana* and *Pterocarpus erinaceus* shows an obvious predominance of taxa from Intertropical Africa (A) on the two sites studied **(Figure 60; Figure 61; Figure 62).** In the Badenou Classified Forest, this type alone accounts for 178 species (nearly 60% of the total), followed by pantropical taxa (PanT, 26 species) and palaeotropical taxa (PaléoT, 15 species). The other phytogeographic types (AM, AN, N, ACo, As, COAm, Cosm, Ind and Mc) are poorly represented, with less than 10 species each. The same general trend can be seen in the Lamto Scientific Reserve, where African intertropical taxa are even more dominant (232 species, i.e. around 68% of total numbers), far ahead of pantropical (24 species) and palaeotropical (7 species), with the other categories being very marginal (less than 8 species each)**.**

When each target species is analysed specifically**,** the dominance of the African intertropical type (A) remains clear for *Afzelia africana* at both sites: at Badenou, 160 species (around 81%), and at Lamto, 209 species (around 87%). This predominance is similar, but less marked, for *Pterocarpus erinaceus*, with 101 species at Badenou (around 73%) and 75 species at Lamto (around 69%). The other phytogeographical categories remain very poorly represented for these two species**.**

Finally, an analysis by habitat (Open Forest, Dense Dry Forest, Gallery Forest, Tree Savanna, Shrub Savanna, Semi-deciduous Dense Forest, Wooded Savanna) further confirms the strong dominance of the African intertropical type, with 192 species recorded in Semi-deciduous Dense Forest at Lamto for *Afzelia*. The other phytogeographical groups (pantropical, palaeotropical, cosmopolitan, Afro-Malagasy, etc.) remain marginal, with numbers generally below 10 species per habitat**.**

6.1.2.4. Morphological Types

The morphological analysis of the species associated with *Afzelia africana* and *Pterocarpus erinaceus* reveals the presence of five distinct types: trees (a), shrubs or bushes (b), herbs (h), lianas (l) and sarmentaceous or sarmentous (bl), the distribution of which varies according to the sites, habitats and species studied. Overall, shrub or shrub-like species (type b) largely dominate the two sites studied **(Figure 63; Figure 64; Figure 65).** At the Badenou Classified Forest, there are 129 shrub species, the absolute majority, followed by grasses (41 species), trees (23 species), lianas (5 species) and sarmentous (1 species).

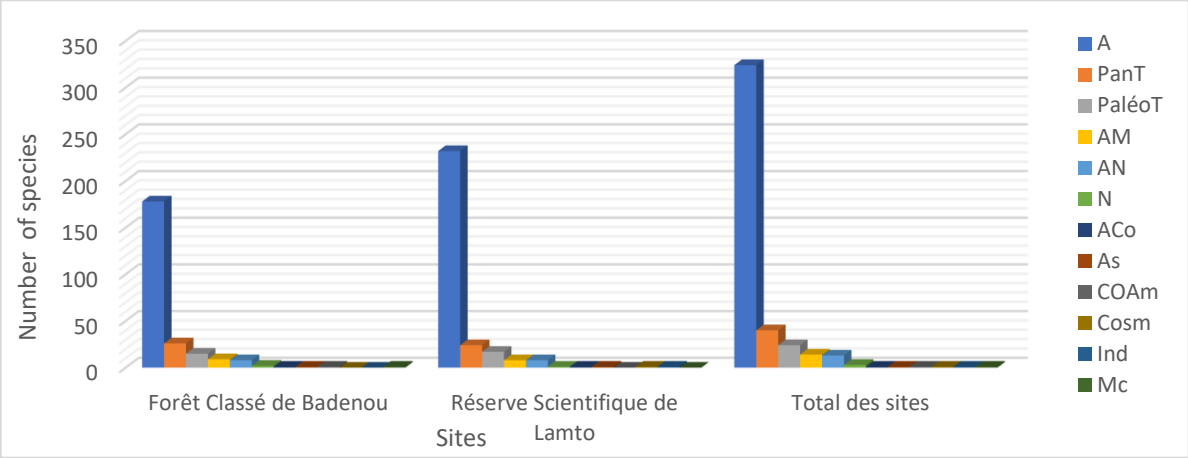

Figure 60: Phytogeographical types by site

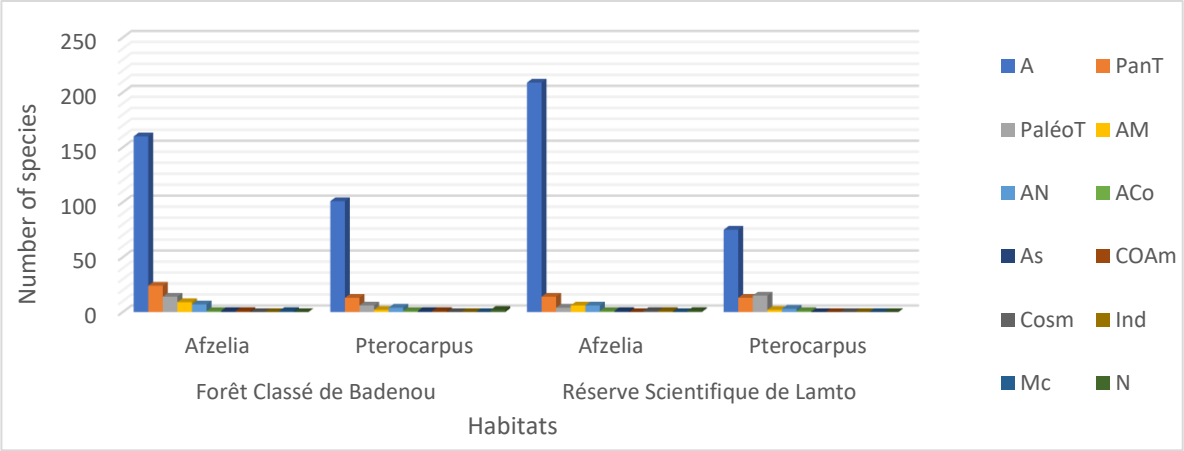

Figure 61: Phytogeographical types of target species by site

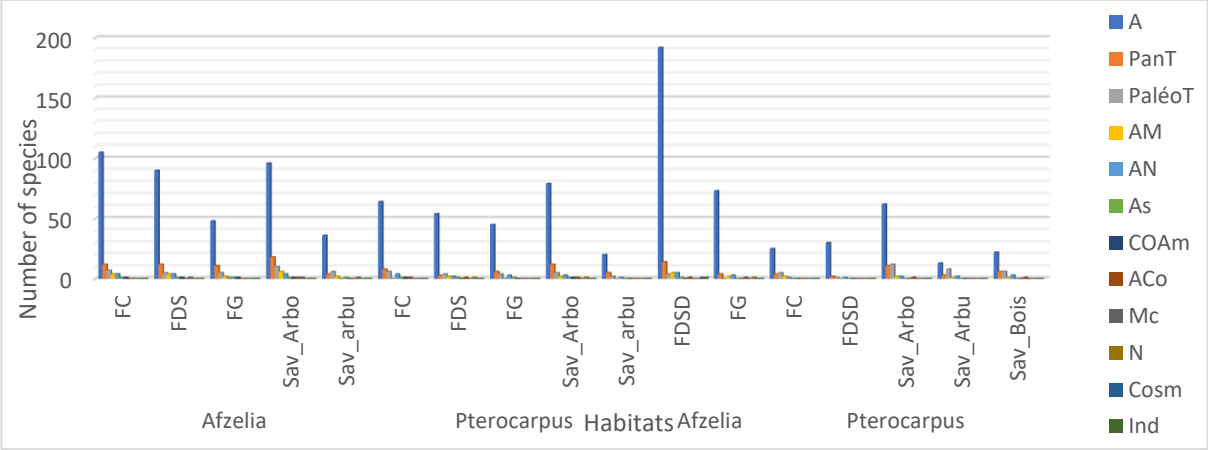

Figure 62: Phytogeographical types by target species' habitat for each site

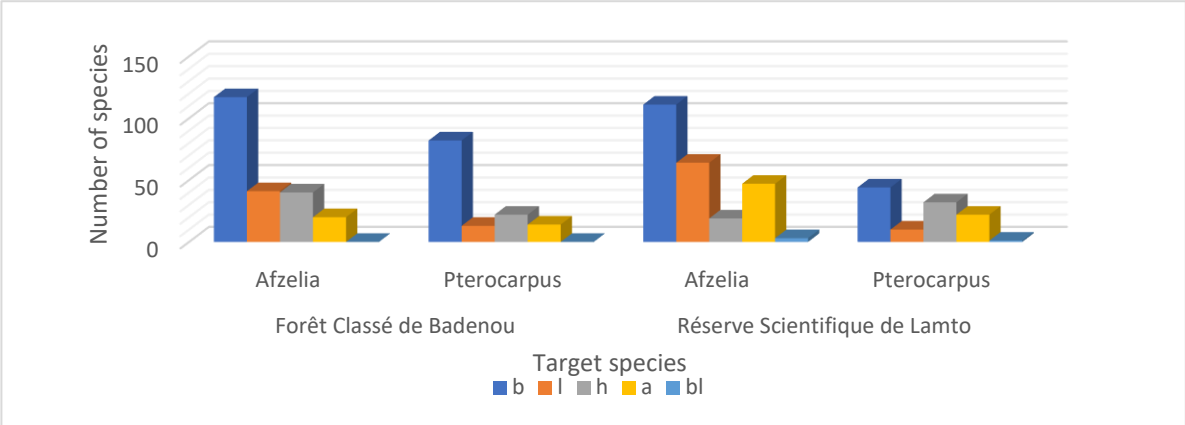

Figure 63: Morphological types by site

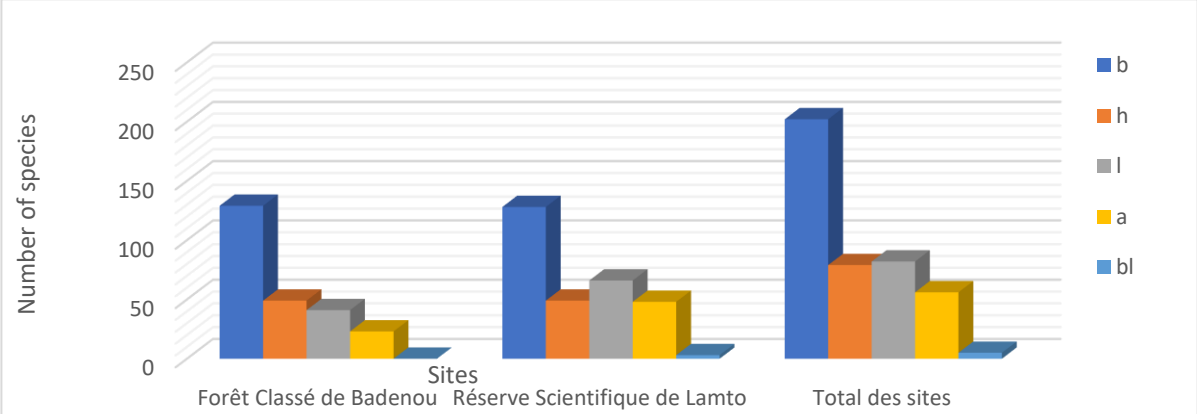

Figure 64: Morphological types of target species by site

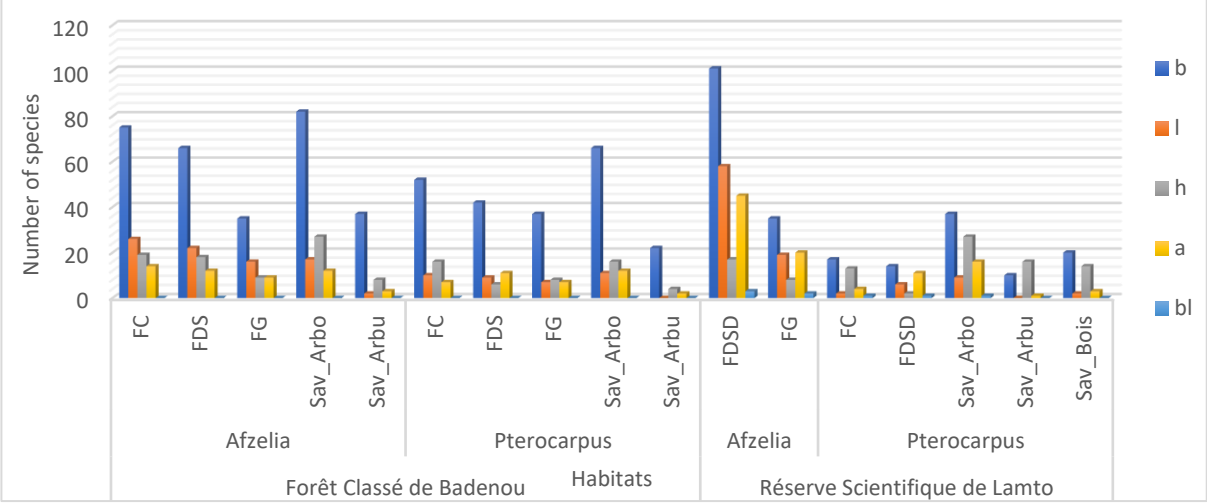

Figure 65: Morphological types by target species' habitat for each site

In the Lamto Scientific Reserve, the same marked predominance of shrubs can be seen, with 128 species recorded, followed by lianas (66 species) and trees (48 species). Grasses are less common (49 species), while sarmentaceous plants (bl) are virtually absent from both sites.

At the level of the species studied, the dominance of the shrub type is still very clear, but varies according to the sites and species concerned. For *Afzelia africana*, shrubs are still in the majority, with 160 species at Badenou (around 81% of total numbers) and 111 species at Lamto (around 55%), accompanied by a significant number of herbs (41 species at Badenou and 64 at Lamto). For *Pterocarpus erinaceus*, shrubs also predominate, but in smaller numbers: 82 species at Badenou (nearly 61%) and 44 at Lamto (around 40%). In both sites, trees, lianas and sarmentaceous plants remain poorly represented around these two species.

When the results are examined by habitat, this dominance of shrubs remains systematic, reaching its maximum in the Semi-deciduous Dense Forest of Lamto with 192 species associated with *Afzelia africana*. In the other habitats (Open Forest, Dense Dry Forest, Gallery Forest, Shrub Savanna, Shrub Savanna, Wooded Savanna), shrubs are still in the majority, with numbers varying between 36 and 105 species depending on the habitat at Badenou and between 22 and 192 species at Lamto. The other morphological types (trees, grasses, lianas, and sarmentose) are much less frequent, rarely exceeding 30 species per habitat.

6.1.3. Species of Special Status

The analysis of habitats shows that environments associated with *Afzelia africana* are home to 65 species of special status or conservation value, compared with 14 for those of *Pterocarpus erinaceus* **(Table XVI)**. Of these species, 4 are endemic to Côte d'Ivoire (GCI), while 20 are endemic to the Guinea-Congolese forest block west of Togo or in West Africa (GCW), illustrating the biogeographical importance of these habitats for regional conservation. The distribution of species of conservation value differs between the two sites **(Table XVII).** Lamto is home to 60 remarkable species, i.e. 75% of the species identified as priorities for conservation and 12.59% of its local floristic wealth, compared with 30 species for Badenou, i.e. 40.86% of the remarkable species and 8.26% of the site's total flora. At Lamto, *Afzelia africana* habitats contain 53 species of conservation value, with a high proportion of Guinean-Congolese endemic species (GCI = 3, GCW = 20).

Table XVI: Species of conservation value, on all sites surveyed

	Habitats	Endemism			UICN, 2024		Threatened species according to Aké-Assi, 1998		Total
		GCI	GCW	HG	EnD	VU	PDRE	PRE	
Total	Habitat of *Afzelia*	4	20	20	2	7	1	11	65
	Habitat of *Pterocarpus*	0	3	3	1	3	0	4	14
	Total per category	4	23	23	3	10	1	15	79

Table XVII: Species of conservation value at each site and preferred *Afzelia africana* and *Pterocarpus erinaceus* habitats by site

Site	Habitats	Endemism			UICN, 2024		Threatened species according to Aké-Assi, 1998		Total
		GCI	GCW	HG	EnD	VU	PDRE	PRE	
Badénou	Habitat of *Afzelia*	1	2	2	2	4	1	6	18
	Habitat of *Pterocarpus*	0	2	2	1	3	0	3	11
	Total Badenou	1	4	4	3	7	1	10	30
Lamto	Habitat of *Afzelia*	3	20	19	0	4	0	7	53
	Habitat of *Pterocarpus*	0	1	2	1	2	0	1	7
	Total Lamto	3	21	21	1	6	0	8	60

GCI: species endemic to Côte d'Ivoire; GCW: species endemic to the forest block west of Togo; HG: species from Upper Guinea; EnD: Endangered species; VU: Vulnerable; PDRE: Plant Endemic to Restricted Distribution in West Africa; PRE: Plant Endemic to Extensive Distribution.

This site is also notable for the presence of 4 vulnerable species (VU) according to the IUCN (2024) and 7 rare and endangered plant species (PRE) according to Aké-Assi (1998). In contrast, the habitats of *Pterocarpus erinaceus* contain only 6 species of special status, including one endemic to Côte d'Ivoire (GCI = 1) and two vulnerable species according to the IUCN.

At Badenou, the distribution is more balanced between the habitats of the two target species. The *Afzelia africana* habitats contain 18 species of conservation value, including 1 endemic to Côte d'Ivoire (GCI), 2 vulnerable according to the IUCN and 6 Rare and Endangered Plants (REP). Pterocarpus erinaceus habitats are more diverse here than at Lamto, with 10 remarkable species, including 2 endemic to the West African forest block (GCW), 3 vulnerable according to the IUCN and 3 Rare and Endangered Plants (PRE).

6.2. Quantitative Diversity of species

6.2.1. Diversity Indices

6.2.1.1. Intra-habitat Diversity

Specific diversity, assessed by the Shannon index, is high overall at both sites, with values varying between 2.50 and 4.15. In addition, Piélou's equitability ranged from 0.68 to 0.88, indicating a variable distribution of individuals between species. Simpson's index, at between 0.85 and 0.97, reveals a low dominance species. Finally, the Hill indices confirm these trends, with higher values in the richest habitats **(Table XVIII).**

At Badenou, the habitats of *Afzelia africana* show a higher diversity than those under *Pterocarpus erinaceus*. The Shannon index varies from 3.11 in the shrub savanna to 4.12 in the tree savanna. Similarly, equitability is relatively homogeneous between 0.78 and 0.84, reflecting a good distribution of individuals between species. Simpson's index fluctuates between 0.89 and 0.97, indicating low dominance. As for the Hill indices, in particular Hill 1 (22.38 to 61.60) and Hill 2 (9.27 to 36.43), they show high diversity, particularly in wooded savannah and open forest.

In the case of *Pterocarpus erinaceus*, species diversity remains high but lower than that observed for *Afzelia*. The Shannon index varies from 2.56 in shrub savannah to 3.65 in dense dry forest. Equitability is slightly more variable, ranging from 0.70 to 0.87. In addition, Simpson's index remains high (0.85 to 0.96), reflecting low specific dominance. The Hill indices (Hill 1 between 12.89 and 38.48; Hill 2 between 6.50 and 23.87) confirm a more moderate diversity than that of the habitats under *Afzelia*.

Table XVIII: Diversity indices for different plant communities

Sites	Target species	Categories	Habitats or biotopes	Number of plots	Species richness	Shannon index	Piélou Evenness index	Simpson index	Hill 1 index	Hill 2 index
Badenou Classified Forest	*Afzelia*	Forest	Open Forest	8	134	3.99	0.81	0.97	53.80	32.10
		Forêt	Dense Dry Forest	3	118	3.89	0.82	0.94	48.89	17.63
		Forest	Gallery Forest	2	69	3.29	0.78	0.89	26.88	9.27
		Savanna	Tree Savanna	9	138	4.12	0.84	0.97	61.60	36.43
		Savanna	Shrub Savannah	1	50	3.11	0.79	0.91	22.38	11.76
	Pterocarpus	Forest	Open Forest	5	85	3.52	0.79	0.95	33.72	18.43
		Forest	Dense Dry Forest	3	68	3.65	0.87	0.96	38.48	23.87
		Forest	Gallery Forest	4	59	2.85	0.70	0.85	17.37	6.50
		Savanna	Tree Savanna	9	105	3.62	0.78	0.94	37.52	17.54
		Savanna	Shrub Savanna	2	28	2.56	0.77	0.88	12.89	8.29
Lamto Scientific Reserve	*Afzelia*	Forêt	Dense Semi-deciduous Forest	22	224	4.15	0.77	0.97	63.45	31.87
		Forest	Gallery Forest	3	78	3.67	0.83	0.95	39.32	20.28
	Pterocarpus	Forest	Open Forest	2	37	2.82	0.78	0.91	16.79	11.20
		Forest	Dense Semi-	1	34	3.04	0.86	0.94	21.00	15.53

		deciduous Forest							
	Savanna	Wooded Savanna	17	39	2.50	0.68	0.85	12.18	6.59
	Savanna	Tree Savanna	1	90	3.13	0.70	0.91	22.99	11.17
	Savanna	Shrub Savanna	2	27	2.90	0.88	0.91	18.11	11.64

In the Lamto reserve, the *Afzelia africana* community exhibits the highest species diversity in the semi-deciduous dense forest, with a Shannon index of 4.15, a Simpson index of 0.97, and Hill indices (Hill 1 = 63.45; Hill 2 = 31.87), indicating high floristic richness. The gallery forest also shows high diversity, with a Shannon index of 3.67 and an evenness of 0.83.

In comparison, habitats dominated by Pterocarpus erinaceus exhibit lower diversity, with Shannon indices ranging from 2.50 to 3.13 in wooded savannas. Equitability is more variable (between 0.68 and 0.88). However, the Simpson index remains high (from 0.85 to 0.94), indicating low specific dominance. The Hill indices are also lower (Hill 1 between 12.18 and 22.99; Hill 2 between 6.59 and 15.53), indicating moderate specific richness.

Among all the studied biotopes, the semi-deciduous dense forest of Lamto shows the greatest diversity (Shannon index 4.15; Hill 1 = 63.45), closely followed by the wooded savanna of Badenou (Shannon index 4.12; Hill 1 = 61.60). The wooded savanna of Badenou shows similar values (Shannon index 4.12; Hill 1 = 61.60). The open forest and the dry dense forest of Badenou display intermediate diversity, with respective Shannon indices of 3.99 and 3.89. In contrast, the gallery forest (3.29) and the shrub savanna (3.11) exhibit lower diversity.

Regarding *Pterocarpus erinaceus*, the most favourable habitats are found in the dry dense forest of Badenou (Shannon index 3.65; Hill 1 = 38.48) and the wooded savanna of the same site (Shannon index 3.62; Hill 1 = 37.52). The open forest exhibits moderate diversity (Shannon index 3.52). In Lamto, the wooded savanna is the least diverse habitat for *Pterocarpus erinaceus* (Shannon index 2.50; Hill 1 = 12.18), thus confirming this species' preference for denser and semi-open environments.

In comparison, *Afzelia africana* is consistently associated with greater species diversity than *Pterocarpus erinaceus* in all the studied habitats. Generally, forest environments exhibit greater floral richness, although the wooded savanna of Badenou stands out with diversity comparable to that of certain forest formations. The semi-deciduous dense forest of Lamto remains the richest habitat for *Afzelia africana*, while the dry dense forest and wooded savanna of Badenou appear as the preferred biotopes for *Pterocarpus erinaceus*.

6.2.1.2 Floristic Similarity between the Different Habitats

- **Floristic Similarity according to Morisita-Horn**

The Morisita-Horn similarity index reveals varying levels of resemblance between the studied habitats **(Table XIX).** The *Afzelia* communities of Badenou and Lamto exhibit a very high floristic similarity (Cλ = 0.88), indicating that they share a large majority of species with comparable abundances. The comparison between *Afzelia* of Badenou and *Pterocarpus* of

Badenou shows a moderate similarity (Cλ = 0.54), reflecting a significant share of common species, but also notable differences in their floristic composition. Between *Afzelia* of Badenou and *Pterocarpus* of Lamto, the similarity is low (Cλ = 0.23), highlighting a low proportion of shared species. Moreover, *Pterocarpu*s from Badenou and *Afzelia* from Lamto display an intermediate similarity (Cλ = 0.68), showing significant floristic overlap despite some differences. The communities of *Pterocarpus* in Badenou and Lamto are relatively close (Cλ = 0.77), despite their different geographical locations. Finally, *Afzelia* and *Pterocarpus* at Lamto show low similarity (Cλ = 0.43), with less than half of the species in common.

- **Venn Diagram**

The analysis of the floristic similarity between the Lamto Scientific Reserve and the Badenou Classified Forest highlights both similarities and divergences in the composition of plant communities. In Lamto183 species are exclusive, 130 to Badenou, while 112 species are common to both sites. This distribution reflects a certain ecological continuity between the two protected areas, while revealing marked floristic differences, probably linked to the environmental characteristics specific to each site.

In Badenou, the comparison of habitats associated with the two target species, *Afzelia africana* and *Pterocarpus erinaceus*, reveals contrasting ecological dynamics. *Afzelia africana* is associated with a great diversity of companion species spread across several types of habitats. In gallery forests 22 species are strictly confined, 28 to dry open forests, and 23 to wooded savannas. A notable ecological overlap is observed between the wooded savanna and the forested savanna, with 22 common species, suggesting a wide ecological amplitude in the open and semi-open environments of the forest-savanna transition. On the other hand, *Pterocarpus erinaceus* exhibits a more restricted ecological affinity. Among its associated species, 17 are exclusively found in wooded savanna, while only 5 species are confined either to gallery forest or to dry open forest.

Table XIX: Morisita-Horn species similarity matrix

Habitats	*Afzelia*_Badenou	*Afzelia*_Lamto	*Pterocarpus*_Badenou	*Pterocarpus*_Lamto
*Afzelia*_Badenou	1			
*Afzelia*_Lamto	0.88	1		
*Pterocarpus*_Badenou	0.54	0.68	1	
*Pterocarpus*_Lamto	0.23	0.43	0.77	1

Although there is an overlap between the wooded savanna and the forested savanna (15 common species), it is less pronounced than in *Afzelia africana*, indicating a stronger specialisation for open environments.

In Lamto, the floristic analysis also shows differentiated structures according to the species. *Afzelia africana* exhibits a high species diversity distributed between the semi-deciduous dense forest and the gallery forest. To both habitats 64 species are common while 160 species (65.57%) are exclusive to the semi-deciduous dense forest and only 20 species (8.19%) to the gallery forest. This distribution indicates a stronger ecological affinity for the semi-deciduous dense forest.

As for *Pterocarpus erinaceus*, its species diversity in Lamto extends over five types of habitats: semi-deciduous dense forest, open forest, wooded savanna, tree savanna, and shrub savanna. The wooded savanna exhibits the highest specificity with 32 exclusive species. The wooded savanna also has 8 specific species, while the semi-deciduous dense forest hosts only 3. Floral overlaps exist, particularly between the wooded savanna and the semi-deciduous dense forest (13 common species), as well as between the wooded savanna and the wooded savanna (9 common species). These results highlight the predominance of savanna habitats in the distribution of *Pterocarpus erinaceus* at Lamto **(Figure 66; Figure 67; Figure 68; Figure 69; Figure 70).**

6.3. Structural Diversity

6.3.1. Stem Density

The mean tree density varies between 28 trees/ha in the *Pterocarpus erinaceus* shrub savanna at Lamto (Ptero-Lt_Sav_Arbu) and 348 trees/ha in the *Afzelia africana* shrub savanna at Badenou (Afz-Bd_Sav_Arbu). In general, *Afzelia africana* habitats show higher densities than those of *Pterocarpus erinaceus*, particularly in forest formations.

The dense dry forest and the gallery forest have the highest densities among the natural formations. At Badenou, the dense dry forest (Afz-Bd_FDS) and gallery forest (Afz-Bd_FG) show densities of 206 and 146 trees/ha, respectively, while at Lamto, these same formations show lower densities (76.82 and 66.33 trees/ha, respectively).

Conversely, the shrub and tree savannas had lower densities, particularly those associated with Pterocarpus erinaceus. At Badenou, the tree savanna and the shrub savanna with *Pterocarpus erinaceus* have 84.44 and 75 trees/ha, respectively, whereas at Lamto, these values drop to 46.06 and 28 trees/ha **(Table XX).**

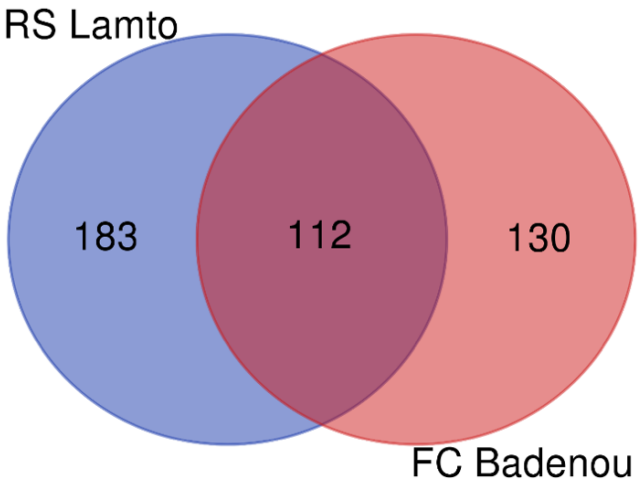

Figure 66: Venn diagram showing the number of species shared between the different sites

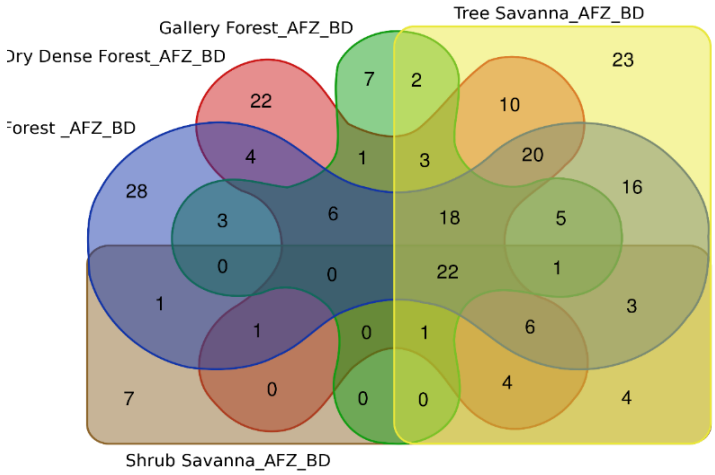

Figure 67: Venn diagram showing the number of species shared between the different preferred habitats of *Afzelia africana* in the Badenou Forest.

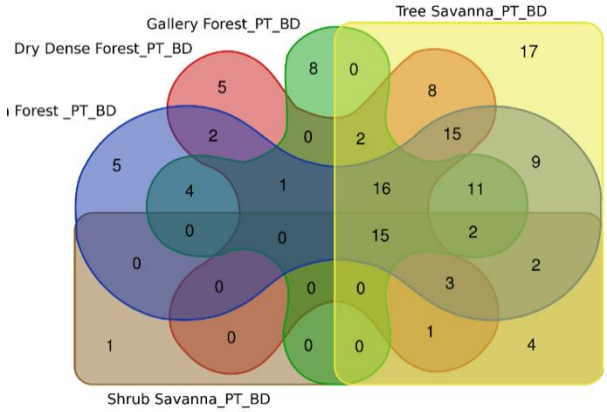

Figure 68: Venn diagram showing the number of species shared between the different preferred habitats of *Pterocarpus erinaceus* in the Badenou Forest.

Figure 69: Venn diagram showing the number of species shared between the different preferred habitats of *Afzelia africana* in the Lamto Scientific Reserve.

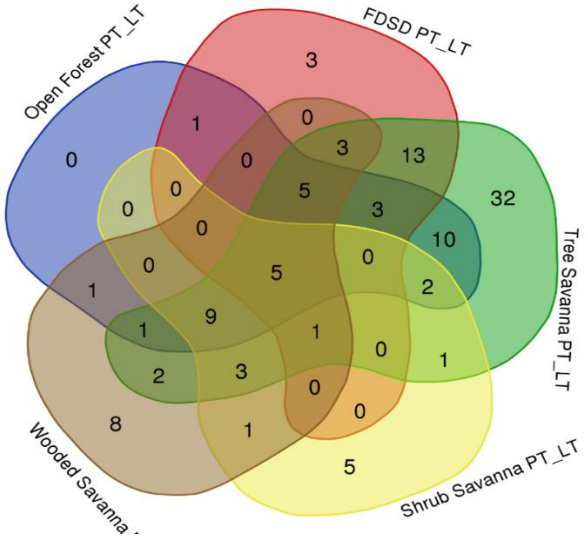

Figure 70: Venn diagram showing the number of species shared between the different preferred habitats of *Pterocarpus erinaceus* in the Lamto Scientific Reserve.

Table XX: Density and basal area of different plant communities

Site	Target species	Habitats	Mean Basal Area (m^2/ha)	Mean Density (stem/ha)
Badenou	*Afzelia*	Open Forest	6.25	215.75
		Dense Dry Forest	8.98	206.00
		Gallery Forest	9.68	146.00
		Tree Savanna	4.68	150.56
		Shrub Savanna	4.70	348.00
	Pterocarpus	Open Forest	4.34	173.40
		Dense Dry Forest	3.08	67.67
		Gallery Forest	8.17	162.50
		Tree Savanna	2.52	84.44
		Shrub Savanna	1.47	75.00
Lamto	*Afzelia*	Dense Semi-deciduous Forest	3.67	76.82
		Gallery Forest	5.15	66.33
	Pterocarpus	Open Forest	2.40	64.50
		Dense Semi-deciduous Forest	2.04	117.00
		Tree Savanna	1.62	46.06
		Shrub Savanna	0.41	28.00
		Wooded Savanna	2.00	86.50

6.3.3 Horizontal Structure of Plant Formations

The distribution of diameter classes shows a high representation of small classes, **(Figure 71)**. Thus, at Badenou, the *Afzelia africana* and *Pterocarpus erinaceus* habitats have an 'inverted J' structure. At Lamto, the observation is the same for the *Afzelia africana* habitats, but the diametral structure of the *Pterocarpus erinaceus* habitats has a 'bell-shaped' structure.

6.4. Interactions between *Afzelia africana* and *Pterocarpus erinaceus* and their Companion Species

6.4.1. Habitats of *Afzelia africana* and *Pterocarpus erinaceus*

The analysis of the spatial distribution of the target species highlighted marked differences between the Lamto and Badenou sites.

In Lamto, *Afzelia africana* is mainly found in semi-deciduous dense forests (FDSD) and gallery forests (FG). In contrast, *Pterocarpus erinaceus* is predominantly found in wooded savannas and open forests, more open environments exposed to drier conditions.

In Badenou, the dynamics are different. *Afzelia africana* and *Pterocarpus erinaceus* coexist more in several habitats, particularly in gallery forests and open forests **(Figure 72).**

6.4.2. Identification of the Species Most Associated with *Afzelia* and *Pterocarpus*

The analysis of co-occurrences of species associated with Lamto and Badenou in a global manner allowed for the identification of the species most frequently associated with *Afzelia africana* and *Pterocarpus erinaceus* at each site**.** Regarding *Afzelia africana*, the species most commonly found in its habitats differs depending on the study site. Thus, in Lamto, *Afzelia* is more correlated in order of predominance with the presence of *Mimusops kummel*, with a correlation of +0.88, *Cola cordifolia* (Cav.) R.Br. (0.68), and *Erythrophleum suaveolens* (Guill. & Perr.) Brenan (0.68). In Badenou, it is rather *Vitellaria paradoxa* C. F. Gaertn. (0.74) and *Diospyros mespiliformis* Hochst. ex A. DC. (0.65) that are most commonly found in *Afzelia* habitats. Concerning *Pterocarpus erinaceus*, it is found in environments with a strong presence of *Crossopteryx febrifuga* (G. Don) Benth. (+1.00), *Bridelia ferruginea* Benth. (+0.96), and *Cussonia arborea* Hochst. Ex A. Rich. (+0.74), in Lamto **(Table XXI)**

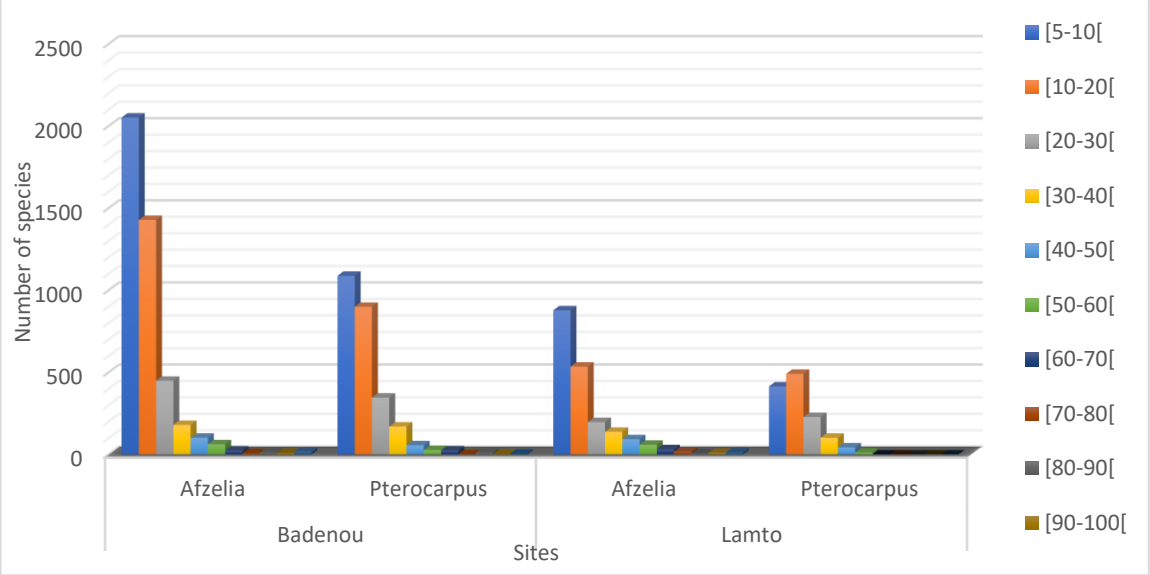

Figure 71: Histograms of diameter classes of different biotopes

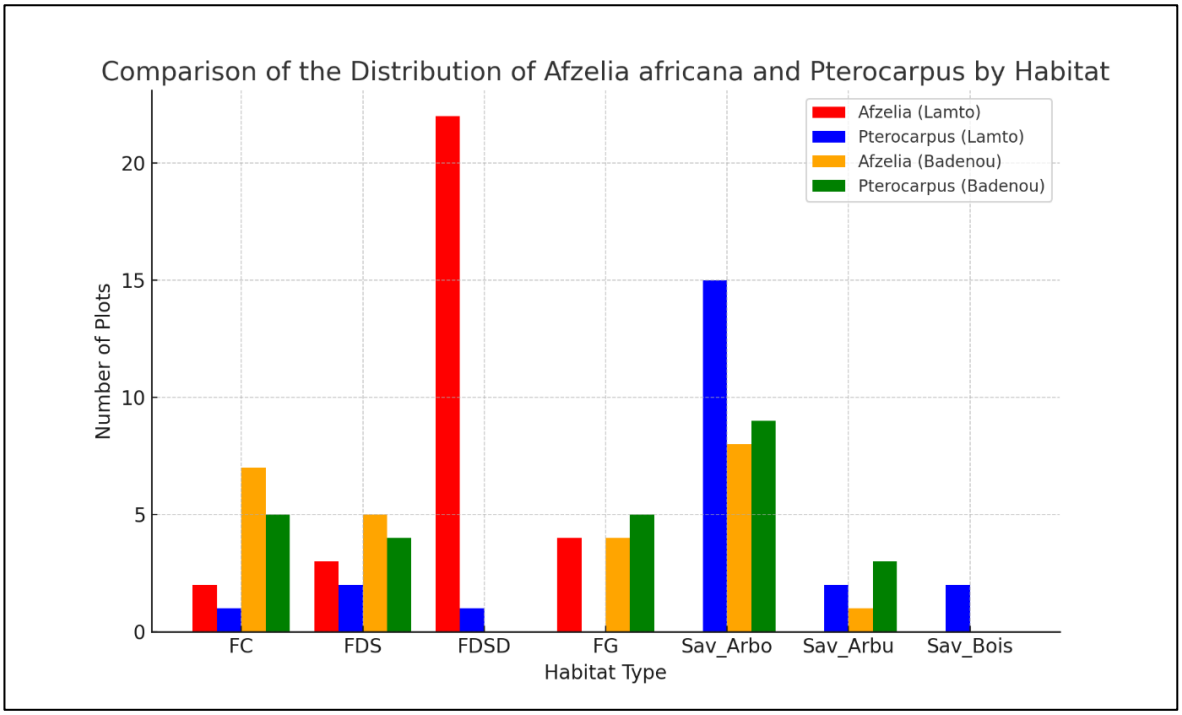

Figure 72: Histogram of the distribution of *Afzelia* and *Pterocarpus* by habitat

Table XXI: Occurrence of companion species near *Afzelia africana* and *Pterocarpus erinaceus*

Species	Mean occurrence with *Afzelia* (Lamto)	Mean occurrence with *Afzelia* (Badenou)	Mean occurrence with *Pterocarpus* (Lamto)	Mean occurrence with *Pterocarpus* (Badenou)
Afzelia africana Sm.	1.00	0.96	0.00	0.22
Mimusops kummel A. DC.	**0.88**	0.52	0.04	0.30
Cola cordifolia (Cav.) R.Br.	**0.68**	0.39	0.04	0.22
Erythrophleum suaveolens ÃŠ(Guill. & Perr.) Brenan	**0.68**	0.22	0.04	0.00
Diospyros mespiliformis Hochst. ex A. DC.	0.60	**0.65**	0.09	**0.52**
Pouteria alnifolia (Bak.) Roberty	0.60	0.22	0.13	0.17
Olax subscorpioidea Oliv.	0.56	0.00	0.17	0.04
Cola gigantea A. Chev. var. glabrescens Brenan & Keay	0.52	0.00	0.13	0.17
Lannea barteri (Oliv.) Engl.	0.44	0.48	0.35	0.30
Lecaniodiscus cupanioides Planch.	0.44	0.00	0.09	0.04
Ficus sur Forsk.	0.32	0.43	0.65	0.30
Terminalia schimperiana ÃŠHochst. ex Engl. & Diels	0.28	0.43	0.43	0.30
Bridelia ferruginea Benth.	0.24	0.22	**0.96**	0.04
Terminalia macroptera Guill. & Perr.	0.24	0.22	0.52	0.09
Ceiba pentandra (Linn.) Gaerth.	0.24	0.04	0.00	0.00
Vitex doniana Sweet	0.24	0.00	0.26	0.04
Crossopteryx febrifuga (G. Don) Benth.	0.20	0.22	**1.00**	0.09
Cola caricifolia ÃŠ(G.Don) K.Schum.	0.20	0.09	0.00	0.00
Allophylus africanus P. Beauv.	0.20	0.04	0.04	0.00
Piliostigma thonningii (Schum.) Millne-Redhead	0.16	0.61	0.61	**0.57**

Cussonia arborea Hochst. Ex A. Rich.	0.16	0.09	**0.74**	0.04
Antidesma membranaceum MÅ¸ll. Arg.	0.16	0.09	0.13	0.09
Zanthoxylum Zanthoxyloides (Lam.) Zepern. & Timler	0.12	0.52	0.09	**0.57**
Terminalia avicennioides Guill. & Perr.	0.12	0.43	0.00	0.09
Ficus thonningii Blume	0.12	0.22	0.00	0.13
Vitex madiensis ÃŠOliv.	0.12	0.13	0.04	0.09
Psydrax arnoldiana (De Wild.& T. Durand) Bridson	0.12	0.04	0.00	0.00
Albizia adianthifolia (Schumach.) W.F. Wright	0.08	0.04	0.00	0.00
Mimusops andongensis Hiern	0.08	0.04	0.00	0.00
Gmelina arborea Roxb.	0.04	0.52	0.00	0.22
Flacourtia indica Willd.	0.04	0.48	0.00	0.30
Margaritaria discoidea (Baill .) Webster	0.04	0.13	0.04	0.00
Entada abyssinica Steud. ex A. Rich.	0.04	0.09	0.00	0.00
Entada africana Guill. & Perr.	0.04	0.09	0.00	0.00
Maytenus senegalensis (Lam.) Exell	0.04	0.04	0.00	0.04
Albizia zygia (DC.) J.F. Macbr.	0.04	0.04	0.00	0.00
Ficus ovata Vahl	0.04	0.04	0.00	0.00
Garcinia epunctata ÃŠStapf	0.04	0.04	0.00	0.00
Ficus platyphylla Del.	0.04	0.00	0.00	0.09
Antiaris toxicaria var. welwitschii (Engl.) Corner	0.04	0.00	0.00	0.04
Vitellaria paradoxa C. F. Gaertn.	0.00	**0.74**	0.04	**0.57**
Pterocarpus erinaceus Poilr .	0.00	0.57	1.00	1.00
Cassia sieberiana DC.	0.00	0.52	0.04	0.57

Annona senegalensis Pers.	0.00	0.30	0.30	0.09
Dichrostachys cinerea (Linn.) Wight & Arn. subsp. Cinerea	0.00	0.13	0.09	0.04
Combretum zenkeri Engl. & Diels	0.00	0.00	0.04	0.04

6.4.3. Analysis of Co-occurrences and Interactions

The analysis of co-occurrences and interactions between species was carried out using two complementary approaches: a star chart or star network and analysis of the indicator value (IndVal). The star network was used to visualise the relationships between the target species (*Afzelia africana* and *Pterocarpus erinaceus*) and the other plant species coexisting in the same ecological plots. This graphic representation provides an intuitive and spatially explicit view of floristic co-occurrences and associative interactions in the Badenou and Lamto classified forests. In the star network, each node corresponds to a plant species, while the edges indicate the co-occurrences observed in the same vegetation plots. The thickness of the edges indicates the strength or frequency of these associations. This visual model highlights the ecological centrality of *Afzelia africana* and *Pterocarpus erinaceus* in the composition and structure of local plant communities in the two forest landscapes.

6.4.3.1. Correlations and Co-occurrences between Species

The analysis of correlations and co-occurrences has deepened the understanding of the interactions between *Afzelia africana*, *Pterocarpus erinaceus*, and their companion species at the two studied sites.

At Lamto, *Afzelia africana* is strongly associated with *Dialium guineense* and *Crossopteryx febrifuga*. *Dialium guineense*, in particular, seems to be a key indicator of environments where *Afzelia* is dominant **(Figure 73).**

On the other hand, *Pterocarpus erinaceus* seems more independent, with few species strongly associated. Its distribution indicates that it occupies more open habitats and is less influenced by co-occurrence relationships with other species. This ecological independence is also reflected in a clear separation of habitats between *Afzelia* and *Pterocarpus* at Lamto, with these two species rarely found together in the same plots **(Figure 74).**

The situation is different in Badenou. Here, *Afzelia africana* and *Pterocarpus erinaceus* share several species in common, suggesting a stronger coexistence between these two species. Unlike Lamto, the environmental conditions of Badenou seem to favour a greater overlap of habitats and resources between *Afzelia* and *Pterocarpus* **(Figure 75)**.

A key species in this dynamic is *Mimusops kummel*, which appears as a central species, found both with *Afzelia africana* and with *Pterocarpus erinaceus* **(Figure 76)**.

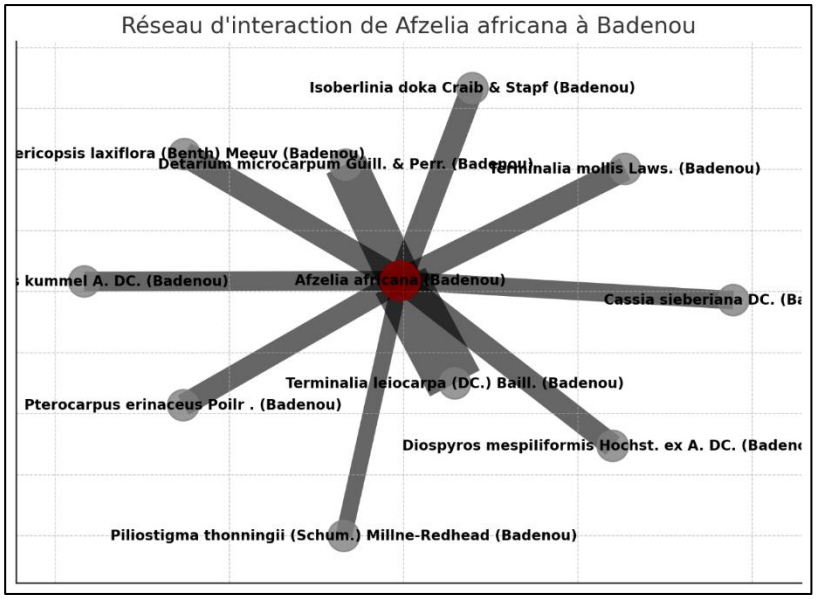

Figure 73: Star network graph showing the interaction networks of *Afzelia africana* and companion species in the Lamto Scientific Reserve

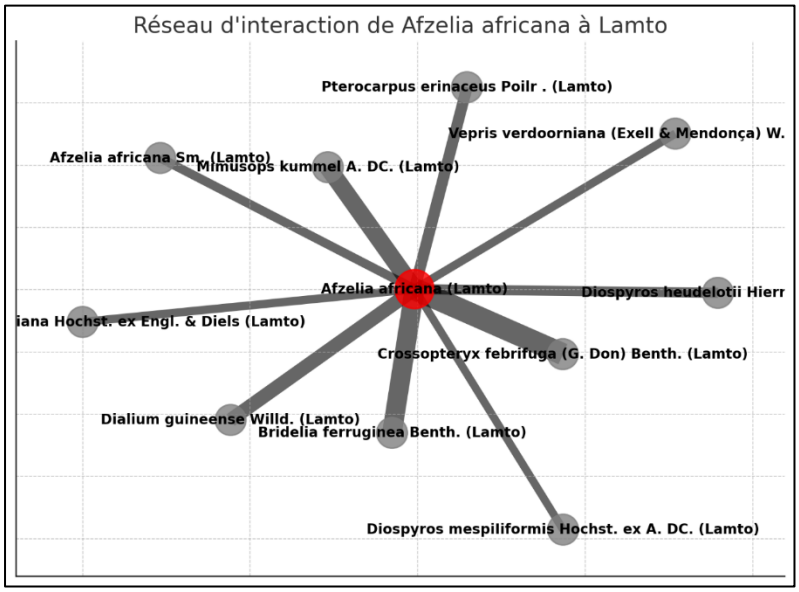

Figure 74: Star network graph indicating Interaction networks of *Pterocarpus erinaceus* and companion species in the Classified Forest of Badenou

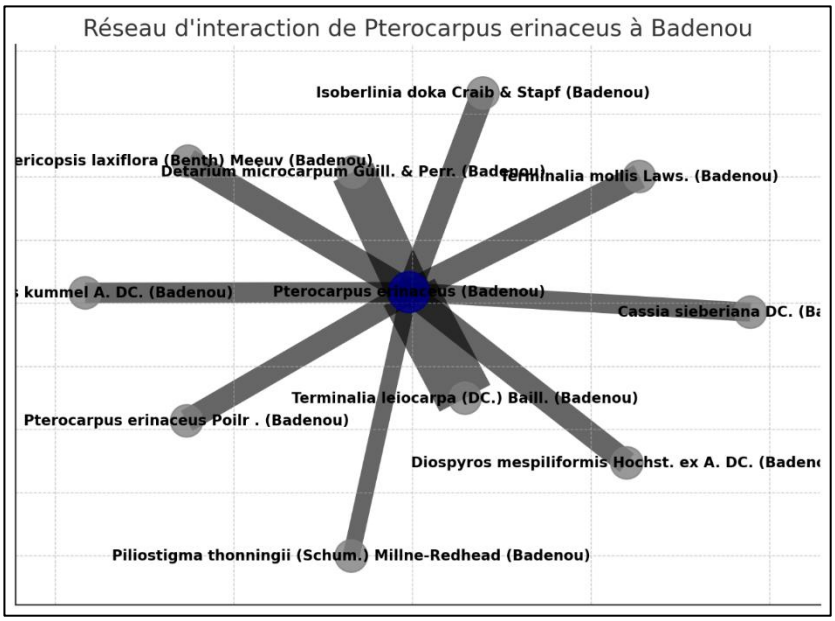

Figure 75: Star network graph showing the interaction networks of *Afzelia africana* and companion species in the Badenou Classified Forest

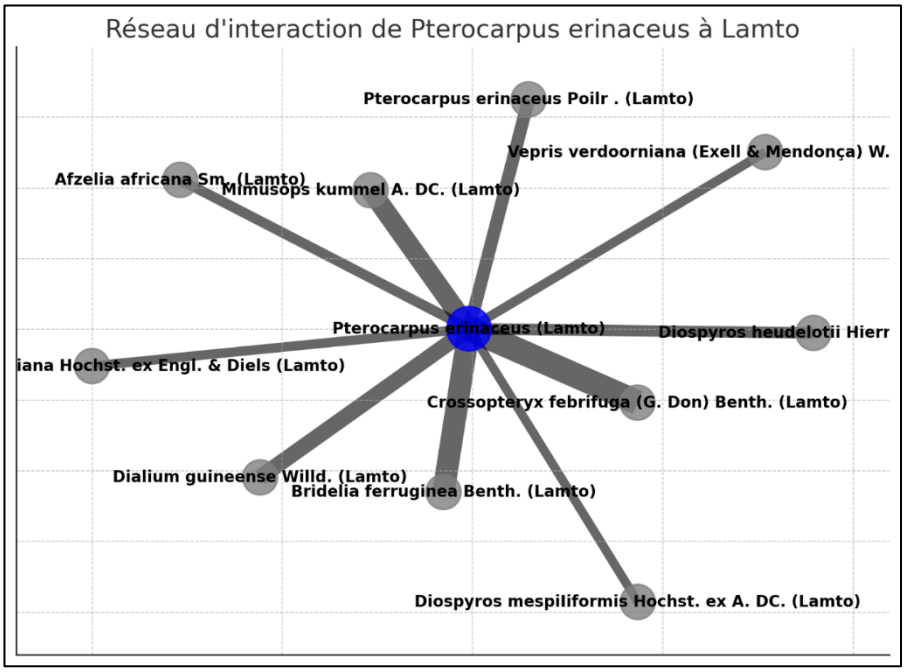

Figure 76: Star network graph showing the interaction networks of *Pterocarpus erinaceus* and companion species in the Lamto Scientific Reserve

6.4.3.2. Analysis of Indicator Species (IndVAL)

The IndVAL analysis made it possible to identify the indicator species of the habitats of *Afzelia africana* and *Pterocarpus erinaceus*.

- Strong indicator species for *Afzelia africana*

Some species are particularly associated with the habitats occupied by *Afzelia africana*, indicating that they share similar ecological preferences or benefit from the same environmental conditions.

Among them, there are:

- *Diospyros mespiliformis*, a species often found in gallery forests and protected wooded areas;
- *Mimusops kummel*, which appears as a key element of forest habitats where *Afzelia* is dominant;
- *Dialium guineense*, identified as an indicator species only at Lamto, which suggests a strong local specificity in this ecosystem.

For Pterocarpus erinaceus, other species are revealed as indicators of its preferred habitats:

- *Piliostigma thonningii*, a species widely associated with open environments and wooded savannas, is typical of areas where *Pterocarpus* is well established;
- *Mimusops kummel*, which is found with both target species, indicating its role as a generalist species capable of cohabiting in different types of habitats;
- *Terminalia avicennioides*, a species of open forest and savanna, is well correlated with areas occupied by *Pterocarpus*.

CHAPTER 7: IMPACT OF CLIMATE ON THE CARBON SEQUESTRATION CAPACITY OF *Afzelia africana* AND *Pterocarpus erinaceus*

7.1. Characteristics of the Growth Rings of the Studied Species

The studied species, *Afzelia africana* and *Pterocarpus erinaceus* exhibited distinct growth rings**.** The growth rings of *Afzelia africana* were much more distinct than those of Pterocarpus erinaceus. *Afzelia africana* exhibited growth rings characterised by marginal bands of parenchyma, while *Pterocarpus erinaceus* had rings distinguished by variations in vessel size and distribution, as well as a repeated pattern of alternating fibres and parenchymatous tissues. The two species studied are distinguished by a vascular distribution limited to annular pores, without specific variation in pore size **(Figure 77).** The vessels can appear individually or be arranged in radial clusters. Next, the widths of the rings showed a great variability, ranging from very narrow rings to more or less wide rings. In some cases, compression wood rings were identified using analysis of various rays on the stem discs. The wood colouration is a light brown, gradually darkening towards the pith for both species studied. The dendrochronological analyses revealed that the age of *Afzelia africana* individuals ranged from 33 to 122 years and that of *Pterocarpus erinaceus* individuals ranged from 52 to 78 years in the Lamto Scientific Reserve. On the other hand, within the Badenou Classified Forest, the age of *Afzelia africana* individuals ranged from 75 to 180 years and that of Pterocarpus erinaceus individuals ranged from 73 to 99 years.

7.2. Impact of Climate on Carbon Sequestration

7.2.1. Interspecific Differences in Carbon Sequestration

Measurements taken in the Badenou Forest reveal marked differences between the two species in terms of biomass and carbon storage. *A. africana* has systematically higher values, with an average biomass of 95.4 t compared with 28.1 t for *Pterocarpus erinaceus* (**Table XX**). These differences are reflected in carbon stocks (66.8 t for *Afzelia africana* and 19.7 t for *Pterocarpus erinaceus*) and CO_2 equivalents (244.9 t versus 72.3 t).

The data from the Lamto Scientific Reserve confirms this trend, although the absolute values differ. *Afzelia* maintains a clear superiority in carbon stock there (82.09 t on average) compared with *Pterocarpus* (23.63 t). The records show that this interspecific difference persists despite variations in environmental conditions between the two sites.

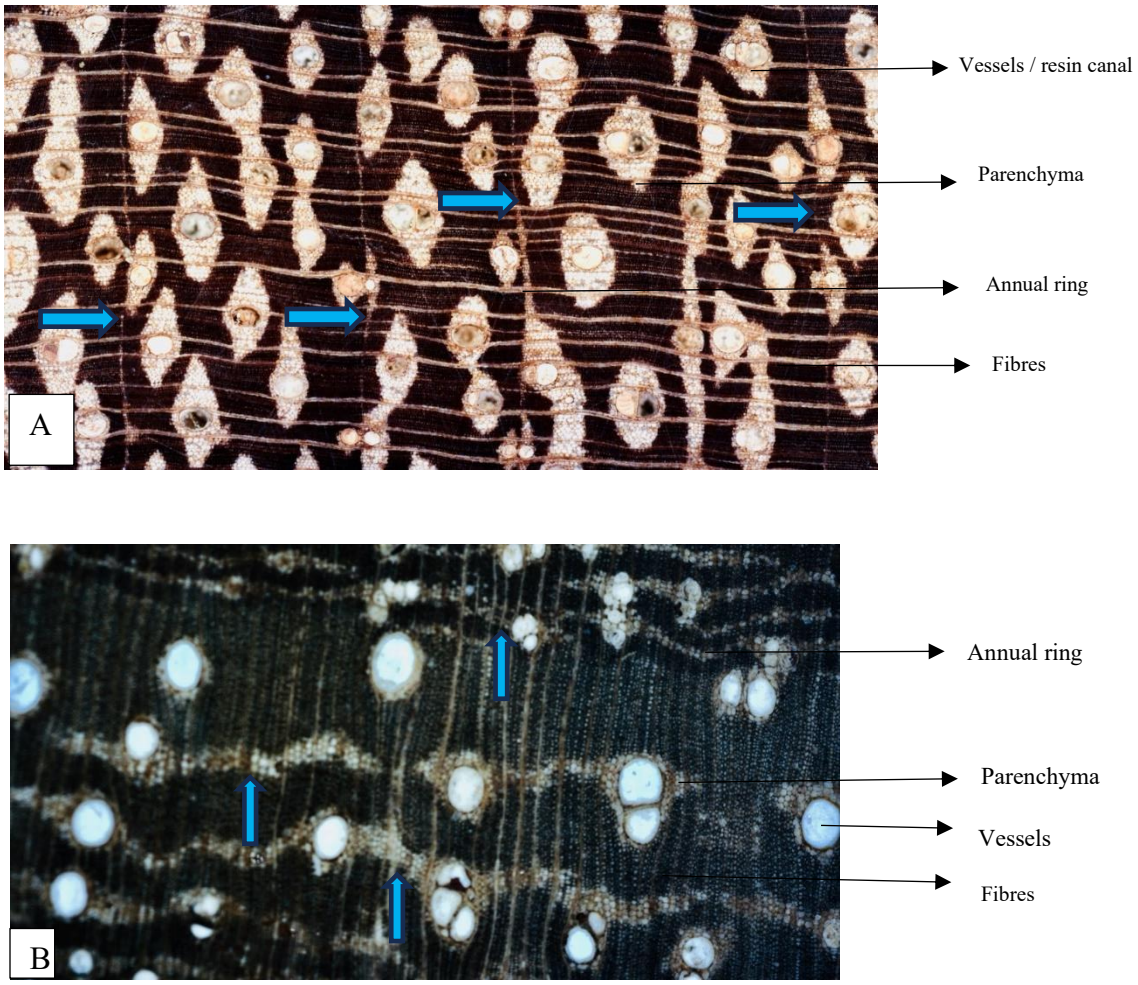

Figure 77: Growth ring boundaries of *Afzelia africana* (A) and *Pterocarpus erinaceus* (B)

The analysis of growth dynamics reveals distinct results between species. *Afzelia africana* maintains sustained growth over the long term, with moderate interannual variability. *Pterocarpus erinaceus*, on the other hand, exhibits a greater amplitude in its annual growth variations, particularly noticeable at Badenou. These differences are reflected in the sequestration capacities, with a more stable accumulation in *Afzelia* and a more pronounced response to interannual variations in *Pterocarpus*. The results highlight significant differences between the two species studied in terms of sequestration capacity**.** In Badenou, *Afzelia africana* shows higher average values for biomass (95.40 ± 74.20 t) and carbon stock (66.80 ± 51.31 t) compared to *Pterocarpus erinaceus* (28.10 ± 39.00 t and 19.70 ± 27.34 t), respectively, for biomass and carbon stock. The statistical tests confirm these differences (x=5.298, p=0.021). At Lamto, the interspecific differences are even more pronounced. *Afzelia* shows significantly higher values for all measured parameters (biomass: 117.27±90.03 t; C stock: 82.09 ± 63.31 t; CO_2 eq: 300.31 ±231.37 t) compared to *Pterocarpus* (34.50 ± 60.00 t; 23.63 ± 41.10 t; 86.66 ± 150.68 t), with highly significant differences (x=67.691, p<0.0001).

In the Badenou Classified Forest, *Afzelia africana* exhibits higher individual biomass and carbon stock than *Pterocarpus erinaceus* **(Table XXII).**

Table XXII: Comparison of biomass and mean carbon stocks of the two species at Badenou and Lamto

Sites	Studied Species	Biomass (t)	Stock C (t)	eq CO_2 (t)
Badenou	*Afzelia*	95.40 ± 74.20^{a}	66.80 ± 51.31^{a}	244.90 ± 188.31^{a}
	Pterocarpus	28.10 ± 39.00^{b}	19.70 ± 27.34^{b}	72.30 ± 100.39^{b}
	Statistical Test	*x=5.298 ; p=0.021 ;α=0.05*		
Lamto	*Afzelia*	117.27 ± 90.03^{a}	82.09 ± 63.31^{a}	300.31 ± 231.37^{a}
	Pterocarpus	34.50 ± 60.00^{b}	23.63 ± 41.10^{b}	86.66 ± 150.68^{b}
	Statistical Test	*x=67.691 ; p<0.0001 ;α=0.05*		

7.2.2 Temporal Evolution of Carbon Sequestration Capacity

In the Badenou Classified Forest, observations show a strong interannual variability. The data from the Badenou Classified Forest reveal distinct temporal dynamics between the two species. For *Pterocarpus erinaceus*, the records show a strong interannual variability in biomass gains, with pronounced fluctuations following different climatic episodes. The measurements of stored carbon follow the same trend, showing marked variations from year to year. *Afzelia africana*, on the other hand, shows a more stable trend, although a gradual decline in growth rates has been observable since the 1990s **(Figure 78).**

The time series highlights a notable change around 1950 for both species. This period corresponds to a change in growth parameters, with a general increase in the measured values. The curves, however, show differentiated responses: while *Afzelia* maintains a relatively linear trend after this date, Pterocarpus continues to display significant variations **(Figure 79).**

In the Lamto Scientific Reserve, the evolution profiles differ significantly. The data indicate a stabilisation of sequestration rates starting from the 1950s for both species. *Afzelia africana* shows a regular biomass accumulation, with annual values exhibiting low dispersion. *Pterocarpus erinaceus*, however, retains a certain variability, although less pronounced than at Badenou **(Figure 80)**. The measurements of stored carbon at Lamto confirm these trends. The post-1950 records show greater temporal homogeneity, particularly noticeable for *Afzelia*. The values for *Pterocarpus*, although more stable than at Badenou, continue to show notable interannual fluctuations **(Figure 81).**

7.2.3 Influence of Climatic Variables on Carbon Sequestration

7.2.3.1 Analysis of Relationships in Badenou

The results highlight more pronounced contrasts in the Badenou Classified Forest. *Afzelia africana* shows a low general sensitivity to climatic variables, with a slight negative correlation with temperature ($r = -0.28$) and non-significant relationships with other parameters ($p > 0.05$). The temporal trend reveals a slight, non-significant decrease in carbon stock (-0.085 t/year, $p = 0.134$). In contrast, *Pterocarpus erinaceus* shows a strong dependence on water conditions, with high correlations for precipitation ($r = +0.82$, $p < 0.001$), the SPI index ($r = +0.65$, $p = 0.007$), and the PDSI index ($r = +0.58$). Carbon accumulation shows a positive trend (+0.345 t/year), although not significant ($p = 0.081$), reflecting the high variability of interannual responses **(Figure 82).**

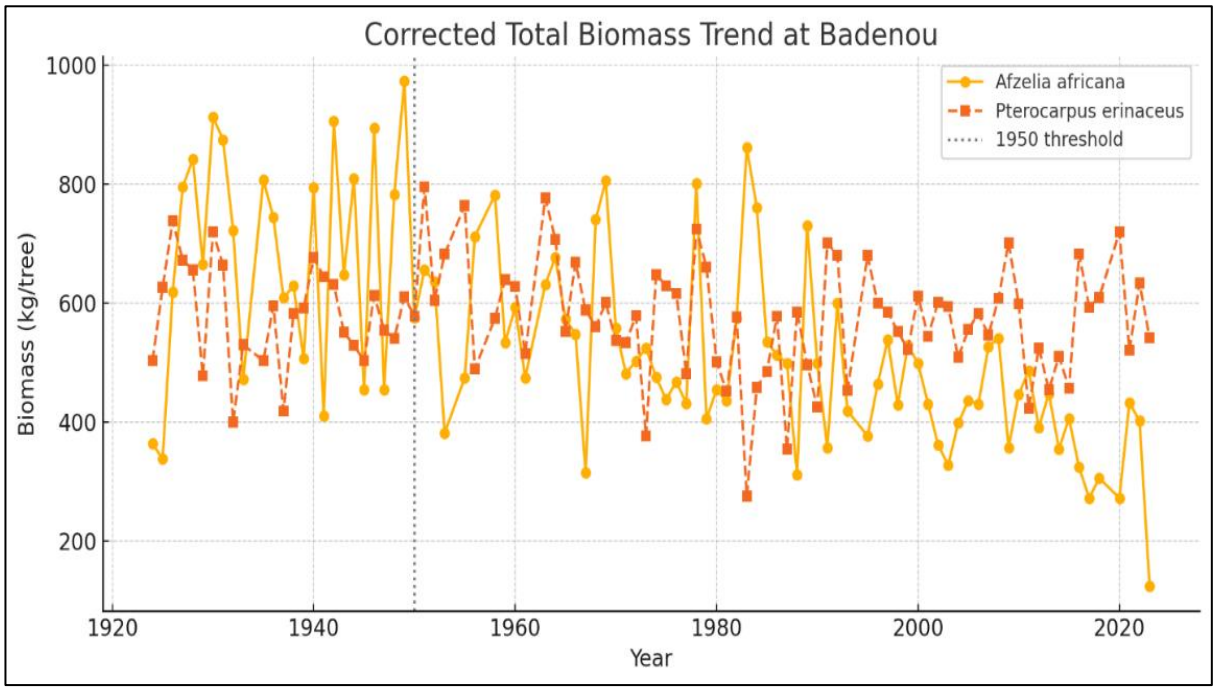

Figure 78: Temporal evolution of biomass by species at Badenou

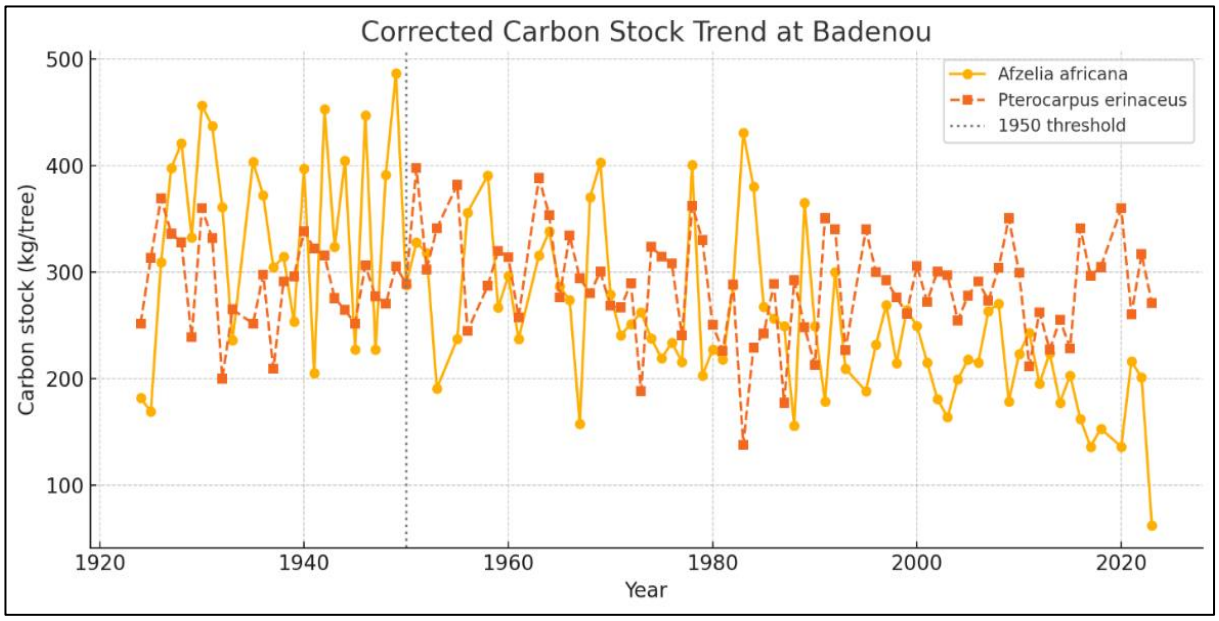

Figure 79: Temporal evolution of carbon sequestration by species at Badenou

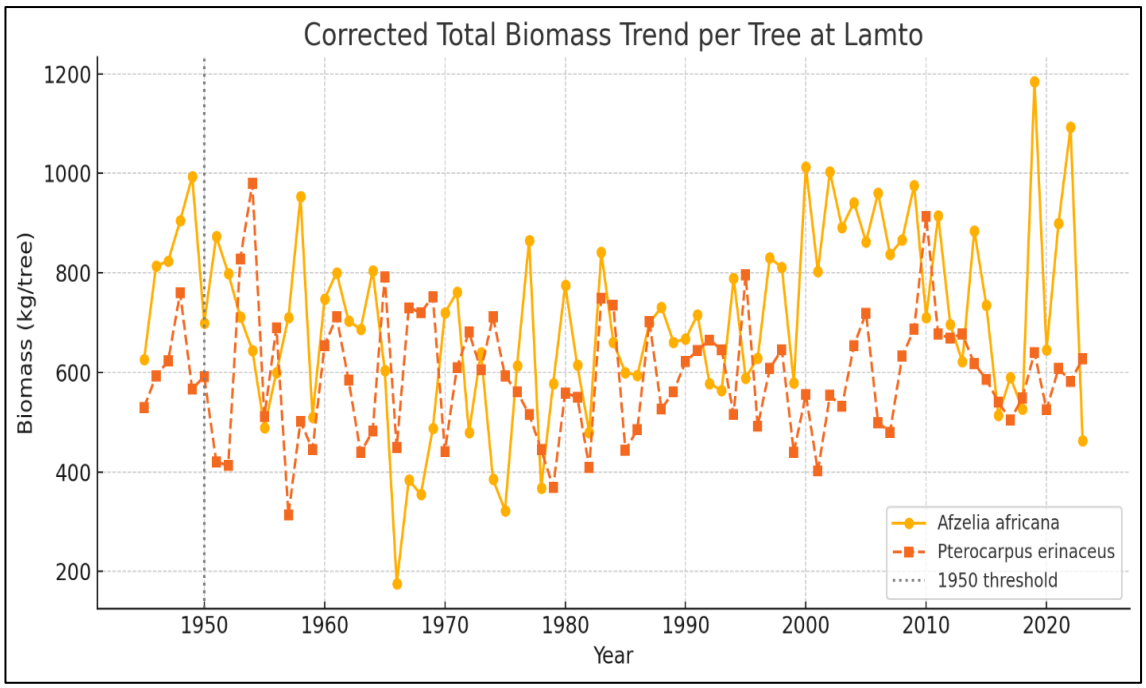

Figure 80: Temporal evolution of biomass by species at Lamto.

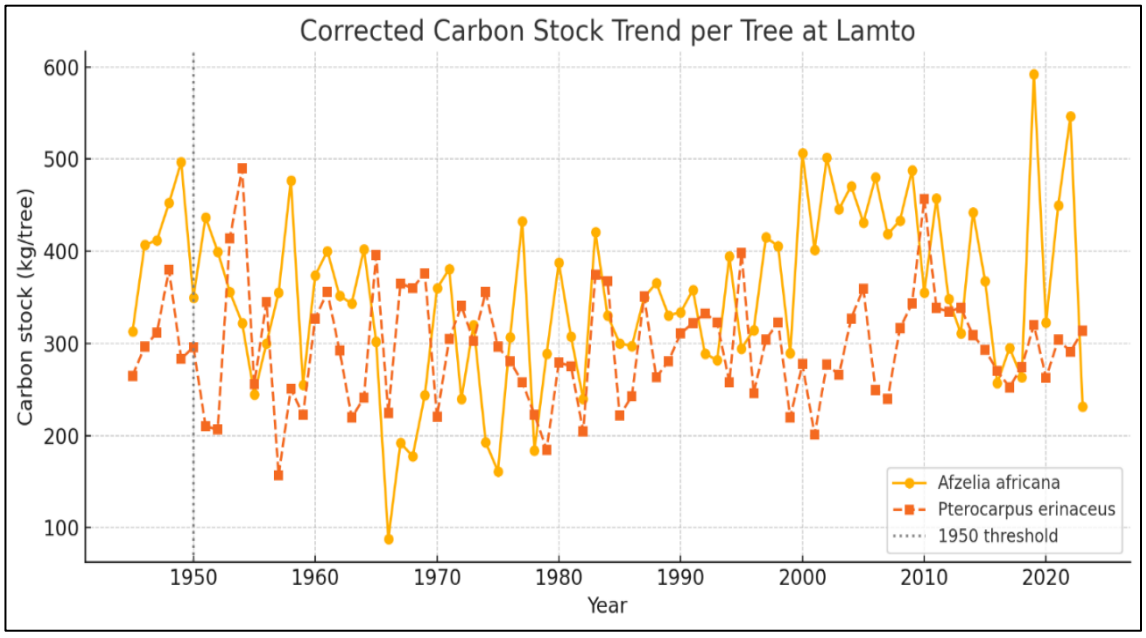

Figure 81: Temporal evolution of carbon sequestration by species at Lamto.

7.2.3.2 Analysis of Relationships at Lamto

The results obtained at the Lamto Scientific Reserve reveal distinct patterns between the two species studied. For *Afzelia africana*, a moderate correlation with temperature is observed ($r = +0.41$), while the relationships with precipitation and water indices remain non-significant ($p > 0.05$). The analysis of time series shows a progressive accumulation of carbon at an average rate of +0.265 t/year ($p < 0.0001$)**.** *Pterocarpus erinaceus*, on the other hand, shows a significant sensitivity to precipitation ($p = 0.026$) and the SPI index ($p = 0.025$). Although showing a faster carbon accumulation (+1.919 t/ha/year, $p < 0.0001$), this species exhibits greater interannual variability. The correlations with temperature ($r = +0.20$) and the PDSI index ($r = -0.11$) remain weak **(Figure 83).**

7.2.3.3 Inter-site Comparison

The comparison between the two sites highlights notable differences in climate-sequestration relationships. At Lamto, the climatic effects appear to be mitigated, with relationships mainly non-significant, except for *Pterocarpus* concerning precipitation and SPI. In Badenou, the climatic influences are more pronounced, particularly for *Pterocarpus* which shows a strong sensitivity to water indicators**.**

These results highlight the importance of local conditions in modulating the relationships between climate and carbon sequestration. The interspecific differences observed reflect distinct ecological strategies, with *Afzelia*, while *Pterocarpus* exhibits more pronounced responses to environmental fluctuations**.** The interspecific differences observed reflect distinct ecological strategies, with *Afzelia* showing greater stability in the face of climatic variations, while *Pterocarpus* exhibits more pronounced responses to environmental fluctuations **(Figure 84).**

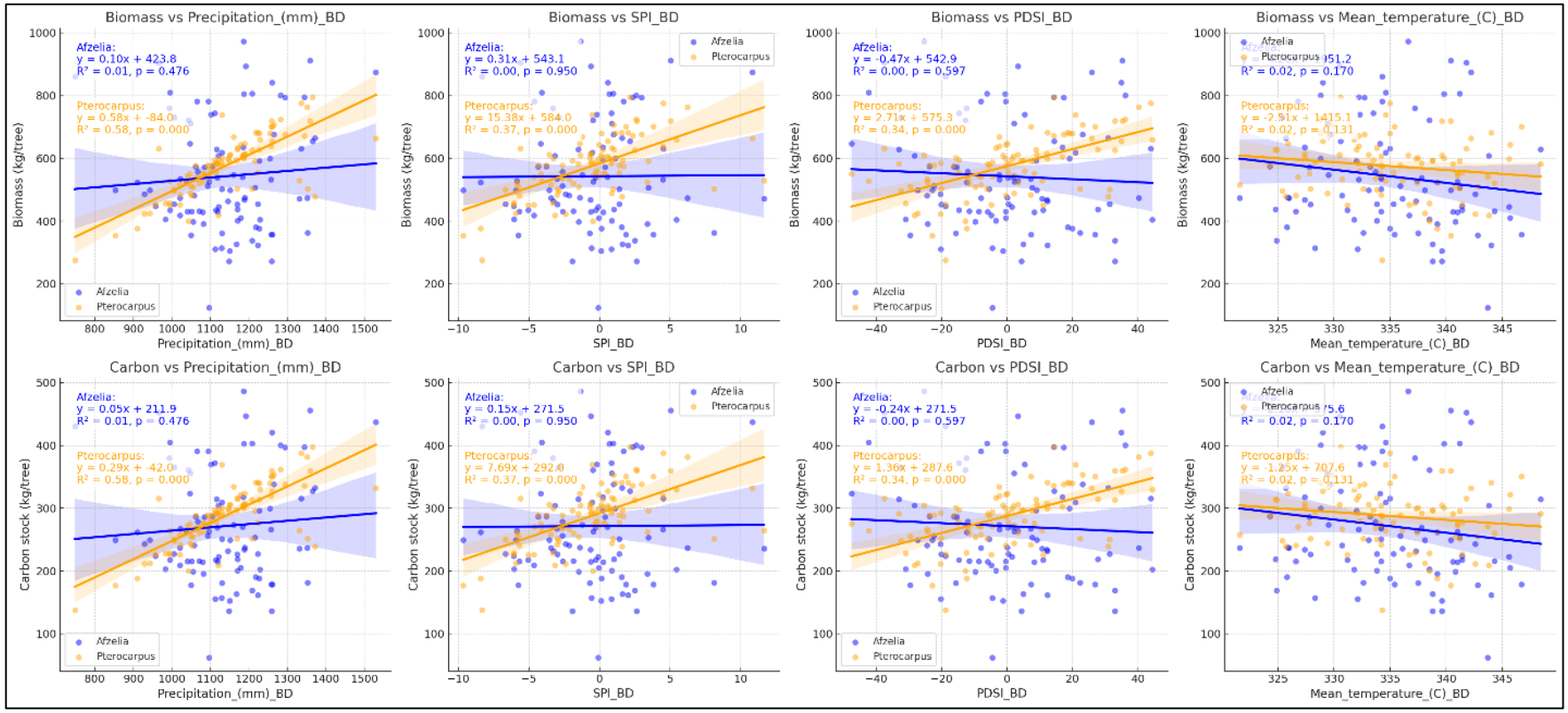

Figure 82: Impact of climatic variables on the biomass and carbon stock of *Afzelia africana* and *Pterocarpus erinaceus* in Badenou

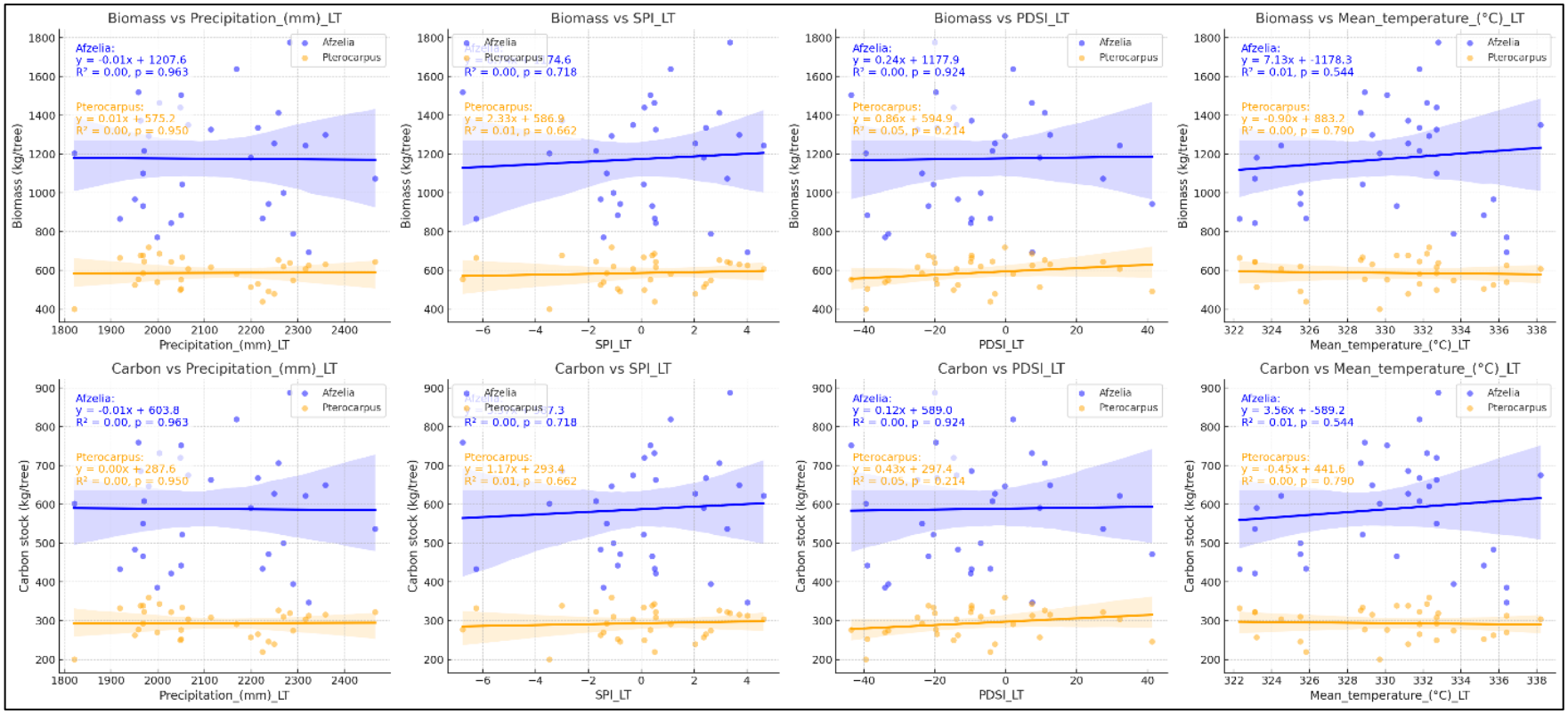

Figure 83: Impact of climatic variables on the biomass and carbon stock of *Afzelia africana* and *Pterocarpus erinaceus* in Lamto

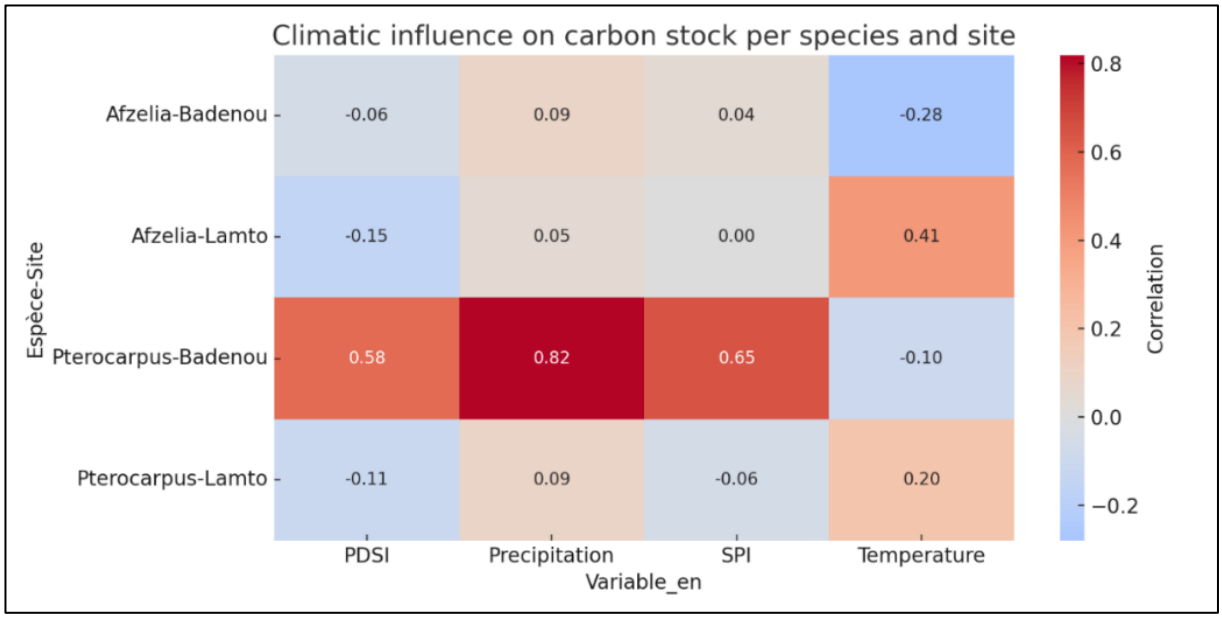

Figure 84: Climatic influence on carbon stock per species and site

CHAPTER 8: MODELLING THE DISTRIBUTION AREA OF *Afzelia africana* and *Pterocarpus erinaceus* IN CÔTE D'IVOIRE

8.1. Contribution of the Variables and Model Validation

The modelling of the distribution area of A. *africana* and P. *erinaceus* resulted in an AUC (Area Under the Curve) of 0.95 for *A. africana* and 0.91 for *P. erinaceus*. This explains that the model has a very good ability to predict the suitable habitats of the studied species (**Figure 85; Figure 86**). The correlation analysis and the Jackknife test, respectively determined nine least correlated variables ($r < 0.80$) for A. *africana* and nine least correlated variables ($r < 0.80$) for *P. erinaceus* (**Figure 87**;**Figure 88**). These are the variables that contributed the most to the modelling. The precipitation of the warmest quarter (BIO18) with a value of 46.9% and the maximum temperatures of the warmest month (BIO5) with a value of 18.5% are the variables that most contributed to the chosen model (**Table XXIII; Table XXIV**) for the species *A. africana.* Next, the maximum temperatures of the warmest month (BIO5) with a value of 72.5% and isothermality (BIO3) with a value of 11.5%, are the variables that contributed the most to the chosen model for the species *P. erinaceus*. The results of the Jackknife test show that the individual environmental variable that contributed the most to the prediction model is BIO18 for *A. africana* and BIO5 for *P. erinaceus*. It therefore has the most useful information. On the other hand, the environmental variable that contributed the least to the prediction model when omitted is BIO4 for *A. africana* and BIO6 for *P. erinaceus*. It therefore seems to have more information not present in the other variables. The displayed value is the average of the model's repeated outputs.

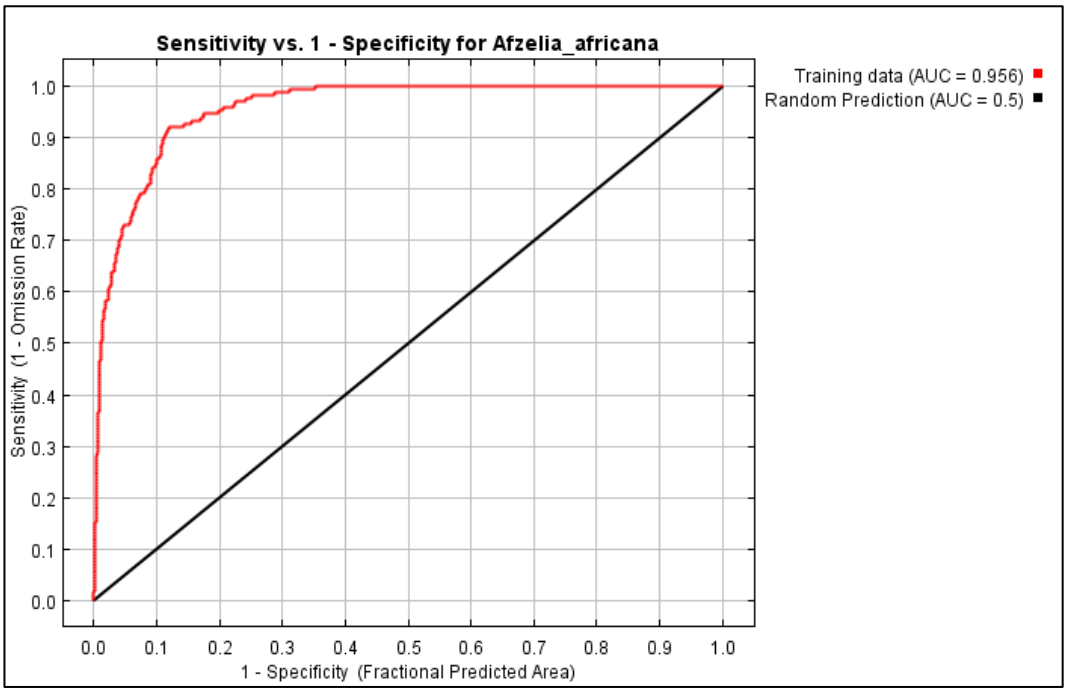

Figure 85: Presentation of the AUC (Area Under the Curve) validation value of the model related to *Afzelia africana*

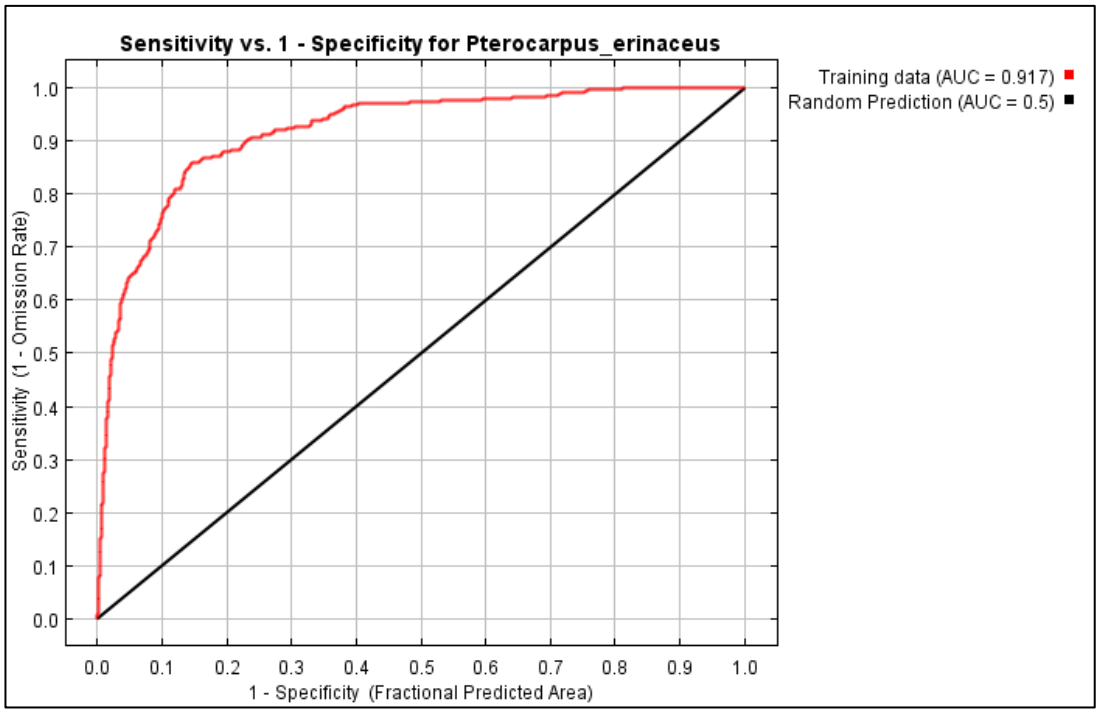

Figure 86: Presentation of the AUC (Area Under the Curve) validation value of the model related to *Pterocarpus erinaceus*

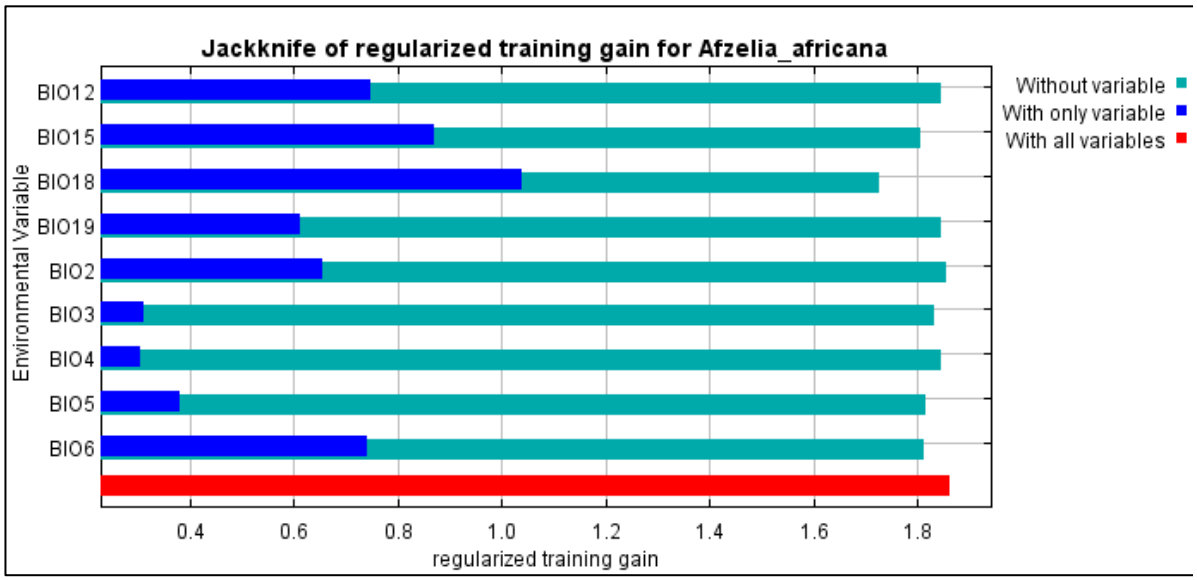

Figure 87: Result of the Jackknife test on the contribution of *Afzelia africana* models

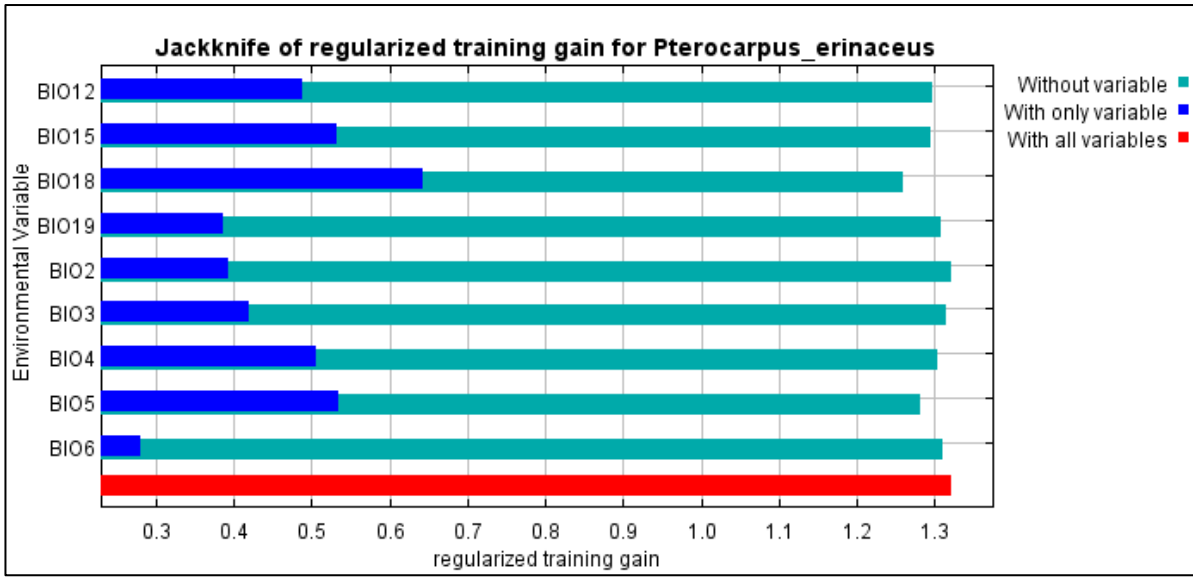

Figure 88: Result of the Jackknife test on the contribution of *Pterocarpus erinaceus* models

Table XXIII: Bioclimatic variables used and their contributions to the *Afzelia africana* model

Code	Bioclimatic variables	Current percent contribution	SSP2 4.5 percent contribution	SSP5 8.5 percent contribution
BIO18	Precipitation of warmest quarter	46.9	3.1	6.3
BIO5	Max temperature warmest period	18.5	23.2	19.7
BIO6	Min temperature of coldest period	12.8	10.4	4.8
BIO12	Annual precipitations	9.9	1.7	1.5
BIO15	Precipitations seasonality	5.5	37.7	44.5
BIO3	Isothermality (Bio2/Bio7 × 100)	4.1	2	4.8
BIO4	Temperature seasonality	1.2	1.7	0.1
BIO19	Precipitations of coldest period	0.9	3	8
BIO2	Mean diurnal rang	0.3	17.2	10.4

Table XXIV: Bioclimatic variables used and their contributions to the *Pterocarpus erinaceus* model

Code	Bioclimatic Variables	Current percent contribution	SSP2 4.5 percent contribution	SSP5 8.5 percent contribution
BIO5	Max temperature warmest period	72.5	65.2	48.7
BIO3	Isothermality (Bio2/Bio7 × 100)	11.5	9.9	25.5
BIO12	Annual precipitations	4.2	11.7	9.4
BIO6	Min temperature of coldest period	4	5.4	5.3
BIO18	Precipitation of warmest quarter	2.5	2.6	5.2
BIO19	Precipitations of coldest period	2.1	1.1	2.8
BIO2	Mean diurnal rang	1.8	3.5	2.2
BIO4	Temperature seasonality	1.3	0.5	1
BIO15	Precipitations seasonality	0.1	0.1	0

8.2. Current and Future Distribution of Suitable Habitats for *Afzelia africana* and *Pterocarpus erinaceus*

The habitat analysis reveals an area of 63492.7017 km², which represents 19.75% of the suitable zone for the potential distribution of *Afzelia africana* under current conditions (**Table XXV**). This suitable area is mainly located in the centre and north of Côte d'Ivoire (**Figure 89**). The highly suitable areas cover approximately 16722.3147 km², which represents 5.20% of the total area of Ivorian territory. These habitats particularly suitable to the species are located in the central and northern regions. The results of the modelling based on the SSP2 4.5 scenario for the period up to 2050 (2041-2060) reveal that the areas suitable for the growth of *Afzelia africana* extend over approximately 84338.0916 km², which represents 26.23% of the total area of the Ivorian territory. It is mainly located in the central region and in the north of the country (**Figure 90**). Regarding the region highly suitable for the expansion of *Afzelia africana,* it covers an area of 21851.7395 km², which represents 6.80% of the total area of the Ivorian territory. The forecasts from the SSP5 8.5 scenario for the period up to 2100 (2081-2100) reveal that the areas suitable for the distribution of *Afzelia africana* cover approximately 94769.0684 km², which is 29.48% of its area. In terms of the highly suitable zone, it extends over an area of 17950.2654 km², which represents 5.58% of the total area of Côte d'Ivoire. Addressing the SSP5 8.5 scenario, the future distribution of *Afzelia africana* species in Côte d'Ivoire is located in the same areas as those predicted for the SSP2 4.5 scenario (**Figure 91)**. As for *Pterocarpus erinaceus*, the habitat analysis for current conditions gives an area of 95302.9116 km², or 29.65%, as a potentially suitable distribution zone (**Table XXVI**). This suitable area is largely located in the central northern part of Côte d'Ivoire (**Figure 92**). The highly suitable areas represent approximately 9,548,142.56 km² in surface area, which is 29.70% of the total surface area of Ivorian territory. This type of habitat is highly suitable for the species is located in the centre and in the north. The result of the simulation with the SSP2 4.5 scenario for the horizon 2050 (2041-2060) indicates that the suitable areas for *Pterocarpus erinaceus* cover approximately 10591.8021 km², corresponding to 32.95% of the total area of the Ivorian territory. This suitable area is located in the centre and mainly in the north, northeast, and northwest of the country **(Figure 93).** As for the area highly suitable for the distribution of *Pterocarpus erinaceus*, it extends over 10,923,670.73 km², which is 33.98% of the total area of the Ivorian territory. The projections obtained with the SSP5 8.5 scenario for the year 2100 (2081-2100) indicate that the suitable areas for *Pterocarpus erinaceus* cover approximately 13152.3952 km², which is 40.91% (**Figure 94**).

Table XXV: Variation in the areas of suitable and highly suitable habitats for *Afzelia africana*

Scenario	Not suitable habitat		Suitable habitat		highly suitable habitat	
	Area (Km²)	Proportion %	Area (Km²)	Proportion %	Area (Km²)	Proportion %
Current scenario	241253.3439	75.05	63492.7017	19.75	16722.3147	5.20
SSP2 4.5 scenario	215285.0961	66.97	84338.0916	26.23	21851.7395	6.80
SSP5 8.5 scenario	208748.2245	64.93	94769.0684	29.48	17950.2654	5.58

Table XXVI: Variation in the areas of suitable and highly suitable habitats of *Pteroccarpus erinaceus*

	Not suitable habitat		Suitable habitat		highly suitable habitat	
	Area (Km²)	Proportion %	Area (Km²)	Proportion %	Area (Km²)	Proportion %
Current scenario	130659.6979	40.65	95302.9116	29.65	95481.4256	29.70
SSP2 4.5 scenario	106298.7871	33.07	105918.0213	32.95	109236.7073	33.98
SSP5 8.5 scenario	127091.7112	39.53	131523.9525	40.91	62840.1081	19.54

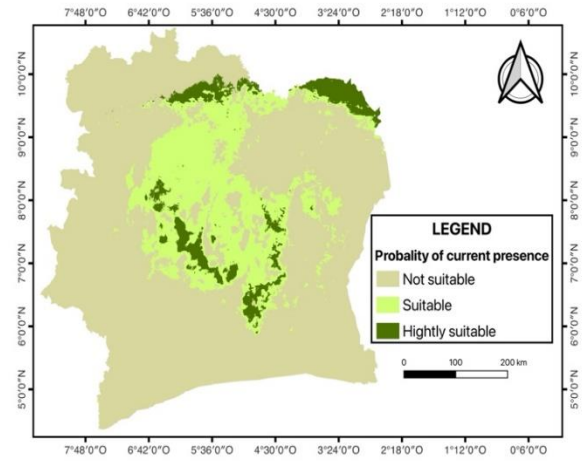

Figure 89: Current potential distribution of *Afzelia africana*

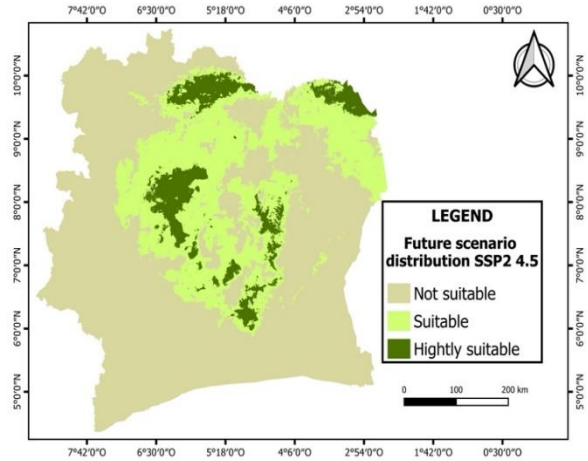

Figure 90: Future potential distribution of *Afzelia africana* under SSP2 4.5 scenario

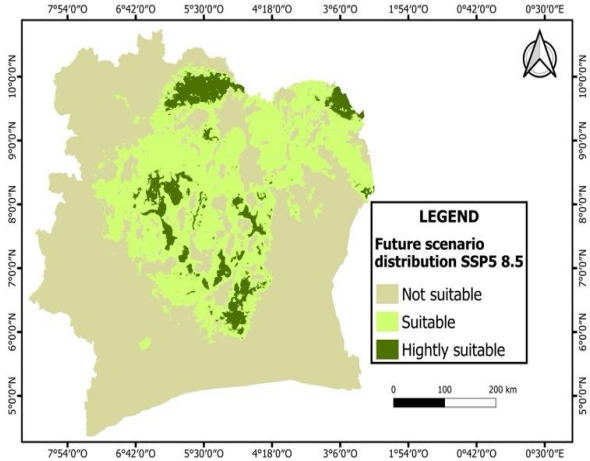

Figure 91: Future potential distribution of *Afzelia africana* under SSP5 8.5 scenario

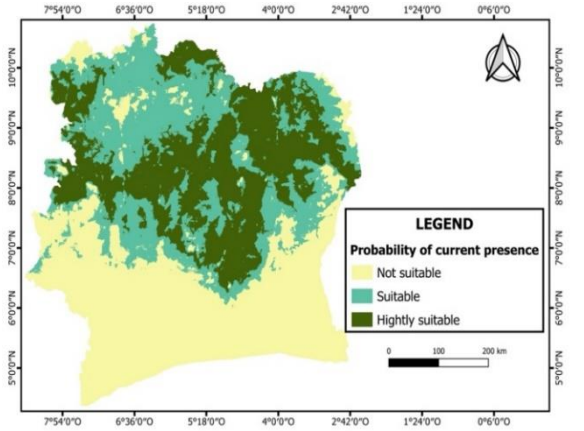

Figure 92: Current potential distribution of *Pterocarpus erinaceus*

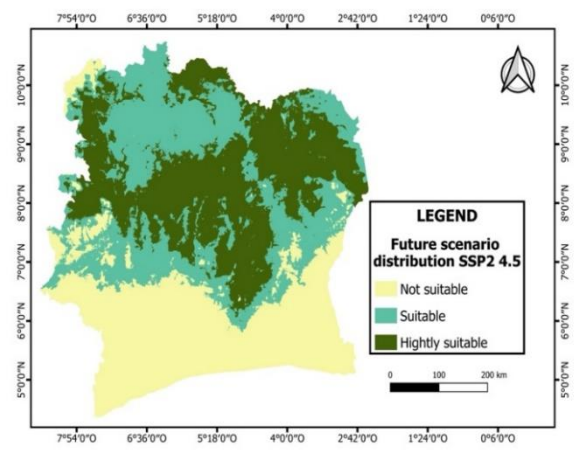

Figure 93: Future potential distribution of *Pterocarpus erinaceus* under SSP2 4.5 scenario

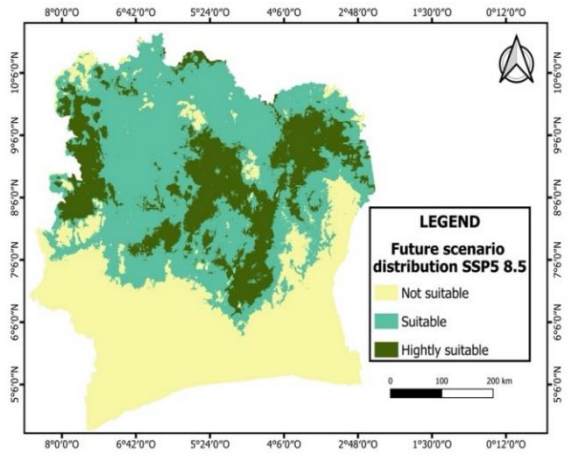

Figure 94: Future potential distribution of *Pterocarpus erinaceus* under SSP5 8.5 scenario

Considering the highly suitable zone, it extends over an area of 6284.0108 km², equivalent to (19.54%) of the total area of Côte d'Ivoire. For the SSP5 8.5 scenario, the future distribution of *Pterocarpus erinaceus* species in Côte d'Ivoire is located in the same areas as for the SSP2 4.5 scenario**.**

8.3. Impacts of Climate Change on the Current and Future Distribution of Habitats of *Afzelia africana* and *Pterocarpus erinaceus*

According to the bioclimatic projections of the SSP2 4.5 and SSP5 8.5 scenarios, *Afzelia africana* will lose an area of 10.76% and 13.47% of not suitable habitats respectively by 2050 (2041-2060) and 2100 (2081-2100) see in table (**Table XXVII**). For a temperature increase of +2°C by 2050 under the Shared Socioeconomic Pathways (SSP2 4.5) scenarios, taking into account future economic parameters and future GHG emissions, the model predicted a significant spatial dynamic of suitable and highly suitable habitats for *Afzelia africana*. Thus, the suitable habitats recorded a gain of 32.83%, while the highly suitable habitats saw a gain of 30.67%. Under a more severe radiative forcing (SSP5 8.5) with a temperature increase of +4.4°C, *Afzelia africana* will gain 49.26% of its suitable habitat. SSP5 8.5 also predicts a 7.34% expansion of the highly suitable habitat for the species, but this has a lower relative probability of occurrence compared to the suitable habitats.

Talking about *Pterocarpus erinaceus*, the bioclimatic projections of the SSP2 4.5 and SSP5 8.5 scenarios indicate that not suitable habitats will experience a decrease of -18.64% and -2.73%, respectively. Considering a 2°C increase in temperature by 2050 according to the Shared Socioeconomic Pathways (SSP2 4.5) scenarios, taking into account future socioeconomic parameters and greenhouse gas emissions, the model anticipated a significant change in the spatial distribution of suitable and highly suitable habitats for *Pterocarpus erinaceus*. The suitable habitats will gain 11.13% while the highly suitable habitats will see their area increase by 14.4%. Under a more severe radiative forcing (SSP5 8.5) with a temperature increase of +4.4°C, *Pterocarpus erinaceus* will gain 38% of its suitable habitat. On the other hand, highly suitable habitats will experience a distribution decrease of -34.18% of their area (**Table XXVIII**).

Table XXVII: Variation in the rate of change of favourable and very favourable habitats of *Afzelia africana*

	Not suitable Habitat		**Suitable Habitat**		**Highly Suitable Habitat**	
	Area (Km²)	**Proportion (%)**	**Area (Km²)**	**Proportion (%)**	**Area (Km²)**	**Proportion (%)**
Current **Scenario**	24125334.39		6349270.17		1672231.47	
SSP2 4.5 Scenario	21528509.61	-10.76	8433809.16	32.83	2185173.95	30.67
SSP5 8.5 Scenario	20874822.45	-13.47	9476906.84	49.26	1795026.54	7.34

Table XXVIII: Change in the rate of change in favourable and very favourable habitats of *Pterocarpus erinaceus*

	Not suitable **Habitat**		Suitable **Habitat**		Highly Suitable **Habitat**	
	Area (Km²)	**Proportion (%)**	**Area (Km²)**	**Proportion (%)**	**Area (Km²)**	**Proportion (%)**
Current **Scenario**	13065969.79		9530291.16		9548142.56	
SSP2 4.5 Scenario	10629878.71	-18.64	10591802.13	11.13	10923670.73	14.4
SSP5 8.5 Scenario	12709171.12	-2.73	13152395.25	38	6284010.81	-34.18

PART FOUR: DISCUSSION

The overall accuracies of the various land-use maps are 98.66%, 99.83%, 99.27% and 98.32% respectively for the 1990 Landsat TM, 2002 ETM+, 2012 ETM+ and 2022 OLI TIRS images. For the Badenou classified forest, the results are 95.98%, 95.60%, 92.65% and 94.39% respectively for Landsat TM images from 1990, ETM+ images from 2002, ETM+ images from 2012 and OLI TIRS images from 2022. These results are better than those obtained **by Nanan (2024); Yao (2019); Dahan (2020), N'Da *et al.* (2008), N'Guessan and N'Da (2005),** and **Achard and Blasco (1990),** who obtained respective overall accuracies by classifying a Landsat image covering the forest-savannah transition zone and the Sudan zone. These satisfactory accuracies could be linked to better observing and describing the land use/cover classes during the field phase. The kappa coefficients of the land use maps vary between 0.98 and 0.97 for RS Lamto and 0.93 and 0.87 for FC Badenou.

These values are well above the 75% threshold proposed by **Girard and Girard (1999)** and mentioned by **Nanan *et al.* (2024).** According to **Tankoano *et al.* (2017)** and **Soro *et al.* (2014)**, when the Kappa index evaluated in the classification operations is between 50 and 75% in the land cover work, the classification adopted is good and the results can be used judiciously. This shows that the maps obtained are of excellent quality and reflect the reality on the ground. According to **Olofsson *et al.* (2014),** an overall accuracy of around 98-99% means that classification errors are minimal, which increases confidence in land cover change analyses. **Congalton (2001)** points out that Kappa values close to 1 show that the classification is well above that of a random classification, indicating that the defined classes have been correctly distinguished thanks to a rigorous methodology and quality data. In addition, the quality of the images is also due to the better discrimination of land use classes. In the same vein, **Soulama *et al.* (2015)** and **Maârouhi *et al.* (2011)** have shown that the choice of training areas during supervised classification determines quality results.

However, within the Lamto RS, significant confusion was observed between the classes 'gallery forest/dense semi-deciduous forest' and 'open forest/wooded savannah' in 2022, with a confusion error of 2.58%. This phenomenon is common in image classifications of dense vegetation cover, as the transitions between these forest types can be subtle, especially in areas of forest mosaics such as Lamto **(Goetz *et al.,* 2009).** In Badenou FC, significant confusion was noted between fallow land and open forest/wooded savannah. This 19.95% confusion could be explained by several factors. In terms of structure and floristic diversity, these two classes are very similar,

which could explain this confusion. Our results are similar to those obtained by **Yao (2019)** who worked in Dianra, in the same ecological zone. In fact, this author showed that fallows are difficult to distinguish from the different facies of natural vegetation depending on their level of reconstitution. On the other hand, he showed that the reconstitution of the post-cultivation plant formation (the fallow) takes place after 10 years of reconstitution, always towards the original plant formation. This means that if an open forest/wooded savannah has been destroyed for cultivation, it will recover towards the open forest/wooded savannah.

In terms of vegetation dynamics, within the Lamto SR, the gallery forest/dense semi-deciduous forest class increased slightly during the study period. This increase could be explained by the fire established at the edge of the forest zone, which protects it from the influence of seasonal fire and allows this class to develop more easily. It should also be pointed out that this increase in the gallery forest/dense semi-deciduous forest class is mainly due to its location on the edge of the Bandama. The open forest/wooded savannah and shrub savannah classes were the most unstable during the study period and transferred a large part of their areas to the shrub savannah class. The instability of the former could be explained by its transient nature, which favours its conversion to the forest class, which constitutes the climatic state of the vegetation in the area. Finally, the wooded savannah class recorded a large increase in surface area during the study period. This growth can be explained by the influence of fire. As this class is mainly made up of pyrophytic species, seasonal fire at Lamto allows the dormancy of these species to be lifted, as their seeds are stored in the soil and germinate following the first rains after the fire.

This afforestation of savannas could lead to forest regeneration, which would prove that the ecosystem of the forest-savanna transition is tending towards a forest climax, as opposed to savannisation **(Koulibaly *et al.*, 2016).** This regeneration phenomenon is corroborated by several studies. **Chazdon (2008)** emphasises that tropical forests can recover effectively under favourable conditions, thereby contributing to biodiversity and carbon storage. In addition, **Poorter *et al.* (2021) and N'Guessan *et al.* (2019)** have shown that these forests can regenerate in just 20 years when they are not subject to deforestation or other forms of anthropogenic degradation. This rapid regeneration is essential for maintaining the ecological integrity and ecosystem services of the forests. As far as Badenou FC is concerned, the landscape has evolved towards a regression or even degradation of forest formations such as gallery forests/dense dry forests and open forest/wooded savannahs towards savannah formations such as tree savannahs/shrub savannahs.

This shift in the surface area of these forest formations may correspond to an intensification of human activities, particularly agricultural expansion, illegal gold panning and uncontrolled bush fires **(Andon *et al.,* 2022).**

The political and security crises in Côte d'Ivoire have also played a decisive role in the destruction of woodland in Badenou. The rebellion of 2002 and the post-electoral crisis of 2010-2011 encouraged the invasion of classified forests by local populations, leading to an increase in agricultural clearing and the illegal exploitation of natural resources **(N'Guessan *et al.,* 2025).** The work of **Yao (2019),** carried out in the Dianra department, confirms this trend: forests are gradually being replaced by savannah, fallow land, crops and bare soil. These results highlight the increased vulnerability of these ecosystems to degradation in the absence of targeted conservation measures. In the Bagoué region, **Silué (2018)** also noted a decline in tree formations in favour of open savannahs, as a direct result of agricultural and pastoral pressure. However, the sparsely populated shrub savannahs have become denser, with the majority of their area transformed into tree savannah/shrub savannah. This could be explained by the fact that it was in these sparsely wooded savannahs that grazing took place, with cattle feeding mainly on grasses, thus encouraging the growth and densification of shrub species over the years.

The results relating to climate variability showed a very noticeable dynamic of the climatic variables of RS Lamto and FC Badenou over 32 years of study. Thus, concerning the mean temperature (Tm), a global increase of more than 2°C has been observed in both study areas. The growth trend highlighted by this study demonstrates that these two study areas are not exempt from the global temperature increase, as mentioned by **(IPCC 2021).** According to **Niang *et al.* (2014)**, Africa is experiencing a temperature increase higher than the global average. This result obtained at RS Lamto and FC Badenou is not unique, as authors such as **Biaou *et al.* (2015)** have observed this general increase in temperature in Côte d'Ivoire in general **(Kouao *et al*., 2024; Kouadio and Tohé, 2020; Rutherford and Tohé, 2022).** Furthermore, studies show that West Africa is vulnerable to these variations, influenced by climatic phenomena such as El Niño and La Niña. **Sarr *et al.* (2008),** observed that periods of warming are often linked to fluctuations in precipitation patterns, thereby affecting regional climate systems. The rise in temperatures can also be linked to changes in atmospheric circulation that influence climatic conditions on the African continent, such as Walker, Hadley and monsoon circulations **(Sarr *et al.,* 2008; Nicholson, 2013).** Moreover,

the trade winds, blowing from subtropical regions towards the equator, are also affected by these circulation systems. Changes in the strength and direction of the trade winds can alter the availability of moisture and influence temperatures in West Africa, particularly in Côte d'Ivoire **(Sarr *et al.,* 2008).**

Locally, deforestation and urbanisation are exacerbating these trends. The reduction in forest cover, documented by the **FAO (2020),** alters the microclimate by increasing night-time temperatures, while the urban heat island effect exacerbates maximum temperatures **(Bokaie *et al.,* 2016; IPCC, 2021).** This increase could amplify heat stress, which is particularly critical for hygrophilous species, whose growth and survival could be compromised **(Bond and Midgley, 2000).** The natural cycles, such as the multi-decadal Atlantic Oscillation, modulate these trends on decadal scales, explaining the cooler (1990s) and warmer (post-2000) phases **(Niang *et al.,* 2020). Kouadio *et al.* (2021)** mention that temperature increases can be exacerbated by phenomena such as heat waves, which are becoming increasingly frequent in tropical regions. The **IPCC (2021)** has also pointed out that temperatures in Africa are continuing to rise at a worrying rate, which may be reflected in the meteorological data recorded at the various weather stations in Côte d'Ivoire.

The analysis of wet and dry spells in the Lamto RS and Badenou FC was based on the Standardised Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI). The results of these analyses reveal worrying trends that underline the climatic vulnerability of these regions. The data reveal that almost 67% (RS Lamto) and 63.63% (FC Badenou) of the study period were characterised by periods of drought, highlighting a worrying trend towards aridity. This prevalence of drought could be attributed to many factors, including global climate change, which is intensifying climatic variations on a regional scale. Some studies indicate that increases in global temperatures and changes in atmospheric circulation patterns may lead to a decrease in precipitation and an increase in drought **(IPCC, 2021; Zeng *et al.,* 2020).**

In support of this, studies by **Diawara *et al.* (2014)** show that over the three decades of the study period (1972-1981, 1982-1991 and 1992-2001), West Africa was affected by a rainfall deficit. This persistent lack of moisture could have adverse impacts on biodiversity and local ecosystems.

The study of interactions between climatic variables and land use dynamics in the Lamto Scientific Reserve has shown that temperature is the variable with the greatest influence on the dynamics of the various ecosystems. Precipitation and associated indices (SPI, PDSI), on the other hand, do not correlate significantly with most types of vegetation or land cover in general. There is, however, a specific link between biotopes and climatic variables. For example, forest formations (gallery forest/dense semi-deciduous forest) and pre-forest formations (open forest/wooded savannah) are only linked to the Palmer Drought Severity Index (PDSI), i.e. rainfall. Similarly, temperatures only influence savannah formations (tree and shrub savannahs).

The PDSI shows a positive and average correlation (0.48) with gallery forests/semi-deciduous dense forests, which means that the PDSI, and therefore drought, has no influence on or even encourages the expansion of gallery forests/semi-deciduous dense forests and leads to a regression of pre-forest formations. This expansion of forests during periods of drought could be explained by the resilience of certain plant species present in this habitat. Indeed, the location of the study area in a transition zone favours the establishment of species that can withstand a certain threshold of hydric stress. In addition, this study showed that drought periods, even when they do occur, rarely last for several consecutive years, which could not have a more profound impact on the flora. Many authors, such as **Rammig *et al.* (2010) and Dja *et al.* (2018)**, taking a similar approach, have shown that tropical forests can be resilient to dry periods and maintain their biodiversity by adjusting to the specific adaptation of species.

Unlike forests, pre-forest formations are vulnerable to drought because the PDSI index is negatively correlated with the open forest/wooded savannah class.

Increased drought will accentuate the water deficit in the soil, which will have a negative effect on the flora and therefore, the vegetation. In addition, drought makes these habitats more vulnerable to seasonal fire, which occurs every year to maintain the balance between forest and caravan, leading to degradation and a reduction in their surface area. In a similar approach, **Adjonou *et al.* (2009)** have shown that the reduction in rainfall resulting from climate change hurts the dynamics of woody species in open forests in Togo.

Taking into account the temperature, its increase promotes a progressive dynamic of wooded savannas. Indeed, authors such as **Trenberth and Shea (2005); IPCC (2021),** have shown that the increase in temperature stimulates evapotranspiration, which promotes rainfall. The increase in rainfall will promote the development of vegetation, in the case of wooded savanna, and the

gain in area for watercourses. The regression of shrub savannas, on the other hand, could be explained by the transformation of this habitat into tree savanna when it is subjected to heavy rainfall. This explains the regression of shrub savannas and the progression of tree savannas.

The analysis of the correlations between climatic variables and land use dynamics in the Classified Forest of Badenou, highlights contrasting influences, with a dominant role of temperatures and drought indices.

The significantly negative correlation between average and maximum temperatures and Low-Density Shrub Savannas (LDSS), suggests that the increase in temperatures tends to reduce the area of these formations. This phenomenon reflects a gradual transfer of a significant portion of these savannas to denser formations, particularly Shrub and Tree Savannas (TS/SS), over the past three decades, as justified by the transition matrix. Indeed, the Low-Density Shrub Savannas (LDSS) have decreased from 769.24 ha in 1990 to 254.67 ha in 2022, illustrating this large-scale dynamic.

However, this shift should not be perceived as degradation, but rather as a process of increased vegetation, marked by the gradual densification of Low-Density Shrub Savannas (LDSS). Indeed, these habitats become denser thanks to the regeneration and recruitment of young trees. The increase in tree cover transforms these initially sparse formations into denser formations, to the benefit of shrub and tree savannas (TS/SS). This observation is corroborated by positive correlations between the Palmer Drought Severity Index (PDSI) and Low-Density Shrub Savannas (LDSS), with a correlation value of 0.384 ($p = 0.028$), suggesting an expansion of these formations during periods of increased drought.

On the other hand, other correlations are not statistically significant. Thus, the correlation between Low-Density Shrub Savannas (LDSS) and the standardized precipitation index (SPI) is weak (0.126, $p = 0.483$), indicating that relative humidity does not have a significant effect on this vegetation formation. This highlights the resilience of Low-Density Shrub Savannas (LDSS) to climate variability, particularly the increase in temperatures and prolonged drought. Indeed, in the Classified Forest of Badenou, these formations are dominated by xerophytic species such as *Dicrostachys cinerea*, *Ximenia americana*, *Zanthoxylum zantholoides*, *Acacia seyal*, *Carissa edulis*, *Cassia sieberiana*, *Acacia nilotica*, *Ziziphus mucronate*, *Ziziphus mauritania*, *Waltheria indica*, etc., known for their adaptation to extreme conditions **(N'Guessan *et al.*, 2006).**

Moreover, some Low-Density Shrub Savannas are located along the waterways, between the Gallery Forests and the Wooded Savannas/Open Forests, or at the tops of hills on ferruginous crusts, particularly in the western zone of the classified forest. This positioning provides them with constant access to water, thus promoting their development. Conversely, in the Eastern zone, these formations are found on well-drained soils with a ferruginous character, which may explain some variations in their densification dynamics. The densification of these formations is mainly attributed to natural regeneration, often facilitated by grazing, a mechanism documented in West African pastoral systems **(Venter *et al.*, 2017).** Indeed, in the classified forest of Badenou, the livestock of the Peuhl herders, mostly in transhumance, graze in these areas. This grazing limit competition between grasses and young woody recruits, thereby promoting their growth. This process gradually leads to the transition of formations initially composed of two layers to formations with three or more layers, with tree heights increasing from 6 to 15 meters **(Traoré *et al.*, 2015). Buisson *et al.* (2019)** reinforce this observation by highlighting the resilience of savannah ecosystems to anthropogenic disturbance, thanks to the diversity and specific adaptations of plant species. Savannas resist disturbance effectively thanks to their plant biodiversity, morphological adaptations (deep roots, thick bark, thorns) and natural mechanisms (fire-stimulated regeneration, symbiosis with fungi, pollination).

The positive correlation between Perennial Crop (PC) and mean temperature (0.427, $p = 0.014$), as well as maximum temperature (0.413, $p = 0.017$), suggests that these cultivated species may be favoured in warmer climatic conditions. This trend could be explained by the better resistance to high temperatures or the adaptation of the cultivated species. Indeed, most perennial crops within this classified forest are dominated by cashew tree (*Anacardium occidentale*) and mango tree (*Mangifera indica*), two species well adapted to the climatic conditions in the north of the country, characterised by higher temperatures and lower rainfall than those observed in the southern forest zone **(Yao, 2019).** Thus, higher temperatures and drought do not appear to have a negative impact on these crops. Moreover, the farmers who practice these crops clandestinely in the classified forest of Badenou, tend to settle in open forests and wooded savannas to avoid detection by the Water and Forest agents. When these areas are cleared, they transform into fallow lands (FL) which, if left undisturbed, gradually return to their original formation. This phenomenon is reaffirmed by the works of **Yao (2019) and Silué (2018).**

A similar phenomenon is observed for fallow lands (FL), which are negatively correlated with average temperature (-0.427, p = 0.014) and maximum temperature (-0.413, p = 0.017), meaning that the increase in average and maximum temperatures leads to a reduction of these changing areas. These results confirm the gradual conversion of fallows (FL) into Open Forest/Wooded Savanna and Shrubby Savannas/Tree Savannas (TS/SS).

As with Low-Density Shrub Savannas (LDSS), the fallows are densifying and returning to their original formation. The analysis of transitions highlights the conversion of fallow lands into shrub/wooded savannas and light forests/wooded savannas. Since the classified forest is a protected area, the local populations enter it clandestinely to develop crops. In order to avoid surveillance by the Water and Forest agents, these populations prefer the lighter forests, whose soils are rich, and they camouflage these cultivated areas by deliberately leaving strips of untouched forest. Initially, these areas are exploited for annual crops (rice, cotton, food crops, maize), then gradually replaced by perennial crops such as cashew and mango. This cycle of temporary anthropisation followed by natural regeneration highlights a complex dynamic between human activities, changes in plant cover and ecosystem resilience. The work of several authors confirms this trend, emphasising that this transition to perennial crops is motivated by economic and ecological considerations, ensuring economic stability and better climate adaptation **(Timité *et al.,* 2023; Konan *et al.,* 2023; N'Guessan *et al.,* 2019; Koffi *et al.,* 2019; Kpangui *et al.,* 2021).** In contrast, water bodies (WB) show a significant negative correlation with PDSI (r = -0.545, p = 0.001), confirming their vulnerability to prolonged droughts. The reduction in their surface area, amplified by evaporation in the dry season, is in line with trends observed in West Africa **(Corcoran *et al.,* 2013).** In fact, during this period, intense evaporation, combined with increased demand for water by species, exacerbates the drying up of watercourses. The lack of rainfall prevents them from being recharged, leading to a reduction in their surface area. Some streams and tributaries dry up completely, only recovering their levels when the rainy season returns **(Noufé *et al.,* 2015).**

Furthermore, a positive correlation between the Bare Soil/Habitat (BL/ST) class and the SPI (r = 0.362, p = 0.039) indicates that wet periods exacerbate erosion and promote the expansion of agricultural land as well as gold panning areas. This phenomenon, documented by **Borrelli *et al.* (2017),** is linked to the intensification of human activities, particularly agricultural ploughing and digging for gold panning, which are facilitated by abundant rainfall and lead to increased soil

degradation. During the wet season, farmers take advantage of favourable weather conditions to prepare their fields and sow seeds, which intensifies soil denudation through land clearing. Similarly, gold-panning activities increase during this period, as the increased humidity facilitates extraction and the digging of pits. As a result, the extent of bare soil increased considerably, reducing the protective vegetation cover. These exposed soils, devoid of vegetation, become particularly vulnerable to water erosion during heavy rains. In addition, the numerous holes dug by gold panning activities accumulate large quantities of water, exacerbating erosion of the surrounding soil and encouraging the creation of gullies and rapid impoverishment of the land. This process, which has been widely documented by Ivorian researchers, therefore contributes directly to the emergence and expansion of land degradation phenomena in Côte d'Ivoire **(Aké *et al.,* 2012; Yao, 2023; N'Go *et al.,* 2018).**

The study carried out in the two sites on quantitative diversity of preferred habitats of A. *africana* and P *erinaceus*, identified a total of 424 species divided into 81 families distributed in 233 genera. These results show that these two sites together harbour a significant wealth of flora, representing around 10.6% of the total floristic wealth of Côte d'Ivoire, estimated at 3991 species of flowering plants **(Aké-Assi, 2001; 2002; Chatelain *et al.,* 2011).** However, these figures are still lower than those obtained by **Yao (2019),** who identified 487 species in the SANGARE Mamadou estate in Dianra, northern Côte d'Ivoire. In contrast, the work of **Silué (2018)** on the classified forests of Palé and Pouniakélé recorded 281 and 316 species, respectively, which is significantly lower than the total of 424 species found in this study. Furthermore, in comparison with the studies carried out in the south, the work of **Abrou (2019)** and **Missa *et al.* (2015)** counted 568 and 432 species respectively in the Forêt des Marais Tanoé-Ehy in south-eastern Côte d'Ivoire. When each site is examined individually, notable differences emerge. The Lamto Scientific Reserve stands out for its floristic richness of 294 species divided into 66 families belonged in179 genera, which represents around 14.37% of the floristic richness of the Sudano-Guinean zone (GC-SZ), estimated at 2046 species **(Aké-Assi, 2001; 2002; Chatelain *et al.,* 2011).** These results are slightly lower than those obtained by **Kouakou (2025),** who counted 302 species in the same site. On the other hand, our results exceed those reported by **Guelou *et al.* (2018),** who identified a total of 130 species in the Lamto reserve.

In comparison, the Badenou Classified Forest has a richness of 242 species, divided into 55 families spread in 137 genera. This figure represents around 6.06% of the total floristic richness

of Côte d'Ivoire, but also 15.56% of the 1556 species of the Sudan-Zambezian ecological zone (SZ). These differences can be explained by several factors. Lamto, with its semi-deciduous forests and gallery formations, offers a greater variety of micro-habitats and ecological conditions conducive to higher biodiversity. Badenou, although home to diverse formations such as dense dry forests and wooded savannahs, seems slightly more homogenous in terms of floristic composition, which could explain its lower number of species. All these differences can be explained by the fact that these authors considered all the habitats and all the species present, whereas our work focuses specifically on *Afzelia*, *Pterocarpus* and their companion species. Consequently, only the habitats that were home to these target species were characterised.

Regarding the family spectrum of the two sites, the Fabaceae dominate with 17% of the recorded species. This percentage is in agreement with previous studies on the Ivorian flora, where the Fabaceae are often cited as the most diverse family **(Aké-Assi, 2002; Goné Bi *et al.,* 2013).** The Rubiaceae, Poaceae and Malvaceae follow, contributing 8% and 5% to the diversity, respectively. These results reflect regional trends where these families dominate both forest formations and savannas.

The studied sites reveal significant variations in floristic composition. At Lamto, the Fabaceae dominate with 14% of the recorded species, followed by the Rubiaceae (9%) and the Poaceae (8%). The predominance of these three families (Fabaceae-Rubiaceae-Poaceae) highlights the transitional nature of the Lamto Scientific Reserve, where a mosaic of savannas and forest areas coexist. The Rubiaceae, typical of Ivorian forests, coexist there with the Fabaceae, which represent the most abundant family, as well as with other structuring families such as Euphorbiaceae, Apocynaceae, Combretaceae, Malvaceae, and Moraceae. The Poaceae, on the other hand, dominate the savannas and open spaces, often associated with the Fabaceae and Combretaceae. These observations corroborate the work of **Guillaumet and Adjanohoun (1971), Aké-Assi (2001-2002), Kouamé *et al.,* (2008), and Adou Yao (2005),** among others.

At Badenou, the predominance of Fabaceae is clearly increasing, accounting for 21% of species. This trend can be explained by the fact that the Badenou Classified Forest is part of the savannah biome, a suitable environment for Fabaceae and Poaceae. Malvaceae are better represented here (7%) than at Lamto, while Combretaceae and Rubiaceae each account for 5% of species, followed by Moraceae (4%). This floristic configuration, similar to that described by **Ouattara *et al.*** (**2016**), reflects the ecological influence of savannahs, where Fabaceae play a central role, accompanied

by families adapted to the conditions of light and competition characteristic of open areas. The works of **Thiombiano (1996), Hahn-Hadjali (1998), Silue (2018) and Kouakou (2020),** also highlight this dynamic, which is typical of savannah ecosystems in West Africa.

In terms of target species, the results show that *Afzelia africana* is associated with habitats with higher species diversity than those under *Pterocarpus erinaceus* influence. At Badenou, habitats under *Afzelia africana* influence, such as tree savannah (138 species) and open forest (134 species), are the richest. In contrast, the shrub savannah under *Pterocarpu*s, is the least diverse (28 species). At Lamto, a similar pattern emerges, with *Afzelia africana* occupying more species-rich habitats, such as dense semi-deciduous forest (224 species), while *Pterocarpus* is associated with less diverse shrub savannas (27 species). These differences could be explained by the ecological requirements of the two species, their ability to compete, and their impact on the composition of the undergrowth and the herbaceous cover. Thus, the divergence between the two sites stems fundamentally from their belonging to distinct ecological zones: transitional GC-SZ for Lamto and strictly SZ for Badenou. This distinction shapes not only the dominance of Fabaceae but also the secondary distribution of other families, underlining the importance of climatic and edaphic gradients in the structuring of West African plant communities.

In terms of floral composition, specifically biological types, the overwhelming dominance of Microphanerophytes (MicroP) and Nanophanerophytes (NanoP) at both sites (53-56% of species) reflects a common feature of West African ecosystems subject to anthropogenic or climatic disturbance. A dominance of microphanerophytes is indicative of disturbance in forests, whereas it appears to be a natural or climatic feature of certain types of savannahs, particularly those subject to fire. This preponderance, already documented by **Blanc *et al.* (2003) and Sokpon (1995)**, can be explained by the adaptation of these biological types to shrub and sub-shrub strata, typical of regenerating or fragmented environments. The low representation of therophytes, geophytes and hemicryptophytes (<5%), which are absent from shaded or disturbed habitats, confirms their competitive exclusion, a classic phenomenon in forest ecology **(Devineau, 1984; Bangirinama *et al.*, 2010).**

At Badenou, MicroP dominates (53%), particularly around *Afzelia africana* (60%) and *Pterocarpus erinaceus* (53%). This trend reflects an adaptation to open savannas and recurrent fires, typical of the Sudan-Zambezian biome **(Thiombiano, 1996).** On the other hand, at Lamto,

although MicroP remain in the majority (56%), the higher proportion of Mesophanerophytes (MesoP) (29% compared with 17% at Badenou) indicates a more mature forest structure, characteristic of GC-SZ transition zones or dense forests (GC), where dense tree cover persists **(Guillaumet and Adjanohoun, 1971).**

The habitat analysis reveals notable nuances. In the Semi-Deciduous Dense Forest at Lamto, home to *Afzelia africana*, MicroP reach 75% (126 species), highlighting their adaptation to closed and stable habitats.In Badenou, in the Tree Savanna, *Pterocarpus erinaceus* is associated with 53% of MicroP (82 species), reflecting resilience to disturbances. These differences illustrate how biological types adjust to local ecological constraints, as observed by **Kouamé (1998)** in similar contexts.

Regarding chorology, the chorological differences between Badenou (SZ zone) and Lamto (GC-SZ zone) highlight the impact of biogeographical gradients on floristic composition. Overall, the Guinea-Congolese/Sudano-Zambesian (GC-SZ) species dominate (47% in Badenou, 34% in Lamto), reflecting a gradual ecological transition. However, the specificity of the sites is marked: at Badenou, GC-SZ and SZ species (34%) predominate, adapted to dry savannas and fires (Thiombiano, 1996), while at Lamto, GC species (63% in Semi-Deciduous Dense Forest) dominate, marking a residual connectivity with Guinea-Congolese forests **(Guillaumet and Adjanohoun, 1971).**

In terms of target species, *Afzelia africana* at Lamto is associated with 63% of GC species in Semi-deciduous Dense Forest, confirming its role as an umbrella species for forest flora. At Badenou, on the other hand, 65 GC-SZ species accompany it in the open forest, illustrating its adaptation to disturbed edges. *Pterocarpus erinaceus* displays ecological plasticity: at Lamto, it is linked to 56 GC species in Dense Forest, but also to 30 GC-SZ species, while at Badenou, it dominates the SZ savannahs (58 species), typical of open environments. These variations corroborate the work of **Koffi (2016)** on the flexible ecological niche of *Pterocarpus.*

In terms of phytogeography, the predominance of intertropical African taxa (A) (60-68% in both sites) underlines the West African biogeographical anchorage of these ecosystems. At Badenou, 60% of species are type A, but only 2 strict endemic species (GCi) have been recorded, a sign of increased anthropic pressure **(Ouattara *et al.,* 2016).** At Lamto, this proportion rises to 68%, with 87% of the species associated with *Afzelia africana* belonging to this group, confirming its status as a refuge for regional endemism **(Koulibaly *et al.,* 2016).**

In the Semi-deciduous Dense Forest at Lamto, 192 A species (87%) were recorded around Afzelia, including 35 species with special status (4 vulnerable according to the IUCN). At Badenou, in the Tree Savannah, *Pterocarpus erinaceus* is associated with 73% of A species, but with only 2 GCWs, reflecting a flora adapted to disturbance. The scarcity of pantropical taxa (PanT, <10%) at both sites confirms relative isolation, as noted by **Aké-Assi (1984).**

The results on special-status species reveal that *Afzelia africana* emerges as a key species, associated with 46 special-status species, compared with 12 for *Pterocarpus erinaceus*. In Lamto, its habitats host 35 remarkable species (including 3 GCI and 20 GCW), highlighting its role as an ecological umbrella for conservation **(Koulibaly *et al.,* 2016).** In the Semi-deciduous Dense Forest, 4 vulnerable species (IUCN) and 7 species of regional concern **(Aké-Assi, 1998)** have been recorded, reflecting the urgent need to protect these environments.

At Badenou, the *Pterocarpus erinaceus* habitats are home to 10 remarkable species (including 3 vulnerable species), which are adapted to disturbed savannahs. However, the low presence of strict endemics (2 GCI) highlights the limits of resilience to agriculture and fire, as observed by **Ouattara *et al.* (2016).**

The alpha diversity indices (Shannon, Piélou, Simpson) reveal significant variations between the habitats and species studied, reflecting distinct ecological conditions. At Lamto, the dense semi-deciduous forest associated with *Afzelia africana,* has the highest values for the Shannon index (4.15) and the Simpson index (0.97), as well as a high Piélou equitability (0.88). This high diversity is explained by the complex structure of the environment, characterised by pronounced vertical stratification and dense forest cover, which favours the coexistence of specialised species such as *Psychotria capensis* (Rubiaceae) and *Dioscorea preussii* (Dioscoreaceae). These species, adapted to a humid and stable microclimate, benefit from a homogeneous distribution of resources, limiting the dominance of competitive species **(Richards, 1996).**

At Badenou, the tree savannah under *Afzelia africana,* also displays high diversity (Shannon = 4.12; Piélou = 0.84; Simpson = 0.97). All these values are synonymous with an enrichment and diversification of the flora of the site's different biotopes. Indeed, the more stable a habitat, the higher its diversity indices **(Adingra, 2017).** These results could also be explained by the fact that *Afzelia*'s preferred habitats are rich and heterogeneous. This richness could also be explained by the spatial heterogeneity induced by low-intensity seasonal fires, which eliminate sensitive species while stimulating the germination of pyrophytic plants such as *Andropogon gayanus* (Poaceae).

The resistant shrubs, such as *Combretum glutinosum* (Combretaceae), regenerate rapidly after disturbance, maintaining a competitive balance **(Higgins *et al.*, 2000).**

In contrast, *Pterocarpus erinaceus* habitats at Lamto, show the lowest values (Shannon = 2.50; Piélou = 0.68; Simpson = 0.85), particularly in wooded savannah. This low diversity is the result of water stress and the dominance of competitive grasses (*Loudetia simplex*) and drought-resistant Fabaceae (*Stylosanthes erecta*), which monopolise resources. These conditions create a strict environmental filter, excluding less adapted forest species **(Grime, 1977).**

The floristic similarity analysis reveals partial ecological continuity between the sites, but also marked divergences. The high similarity (Cλ = 0.88) between the *Afzelia africana* communities of Lamto and Badenou is explained by common functional traits, such as deep root systems (*Daniellia oliveri*, Fabaceae) and xeromorphic leaves (*Gardenia ternifolia*), which are adapted to dry seasons. These generalist species effectively colonise forest-savannah transition zones, benefiting from moderate disturbance **(Sanon *et al.*, 2007).**

Conversely, the low similarity between *Afzelia* of Badenou and *Pterocarpus* of Lamto (Cλ = 0.23) reflects divergent ecological niches. The ferruginous and leached soils of the Pterocarpus savannahs at Lamto favour psammophilous species (*Piliostigma thonningii*, Fabaceae), while the richer soils at Badenou are home to neutrophilous species (*Khaya senegalensis*, Meliaceae). These edaphic differences, combined with distinct fire regimes, act as environmental filters (**Hahn-Hadjali, 2006).**

Venn diagrams reinforce this interpretation: the 112 common species include generalists such as *Annona senegalensis* (Annonaceae), which are tolerant of a wide ecological gradient. The 183 species exclusive to Lamto, such as *Cola cordifolia* (Malvaceae), depend on the constant humidity of dense forests, while the 130 species exclusive to Badenou, such as *Crossopteryx febrifuga* (Rubiaceae), are adapted to frequent fires. The distribution of species illustrates contrasting adaptive strategies. In the dense semi-deciduous forest of Lamto, the 160 exclusive species (*Nesogordonia papaverifera*, Malvaceae) are linked to a stable microclimate, with abundant litter and persistent humidity. These conditions favour sciaphilous and hygrophilous plants, typical of mature forest ecosystems (**Poorter *et al.*, 2004).**

At Badenou, the 22 species common to both tree and woodland savannas (*Piliostigma thonningii*, *Vitellaria pardoxa*, Sapotaceae) show resilience to disturbance through natural clonal regeneration mechanisms or dormant seeds activated by fire. In contrast, the 28 species exclusive to open forest

(*Indigofera hirsuta*, Fabaceae) take advantage of the temporary light available after *Afzelia* leaves have fallen, illustrating an adaptation to ephemeral microhabitat niches **(Gignoux and Menaut., 1997; Bouché *et al.*, 2018).**

The average tree density shows marked variations between the plant formations studied. At Badenou, habitats dominated by *Afzelia africana*, such as the shrub savannah, reached exceptional densities of 348 trees/ha, while the *Pterocarpus erinaceus* savannahs at Lamto recorded the lowest values (28 trees/ha). These differences can be explained by ecological and management differences between the sites. The Lamto Reserve, strictly protected from all human activity, contrasts with the Badenou Classified Forest, managed by SODEFOR. In Côte d'Ivoire, classified forests are subject to selective and rational exploitation, which encourages the gradual infiltration of populations, particularly after the post-electoral crisis, leading to partial degradation of habitats **(Koffi, 2016).**

Ecologically, *Pterocarpus erinaceus* has a Sudan-Zambezian (SZ) chorology, adapted to arid northern savannas. Its low density at Lamto, located in the Guinean transition zone, is explained by its unsuitability for high rainfall and less favourable soils. By contrast, *Afzelia africana*, which has a Guinea-Congolese and Sudan-Zambezian (GC-SZ) chorology, thrives in these transitional zones (**Aké Assi, 1984; Adou Yao, 2007).** In Badenou, overgrazing favours the regeneration of woody plants to the detriment of grasses, increasing tree density, unlike in Lamto where shrubby savannahs, dominated by Poaceae, limit the establishment of young trees.

The dense dry forests (206 trees/ha) and gallery forests (146 trees/ha) of Badenou have high densities, reflecting favourable microclimatic conditions (humidity, deep soils) and active regeneration, typical of ecosystems protected from fire. Conversely, the Lamto savannahs, which are subject to seasonal fires and hydromorphic clay soils, show minimum densities. These results concur with those of **Kouamé (1998)** in the Forêt Classée du Haut Sassandra, where degraded savannas have less than 50 trees/ha.

The basal area, a key indicator of woody biomass, ranges from 0.41 m²/ha in the shrub savannas of Lamto to 9.68 m²/ha in the gallery forests of Badenou. The latter stand out for their high values associated with the presence of mature trees (*Khaya senegalensis*, *Diospyros mespiliformis*) characteristic of stable riparian ecosystems **(Casanova and Brock, 2000).** A continuous water supply promotes their growth, as observed in the Marahoué National Park (**N'Da *et al.*, 2008).** In Lamto, shrub savannas, dominated by shrubs, have the lowest values with small diameter and

grasses. This could be explained by edaphic constraints (hydromorphic soils) and recurrent fires, limiting the development of trees. In contrast, the dense dry forests of Badenou (Afz-Bd_FDS: 8.98 m²/ha) exhibit a heterogeneous structure, mixing young recruits and older individuals.
The differences between the sites can also be explained by their management history. At Badenou, the gallery forests, relics of the forest cover of the 1900s (16 million hectares at the time), have recently been given greater protection, allowing the conservation of large trees. At Lamto, the forest formations are home to large-diameter trees, but the changing savannahs, dominated by small-diameter pioneer species, are reducing the average basal area overall. These observations corroborate the work of **Coulibaly (2019),** who found higher basal areas (19.36 m²/ha) in the open forests of Napié, which are rich in mature individuals.

The study of interactions between *Afzelia africana*, *Pterocarpus erinaceus* and their companion species reveals marked ecological differences between the Lamto and Badenou sites. These differences are influenced by a number of environmental, climatic and historical factors, which have shaped the distribution of these species within their respective ecosystems. Previous work has also highlighted these dynamics in other regions of West Africa, confirming the trends observed **(Fayolle *et al.,* 2012; Nacoulma *et al.,* 2011).**

The results indicate that the spatial distribution of *Afzelia africana* and *Pterocarpus erinaceus* varies between the two sites. At Lamto, a clear separation of habitats is observed: *Afzelia africana* is mainly present in gallery forests and degraded dry forests, while *Pterocarpus erinaceus* is dominant in tree savannas and open forests. This separation of ecological niches is in line with the findings of **Swaine and Whitmore (1988)**, who point out that forest and savannah species have contrasting adaptive strategies, the former being more dependent on rich soils and humidity, while the latter thrive better under water stress and in open conditions.
In Badenou, the two species coexist more frequently in the same habitats, particularly in gallery forests and open forest. This observation suggests that the environmental conditions in Badenou allow for greater ecological tolerance and cohabitation. A similar study carried out in Burkina Faso by **Ouédraogo *et al.* (2015)** showed that *Pterocarpus erinaceus* can coexist with forest species in transitional plant formations, particularly where there is water availability and deep soils.
These results confirm the work of **Fayolle *et al.* (2012),** who highlighted the strong influence of local ecological conditions on the structuring of dry tropical forests in Africa. They also concur

with the conclusions of **Nacoulma *et al.* (2011)** on the variable coexistence of certain species depending on soil and climatic conditions.

The analysis of co-occurrences and correlations revealed marked trends in ecological interactions between species. *Afzelia africana* is strongly associated with *Mimusops kummel*, *Isoberlinia tomentosa* and *Terminalia avicennioides*, indicating that these species probably share similar ecological requirements. *Erythrophleum suaveolens*, frequently found with *Afzelia africana*, confirms the field observation that these two species often share the same habitats. It also serves as an indicator species in the Lamto reserve.

In contrast, *Pterocarpus erinaceus* shows a negative relationship with *Afzelia africana*, indicating a clear ecological separation. This result is consistent with the observations of **Schmidt *et al.* (2017),** who showed that savannah species often compete with those of forest formations due to differences in space occupation strategy and tolerance to water stress.

A study by **Bognounou *et al.* (2013)** on woody species in the Sudano-Sahelian zone of Burkina Faso found similar trends, with strong ecological associations between certain species and mutual exclusion between those with distinct ecological niches. Our results are therefore part of this general dynamic observed in West Africa **(Traoré *et al.,* 2012; Yelemou *et al.,* 2015; Bognounou *et al.,* 2009, Diop *et al.,* 2005).**

The differences in distribution observed between Lamto and Badenou, are partly explained by soil and local hydrological factors. The Bandama River acts as an ecological corridor, favouring the persistence of forest species in drier environments. At Lamto, the wetter soils favour forest species, which explains the dominance of *Afzelia africana* and its association *with Dialium guineense* and *Diospyros mespiliformis*. This phenomenon was described in the work of **Devineau and Fournier (2007)**, who showed that soils rich in organic matter and well-drained are decisive for the persistence of forest species in the transition zone.

In Badenou, where conditions are drier, water-stress tolerant species such as *Pterocarpus erinaceus* and *Terminalia avicennioides* are favoured. These results are in line with those of **Nacoulma *et al.,* (2011)**, who studied the dynamics of open forests and wooded savannahs in Côte d'Ivoire and Burkina Faso, and found a differentiated distribution of species according to water conditions and soil type. This differentiation is in line with the observations of **Ouédraogo *et al.* (2013)** on the influence of environmental gradients on the structure of African dry forests.

The observed result on the impact of climate change on carbon sequestration capacity of *Afzelia africana* and *Pterocarpus erinaceus* showed a difference in carbon sequestration between them. That can be explained, primarily by their contrasting ecological and physiological strategies. *Afzelia africana* adopts a conservative strategy, characterised by slow growth, long life and dense wood. This strategy is based on moderate and stable metabolic functioning, geared towards storage efficiency rather than growth rate. The cambial activity of the species is regular but not very intensive, producing durable structural wood tissues each year, such as heartwood, sapwood and large roots. These structures, made up of highly lignified dead cells, are biologically inactive but chemically very stable, enabling them to store carbon over several decades or even centuries. In addition, the high density of *Afzelia* wood, often in excess of 0.8 g/cm³, reinforces this capacity, as the denser the wood, the more carbon it concentrates per unit volume. Unlike fast-growing tissues such as leaves or fine roots, which are renewed annually, woody tissues represent permanent carbon reservoirs. From a physiological standpoint, the species operates with moderate but constant photosynthesis, low transpiration due to good stomatal regulation, and a preferential allocation towards long-term support tissues. This allows for a continuous accumulation of biomass, even in slightly constrained environments. This strategy is illustrated by the high biomass values recorded at Badenou (95.4 t/ha) and Lamto (182.09 t/ha), highlighting the structuring role of *Afzelia* in stable tropical carbon sinks **(Stephenson *et al.,* 2014).**

In contrast, *Pterocarpus erinaceus* follows an opportunistic growth strategy. The species prioritizes the rapid exploitation of available resources, with fast growth, lower density wood, and a shorter lifespan. Metabolically, *Pterocarpus* exhibits high stomatal conductance, which allows for efficient CO_2 exchange and high photosynthetic assimilation. This assimilation is supported by high enzymatic activity, notably of rubisco, peroxidases, and cellulases, which promote rapid cell division in the apical meristems. The species also mobilizes a large amount of energy in the production of ephemeral organs such as leaves, fine branches, or superficial roots. These tissues, although inexpensive to produce, are unstable and only temporarily store carbon.

Moreover, since *Pterocarpus* wood is less dense, it stores less carbon per unit volume, even with rapid growth. This species fully takes advantage of wet periods, but remains dependent on climatic variability. It thus plays a complementary role to that of *Afzelia*: its sequestration rate can be high in favourable years, but its contribution remains unstable and less durable **(Malhi *et al.,* 2011; Brienen *et al.,* 2015).** The work of **Giller *et al.* (2021)** emphasises the importance of integrating

resilience approaches into the management of forest ecosystems, allowing for a better understanding of how forests can continue to sequester carbon despite climatic disturbances.

The results reveal that at Badenou, the temporal dynamics of carbon sequestration are strong contrasts between *Afzelia africana* and *Pterocarpus erinaceus*, shaped by a combination of climatic, ecological and anthropogenic factors.

In the case of *Pterocarpus erinaceus*, the high inter-annual variability in biomass gains highlights its marked dependence on water conditions. This sensitivity is corroborated by the high correlations with rainfall ($r = +0.82$, $p < 0.001$), the SPI index ($r = +0.65$, $p = 0.007$) and the PDSI index ($r = +0.58$). This behaviour is consistent with the observations of **Schöngart *et al.* (2006),** who demonstrated that tropical species that are reactive to precipitation show growth that is highly synchronised with rainfall patterns. Although the average sequestration (+0.345 t/yr) is not statistically significant ($p = 0.081$), it reflects high ecological plasticity, enabling the species to take advantage of wet years.

This dynamic is all the more remarkable, given that *Pterocarpus* grows here in its preferred natural zone, the Sudan-Zambezian zone (SZ), which favours its optimal development. In Badenou, its trees are particularly vigorous, with dimensions comparable to those of *Afzelia africana*. Moreover, the species is less targeted by livestock farmers for grazing, which means it can grow with less human disturbance than its counterpart.

Conversely, *Afzelia africana* showed a gradual downward trend in growth, with a slight decline in sequestration (-0.085 t/yr), although this was not significant ($p = 0.134$). This slowdown could reflect increasing heat stress, as highlighted by **Zhou *et al.* (2014)** for other African forests. But this stagnation cannot be explained by climate alone. The Badenou Classified Forest is under heavy human pressure: intensive grazing by cattle, pruning, debarking, illegal gold panning, drying up of watercourses, soil erosion and illegal occupation by infiltrating farmers. The latter often settle in the dense, shady areas that are *Afzelia*'s preferred habitats, exacerbating the degradation of its vital habitats. This multiple pressure greatly weakens the stands, reducing their vigour and their capacity to store carbon.

Finally, the overlap between the two species in a variety of habitats (open, dense forests, galleries, savannahs) indicates a loss of ecological selectivity and reflects the advanced degradation of forest ecosystems. In this context, the apparent resilience of *Afzelia*, a species typical of transition zones (GC-SZ), reflects its ability to persist in disturbed environments. However, this resilience is now

compromised by the loss of its preferred habitats, which were once abundant but have now been reduced to a fraction of their original extent, with the Ivorian forest having shrunk by almost 90% since the beginning of the 20th century. Furthermore, this comparison could reinforce the observation that human pressure, combined with climatic constraints, considerably reduces the resilience of *Afzelia africana* **(Pan *et al.*, 2011).**

At Lamto, the sequestration dynamics exhibit remarkable stability, in contrast to the marked fluctuations of Badenou. This temporal constancy can be explained by several structural and functional factors.

The low climatic variability of the Lamto Scientific Reserve, located in the Guinea-Congolese and Sudanian-Zambezian transition zone (GC–SZ), offers a stable environment in terms of temperature and precipitation. **N'Dri *et al.* (2018),** highlighted this stability, which allows for continuous plant growth without major climatic stress. In parallel, the protected reserve status strongly limits human disturbances, ensuring almost ideal ecological conditions for woody species. In this context, *Afzelia africana* fully expresses its development potential. Present in its optimal ecological zone, it shows particular vigour, with well-developed and abundant individuals in gallery forests and dense semi-deciduous forests. Its conservative strategy (slow growth, dense wood) combined with the absence of human pressures allows for stable and sustained sequestration, in accordance with the results of **Asefi-Najafabady *et al.* (2014),** which show that hardwood species maintain stable productivity in protected environments.

On its part, *Pterocarpus erinaceus* shows moderate growth variability at Lamto. Although it is sensitive to humidity, its growth is less unstable than at Badenou. This can be explained by the fact that *Pterocarpus erinaceus* does not grow here in its preferred habitat. A Sudan-Zambezian (SZ) species, it is better adapted to the savannahs of the north of the country. Lamto, located in the forest-savannah transition zone (GC-SZ), offers a less favourable environment, which hampers its dynamism but also reduces the risk of extreme water stress. In addition, its ability to exploit semi-open niches (open forests, wooded savannahs) means that it can maintain regular growth without competing strongly with *Afzelia*. Finally, the structure of humid tropical soils, subjected to leaching cycles and moderate fertility, could also limit their productivity **(Quesada *et al.*, 2012)**, but without causing major ecological shocks thanks to the local climatic stability. In this same vein, the study by **Quesada *et al.* (2012)** emphasises that the stability of conditions in a protected environment promotes constant carbon sequestration.

The result of the influence of climatic variables on carbon sequestration in the Badenou Classified Forest, reveal that the contrasts become more pronounced. *Afzelia africana* showed a slight negative correlation with temperature ($r = -0.28$), which could reflect thermal stress affecting its growth. No significant relationship was found with rainfall or water indices ($p > 0.05$). The sequestration trend was slightly down (-0.085 t/year), but statistically insignificant ($p = 0.134$), reflecting a possible stagnation in a more restrictive climatic context. These observations suggest relative stability, but limited adaptive capacity in a highly fluctuating environment, as previously reported by **Sosef *et al.* (2017).**

However, the stagnation in carbon stock observed in *Afzelia africana* at Badenou cannot be attributed solely to climatic constraints. It could also be explained by strong human pressure on the area. The Badenou Classified Forest is heavily exploited by Fulani herders, who regularly use *Afzelia* as a grazing plant for their livestock. This use leads to frequent pruning and skinning, which weakens the trees, slows their growth and compromises their carbon sequestration capacity. Unlike in Lamto, where the species studied still maintain distinct ecological niches, *Afzelia* and *Pterocarpus* in Badenou now overlap in a wide variety of plant formations: open forests, dense dry forests, gallery forests, wooded savannahs and wooded savannahs. This overlap, which is unusual given their natural ecological preferences, reflects the advanced degradation of their original habitats, forcing these species to colonise residual and often disturbed environments.

In this context, the apparent resilience of *Afzelia africana* can be explained by its status as a species typical of the transition zones between the Guinean-Congolese and Sudanian-Zambezian zones (GC-SZ). Historically, it has managed to maintain its presence in the northern Ivorian landscape, even after the massive retreat of the forests, which have shrunk from around 16 million hectares at the start of the 20th century to less than 10% today. This decline, caused by agricultural expansion, logging and bush fires, has profoundly transformed the ecosystems. Thanks to its ability to adapt to more open environments, *Afzelia africana* has persisted. However, this historical ecological resilience is no longer sufficient in the face of multiple contemporary pressures, which are now severely limiting its growth.

Among these pressures, illegal gold mining represents a major factor of degradation. This illegal activity promotes accelerated soil erosion, the drying up of watercourses, and the destruction of forest habitats, altering the conditions necessary for the regeneration and development of woody

species. These water disruptions worsen soil dryness, reduce water availability, and compromise carbon sequestration by trees.

In parallel, illegal logging, often targeting valuable species like *Afzelia africana*, as well as uncontrolled agricultural expansion, exacerbate the degradation of the Classified Forest. The infiltrated farmers, to evade the authorities' controls, settle in closed or densely wooded areas, precisely the habitats most favourable to *Afzelia*. By converting them into agricultural zones, they destroy the ecological conditions essential for the survival and growth of the species. Thus, this cumulative anthropogenic pressure grazing, gold panning, deforestation, illegal agriculture, weakens the populations of *Afzelia africana* in Badenou. Although the species has demonstrated its ability to adapt to transitional environments, it now faces a rapid loss of its preferred habitats, exacerbated by thermal stress and water variability. These unfavourable conditions limit its development and inevitably reduce its contribution to carbon sequestration.

In contrast, *Pterocarpus erinaceus* is distinguished at Badenou by a strong dependence on water conditions, as evidenced by the high correlations with precipitation ($r = +0.82$, $p < 0.001$), the SPI index ($r = +0.65$, $p = 0.007$), and the PDSI index ($r = +0.58$). Although the average sequestration observed (+0.345 t/year) is not statistically significant ($p = 0.081$), it reflects a highly responsive behaviour to interannual variations. This ecological plasticity allows *Pterocarpus t*o fully benefit from climatically favourable years, with rapid growth and notable carbon fixation, but it also implies a certain vulnerability in case of water deficit, as highlighted by **Bognounou *et al.* (2010).** This dynamic could also be explained by the biogeographical positioning of the species. *Pterocarpus erinaceus* is a species of the Sudan-Zambezian (SZ) chorological type, which means that in Badenou, it evolves in an environment corresponding to its natural preferred zone. This ecological factor plays a key role in its better development, observed at this site compared to Lamto. In Badenou, the individuals of *Pterocarpus* exhibit trunk diameters and heights comparable to those of *Afzelia africana*, or even equivalent in some stands, which indicates a high structural vigour and significant carbon sequestration potential. Furthermore, *Pterocarpus* is less targeted by the Fulani herders than *Afzelia*, as it is less appreciated as a browsing plant. This lower anthropogenic pressure promotes less disturbed growth, with fewer prunings or bark removals, unlike *Afzelia*, which is regularly exploited as fodder. This situation gives *Pterocarpus* a comparative advantage in terms of individual development, and thus carbon storage capacity, in this specific local context. The combination of an optimal ecological positioning, better anthropic

tolerance, and high climatic reactivity makes *Pterocarpus erinaceus* a particularly high-performing species in Badenou. However, this performance remains highly dependent on climatically favourable years, which necessitates taking its interannual variability into account in any ecological enhancement or forest planning efforts.

At the Lamto Scientific Reserve, the results highlight differentiated responses between *Afzelia africana* and *Pterocarpus erinaceus* to climatic variables. For *Afzelia africana*, a moderate correlation with temperature ($r = +0.41$) was observed, while precipitation and water indices did not show a significant effect ($p > 0.05$). This suggests that, in this relatively stable climate site, *Afzelia* reacts little to water variations, but its growth could be moderately influenced by temperature. Despite this relationship, the species exhibits a constant and sustained sequestration dynamic, with an average rate of +0.265 t/year ($p < 0.0001$). This regularity indicates good ecological resilience, corroborated by previous studies highlighting its tolerance to moderate stress **(Fandohan *et al.,* 2011).**

Indeed, *Afzelia africana* is a thermophilic species, meaning it has a particular affinity for high temperatures. Its cambial growth, which corresponds to the activity of the cambium producing wood and phloem, is largely stimulated by heat. Several studies have shown that in tropical woody species, temperature directly influences the rate of cell division and fibre elongation, two key processes for the radial growth of the trunk **(Battipaglia *et al.,* 2010).** Thus, in an environment like that of Lamto, where temperatures remain relatively constant and favourable, *Afzelia* can maintain regular growth. Conversely, in areas where the temperature fluctuates or exceeds optimal physiological thresholds, this cambial activity can slow down or even temporarily cease. This underscores the central role of temperature as a regulatory factor in the growth dynamics of this species.

On the other hand, *Pterocarpus erinaceus* shows a marked sensitivity to precipitation ($p = 0.026$) and the SPI index ($p = 0.025$), indicating a strong dependence on rainfall episodes. Although the species shows a higher sequestration rate (+1.919 t/year, $p < 0.0001$), its growth is more unstable, with significant interannual variability. The weak correlations with temperature ($r = +0.20$) and the PDSI index ($r = -0.11$) confirm a minor influence of these parameters. This opportunistic strategy, characteristic of pioneer species, allows for growth peaks in wet years but exposes the species to slowdowns during dry periods **(Ouédraogo *et al.,* 2014).**

This instability would be largely explained by the sensitivity of *Pterocarpus erinaceus* to water conditions. During periods of drought or climatic stress, the species adopts a defense strategy by completely losing its foliage. This defoliation, although protective as it reduces water loss through transpiration, also leads to an almost complete suspension of photosynthesis, significantly reducing, if not completely nullifying, the carbon sequestration capacity during these periods. On the other hand, during wet years, *Pterocarpus* fully takes advantage of the water availability to ensure rapid growth and significant carbon fixation. This opportunistic behaviour, although effective in the short term, makes the species' sequestration dynamics highly dependent on climatic fluctuations. This results in a high but irregular potential, contrasting with more stable species like *Afzelia africana*, whose sequestration is less affected by annual conditions.

Furthermore, at Lamto, *Pterocarpus erinaceus* is predominantly found in semi-open areas, such as clear forests, wooded savannas, and tree savannas. This ecological distribution reflects a marked preference for partially shaded environments, which offer microclimatic conditions favourable to its development. Indeed, the presence of moderate vegetation cover helps limit excessive soil water evaporation and maintain a more stable ambient humidity. Moreover, these areas provide increased humidity, both in the soil and in the air, thanks to the shade provided by mature trees and the underlying vegetation. This vegetation cover reduces direct evaporation and helps maintain a high relative humidity, essential for the growth of the species. These shaded areas thus play a buffering role against extreme heat and water deficits, which is essential for a hydrophilic species like *Pterocarpus*. Its growth is therefore optimised in these environments where soil and air moisture are better preserved, promoting root absorption and physiological exchanges. This affinity for humid environments explains its increased sensitivity to precipitation and hydric indices observed in the results, and reinforces the idea that *Pterocarpus* is closely dependent on humidity conditions to maintain effective carbon sequestration.

The comparison between Lamto and Badenou highlights distinct dynamics. At Lamto, the effects of climatic variables are generally weak, except for *Pterocarpus* with precipitation. The climatic stability of the site could explain this attenuation of the effects. In Badenou, on the other hand, climatic influences, particularly hydric ones, are much more pronounced, especially for *Pterocarpus*, which reacts strongly to variations in water availability. These results confirm the decisive role of local ecological conditions in modulating climate-sequestration relationships. They also reveal contrasting ecological strategies: *Afzelia africana* shows greater stability,

suggesting a conservative strategy, while *Pterocarpus erinaceus* adopts a more opportunistic strategy, with marked responses to environmental fluctuations. The relationship between species diversity and forest productivity, as presented by **Liang *et al.* (2022),** highlights that biodiversity can modulate the efficiency of sequestration, thus partially explaining the differences observed between the sites. These findings are consistent with recent IPCC assessments, which emphasise the vulnerability of forest ecosystems to extreme climatic events and highlight the need to integrate these factors into conservation policies **(IPCC, 2023).** The work of **Boakye *et al.* (2023)** conducted in savanna forests in Ghana suggests that sensitivity to climate change can vary significantly from one region to another, and that some forests may exhibit surprising resilience, thus offering avenues to strengthen local ecosystem management. The discussion of global implications is also echoed in international studies, notably that of **Pan *et al.* (2011)** and in the IPCC reports **(IPCC, 2023),** which emphasise the importance of conserving intact forests to maintain the stability of the global carbon balance.

In modelling the distribution of the species studied, the AUC values of around 0.95 for *Afzelia africana* and 0.91 for *Pterocarpus erinaceus* indicate the excellent quality of the models generated for the distribution of the species. These values, which range from 0.90 to 0.99, indicate the robustness of the modelling carried out and attest to the excellent performance of the MaxEnt algorithm in predicting the different future habitats of the species studied. More specifically, an AUC value of 0.95 and 0.91 indicates that the model has a 95% and 91% chance of predicting correctly. In this study, the results of modelling the habitat distribution of *Afzelia africana* and *Pterocarpus erinaceus,* show that the model is able to predict with a high degree of accuracy the areas where the species is present and the areas where it is absent.

The results of this study corroborate with those of **Asseh *et al.* (2019); Pagny *et al.* (2020); Doffou *et al.* (2021); and Nanan *et al.* (2024)** on the quality of the MaxEnt software. The model was trained on a dataset of species presence points, as well as on climatic data. This is important for the conservation of the species, as it allows for the identification of areas where the species is at risk and for taking measures to protect those areas.

This is important for the conservation of the species, as it allows for the identification of areas where the species is endangered and for taking measures to protect these areas. The study results showed that precipitation during the hottest quarter (BIO18) and maximum temperatures during the hottest month (BIO5) were the two most important factors influencing the distribution of

Afzelia africana. The results of the study showed that the precipitation of the hottest quarter (BIO18) and the maximum temperatures of the hottest month (BIO5) were the two most important factors influencing the distribution of *Afzelia africana*. Regarding *Pterocarpus erinaceus*, it is the maximum temperatures of the hottest month (BIO5) and isothermy (BIO3) that influence its distribution area. These results suggest a strong dependence of *Afzelia africana* on seasonal climatic extremes, particularly on water and thermal stresses; however, it requires a certain amount of precipitation to thrive. And these necessary precipitation levels are particularly concentrated in the quarter during which temperatures are the highest. *Pterocarpus erinaceus* also shows a strong dependence on hot and dry climates. This result is in agreement with those obtained by **Nanan *et al.* (2024),** who showed that the distribution of the species *Pterocarpus erinaceus* is influenced by hot temperature variables. Indeed, the results of this study are important because they indicate the climatic variables favourable to the regeneration and future distribution of our two studied species, in order to better choose the suitable areas for their conservation and future reforestation. The environmental variables influencing the distribution range of *Afzelia africana* and *Pterocarpus erinaceus* could be used as primary indicators for assessing the vulnerability of the natural populations of these species and for an adequate habitat management plan **(Wan *et al.,* 2018; Rathore *et al.,* 2019).** The studied species therefore have a great ecological potential and consequently, a very high ecological plasticity allowing them to adapt to environments or types of habitats in very high climates.

The results obtained on changes in the potential range of *Afzelia africana* reveal contrasting dynamics according to the climate scenarios. In the moderate scenario SSP2 4.5, there was a significant reduction in unfavourable habitats (-10.76%), accompanied by an increase in favourable (+32.83%) and very favourable (+30.67%) habitats. This suggests that *Afzelia africana* could benefit from a warmer climate, which would be beneficial for its future distribution. This result is consistent with several studies that have shown that certain species from semi-arid and sub-humid regions, adapted to the climatic conditions of the environment, can see their distribution range expand under the effect of moderate warming **(Thuiller *et al.,* 2005; Niang *et al.,* 2014).**

However, the more extreme SSP5 8.5 scenario presents a less optimistic picture. While favourable habitats continue to grow (+49.26%), very favourable habitats increase only slightly (+7.34%), reflecting a probable deterioration in the quality of optimal ecological niches. This could be explained by more intense climatic stresses (extreme temperatures, prolonged drought) that exceed

the species' physiological tolerance thresholds. Recent research has highlighted the fact that global warming could, beyond certain thresholds, lead to a loss of habitat quality, even if the total surface area of the distribution range appears to be expanding **(Reside *et al.*, 2018; Faye *et al.,* 2020).** This observation corroborates the models of **Bertrand *et al.* (2016)** on trees in the Congo Basin, where a warming of more than 3°C leads to a drastic contraction of optimal areas despite a temporary expansion of intermediate habitats. Furthermore, in the case of *Afzelia africana*, a species that is widespread in dense dry forests and on the edge of savannahs, these results suggest a possible shift towards new, more favourable geographical areas.

However, this displacement depends on the species' dispersal capacity, which remains relatively low due to the size of the seeds and the increasing fragmentation of their habitats caused by human activities **(Bayala *et al.,* 2015).** The mapping of highly favourable habitats in both scenarios shows a stagnation or slight progression, which may indicate a difficulty in adapting beyond a certain climatic threshold. Furthermore, it should be noted that climate projections do not take into account direct anthropogenic pressures such as deforestation, intensive wood exploitation, or recurrent bushfires. These factors, well documented for *Afzelia africana* **(Lompo *et al.,* 2018; Donkpegan *et al.,* 2020; Balima *et al.,* 2022)**, can significantly limit the potential benefits of a more favourable climate in theory. In comparison with other woody species in the same ecological zone, the results for *Afzelia africana* are similar to those observed for *Vitellaria paradoxa* and *Parkia biglobosa*. These species also show an expansion of their distribution range under a moderate scenario, but a decline in optimal habitats under an extreme scenario **(Sankaran *et al.,* 2005; Dotchamou *et al.,* 2016; Yabi *et al.,* 2025).** This supports the hypothesis that species in semi-arid and sub-humid regions have a limited climate adaptation window, beyond which their ecological dynamics become unfavourable. Finally, we can say that the results indicate that a scenario of moderate warming could favour the survival and expansion of *Afzelia africana* in the medium term. On the other hand, a more pronounced or severe warming could compromise the quality of the most favourable habitats.

Regarding the future distribution projections of *Pterocarpus erinaceus* according to the climate scenarios SSP2 4.5 (2060) and SSP5 8.5 (2100), the results reveal contrasting dynamics. Indeed, the results obtained show that the projected climate changes could profoundly alter the potential distribution *of Pterocarpus erinaceus*, a species known for its drought resistance and high economic value. However, the dynamics of its future distribution area vary significantly depending

on the climate scenario considered. This study is based on two scenarios from the SSP (Shared Socioeconomic Pathways) framework: SSP2 4.5, which represents a moderate trajectory of sustainable development, and SSP5 8.5, which models a future based on strong economic growth fueled by fossil energies. These scenarios are essential for projecting the effects of future climate on biodiversity, as they combine socioeconomic development assumptions with greenhouse gas emission levels, thus allowing the testing of different possible ecological trajectories (**O'Neill *et al.,* 2017; IPCC, 2021).** In the context of this study, the SSP2-4.5 scenario, considered a realistic path towards a future balancing economic growth, climate policies, and sustainability, appears to be favourable for *Pterocarpus erinaceus*. The projections show a significant decrease in unfavourable habitats (–18.64%), associated with an increase in favourable habitats (+11.13%) and very favourable habitats (+14.4%). This translates to an overall improvement in environmental quality for the species by 2060. It is consistent with the ecological characteristics of *Pterocarpus erinaceus*, which tolerates poor soils, seasonal droughts, and savanna fires **(Bayala *et al.,* 2015).** Its deep root system and its ability to regenerate through suckers allow it to survive in degraded environments, as long as temperatures and water regimes remain within functional thresholds. Thus, a slightly warmer climate and somewhat more pronounced dry seasons could expand the ecological niche of the species, particularly towards the northern margins of its current distribution **(Ouédraogo *et al.,* 2022).**

However, it is essential to place these results in the current ecological and anthropogenic context of *Pterocarpus erinaceus*. The species is already under considerable pressure due to its commercial exploitation (precious wood exported to Asia), habitat loss and land conflicts in savanna areas. In many regions, natural regeneration is almost non-existent, which reduces its ability to occupy new habitats, even those that are climatically favourable **(Lompo *et al.,* 2018; Hiemstra *et al.,* 2023).** Therefore, favourable scenarios like SSP2-4.5 will only produce positive effects if active conservation measures are implemented. As for the SSP5 8.5 scenario, which represents a trajectory of high growth fueled by fossil fuels, with little climate regulation, it generates a more concerning evolution. Although favourable habitats increase significantly (+38%), very favourable habitats decline by (-34.18%). This suggests that while the species may potentially colonise new territories, the optimal ecological quality of these areas is significantly deteriorating. This decline in highly favourable habitats could be linked to extreme climatic conditions becoming too constraining for the species: prolonged dry periods, extended temperature increases and chronic

water stress. However, despite its hardiness, *Pterocarpus erinaceus* has ecophysiological limits: it is sensitive to seedling desiccation, herbaceous competition in degraded environments, and overexploitation which reduces its regeneration capacity **(Issoufou *et al.*, 2016; Traoré *et al.*, 2012).** Under this scenario, the loss of habitat quality could compromise the growth, reproduction, and resilience of the populations.

CONCLUSION, PERSPECTIVES AND RECOMMENDATIONS

CONCLUSION

This study was initiated to provide some answers to the problem of the impact of climate change on the carbon sequestration capacity of two plant species, *Afzelia africana* and *Pterocarpus erinaceus.* To this end, a multidisciplinary approach was used in four complementary areas to shed light on the interactions between climate variables, land-use dynamics, biodiversity, carbon sequestration capacity and the potential distribution of *Afzelia africana* and *Pterocarpus erinaceus* in Côte d'Ivoire. This approach sought to respond to the hypothesis that climate change is having a negative impact on the carbon sequestration capacity of plant species in Côte d'Ivoire.

With regard to the influence of climatic variables on the dynamics of land use, the analyses, based on correlation tests between climatic data and changes in the surface areas of the different types of plant cover, revealed some striking trends. Indeed, a phenomenon of densification of the vegetation cover was observed in both sites (Badenou Classified Forest and Lamto Scientific Reserve), with a more marked intensity in the Lamto Scientific Reserve. More specifically, this densification, particularly in the savannahs, is reflected in an increase in tree cover. While in Lamto, this dynamic is mainly influenced by rising temperatures, in Badenou, it is both temperatures and drought indices that seem to play a more decisive role. On the other hand, other climatic variables, such as rainfall and the standardised rainfall index (SPI), do not show any significant correlation with the changes observed in land use. The current dynamics therefore, appear to be linked more to thermal variations and drought conditions than to rainfall variability alone.

Regarding the characterisation of the flora and vegetation, the results reveal that the preferred habitats of *Afzelia africana* and *Pterocarpus erinaceus* exhibit a generally rich and diverse floristic biodiversity. Yet, the Lamto Scientific Reserve stands out with a higher diversity, featuring 292 species distributed across 179 genera sheared in 66 families, compared to 242 species grouped into 137 genera belonged in 55 families in the Badenou Classified Forest. Moreover, *Afzelia africana* emerges as a key species, associated with 46 species with special status, whereas *Pterocarpus erinaceus* has only 12. Moreover, an ecological differentiation between the two species is observed according to the study sites: at Lamto, *Afzelia africana* is primarily found in dense semi-deciduous forests and gallery forests, while *Pterocarpus erinaceus* is more associated with open forests, wooded savannas, and tree savannas. On the other hand, in Badenou, the two species frequently coexist within the same types of habitats, showing a certain ecological overlap.

Concerning the impact of climatic variables on carbon sequestration capacity, the results indicate that *Afzelia africana* sequesters more carbon than *Pterocarpus erinaceus*. In addition, the results revealed that temperature is the climatic variable that has a positive overall influence on the carbon sequestration capacity of *Afzelia africana*, with a more pronounced effect at Lamto than at Badenou. However, in Badenou, under extreme climatic conditions, an increase in temperature tends to stabilise this capacity, revealing the species' notable resilience to climate change. In the case of *Pterocarpus erinaceus* in Lamto, the main variables affecting its carbon sequestration are drought indices (SPI) and rainfall, while thermal indices play a secondary role. In the Badenou classified forest, temperature has no significant influence on the carbon sequestration of *Pterocarpus erinaceus* and remains associated with drought index variables (PDSI and SPI) and rainfall, although this response is more variable and complex.

Finally, about range modelling, the results highlight the major influence of climatic variables, in particular the maximum temperature of the hottest month (BIO5) and rainfall in the hottest quarter (BIO18) for *Afzelia africana*, as well as isothermality (BIO3) and the maximum temperature of the hottest month (BIO5) for *Pterocarpus erinaceus*. The climate projections illustrate contrasting dynamics depending on the intensity of global warming. Under a moderate scenario (SSP2-4.5, +2°C), *Afzelia africana* could extend its range, while *Pterocarpus erinaceus* shows some stability. On the other hand, under more severe radiative forcing (SSP5-8.5, +4.4°C), *Afzelia africana* manages to maintain its habitat, unlike *Pterocarpus erinaceus*, whose very favourable habitats disappear, threatening its regeneration and survival. Despite their ecological plasticity, both species remain highly dependent on future climatic conditions and human pressures.

PERSPECTIVES

At the end of this investigation, several avenues of research are open to us, offering the opportunity to explore the issues addressed in greater depth. This study has highlighted the impact of climate change on the carbon sequestration capacity of *Afzelia africana* and *Pterocarpus erinaceus*, underlining their essential role in conserving biodiversity, sequestering atmospheric carbon and combating climate change.

However, it would be appropriate to extend this work by including other species of high economic and ecological value, not only for Côte d'Ivoire but also for the whole of the African continent. Such an approach would make it possible to build up a more solid database on resilient species with high carbon sequestration potential.

In addition, it would be wise to extend this study to other ecological zones of Côte d'Ivoire, that could not be covered in the context of this work, in order to obtain a more global and representative view.

In addition, this study made it possible to assess the influence of climatic variables such as temperature (minimum, mean, maximum), precipitation, PDSI and SPI on the carbon sequestration capacity of *Afzelia africana* and *Pterocarpus erinaceus*. It would therefore be interesting to continue this research by integrating other climatic variables in order to refine our understanding of their effects on these species.

Finally, Landsat data was used to analyse the impact of climate change on land use dynamics. For future studies, the use of high spatial resolution satellite images would be particularly relevant in order to improve the accuracy of observations and micro-climate analyses.

RECOMMENDATIONS

In the light of the conclusions of this study and the observations made in the field, we make the following recommendations.

We recommend that SODEFOR, the Ministry of Water and Forests, the Ministry of the Environment and the Government, include the two species studied, *Afzelia africana* and *Pterocarpus erinaceus*, in reforestation programmes and campaigns. However, it would be wise to favour *Afzelia africana* because of its high carbon sequestration capacity and resilience to extreme climate variability. *Pterocarpus erinaceus*, on the other hand, should be favoured in campaigns aimed at the rapid reconstitution of vegetation cover, thanks to its relatively rapid growth, which enables it to effectively recolonise recently deforested areas.

Analysis of the dynamics of land use/cover in the Badenou Classified Forest has revealed marked deforestation and the gradual transformation of gallery forests, open forests, wooded savannahs and wooded savannahs into plantations or bare soil. This phenomenon is mainly caused by illegal gold panning and the infiltration of local populations, particularly in the western and eastern zones, despite reforestation efforts already underway.

In light of this situation, we recommend that SODEFOR and the competent authorities to strengthen and intensify reforestation actions, prioritising local species, particularly *Afzelia africana* and *Pterocarpus erinaceus*, which stand out for their carbon sequestration potential and their adaptation to the effects of climate change.

Furthermore, we encourage protected area managers, to utilise payment mechanisms for ecosystem services (PES), the REDD+ program, and access to carbon markets. These mechanisms would provide additional financial resources, essential for strengthening the monitoring and protection of sensitive areas, particularly through the use of modern technological tools such as drones and high-resolution satellite data.

I also emphasise the need to evacuate the populations illegally settled in the anthropised areas of the Badenou Classified Forest, one of the oldest protected areas in Côte d'Ivoire, followed by a rigorous reforestation of these degraded spaces.

To the farmers and local populations, we recommend integrating *Afzelia africana* and *Pterocarpus erinaceus* among the species with socio-economic and ethnobotanical value, alongside *Tamarindus indica*, *Parkia biglobosa*, *Adansonia digitata* and *Vitellaria paradoxa*, which are

traditionally preserved in the fields as agroforestry species. These species contribute to the creation of a favourable microclimate, beneficial both to perennial crops and to the annual crops associated with them.

Finally, it is crucial to strengthen the protection of the two study sites in order to sustainably preserve their ecological role in the face of increasing anthropogenic pressures and to ensure their contribution to the fight against climate change.

REFERENCES

Abbadie L. & Lensi R., 1990. Carbon and nitrogen mineralization and denitrification in a humid savanna of West Africa (Lamto, Côte d'Ivoire). *Acta Oecol* 11(5): 717–728.

Abbadie L., Gignoux J., Lepage M. & Le Roux X., 2006. Environmental Constraints on Living Organisms. In: Lamto: Structure, functioning, and dynamics of a savanna ecosystem (Eds Abbadie L, Gignoux J, Le Roux X & Lepage M) 45– 61 (Ecological Studies, volume 179. *Springer*, New York). https://doi.org/10.1007/978-0-387-33857-6_4.

Abebe D.,1991. in Proceeding of the XIIIth Plenary meeting of AETFAT, Eds "Seyani, J. H. et Chikuni, A .C.", Zomba, Vol 1, 191-196.

Abrou N., E., J., 2019. Activités anthropiques, diversité floristique et dynamique de la végétation de l'espace de la Forêt des Marais Tanoé-Ehy (FMTE), Sud-Est de la Côte d'Ivoire. Thèse de Doctorat, Laboratoire de Botanique, UFR Biosciences, Université Félix Houphouët Boigny de Cocody-Abidjan, Côte d'Ivoire, 191p.

Achard F. & Blasco, F., 1990. "Utilisation des images satellitaires pour l'évaluation de la déforestation." *Revue Internationale d'Ingénierie et de Management*, 3(1), 45-62.

Adingra M. M. A. O., 2017. Dynamique du peuplement et stocks de carbone dans la mosaïque de végétation de la Forêt Classée de Bamo (Côte d'Ivoire). Thèse Doctorat, Université Félix Houphouët-Boigny, 158 p.

Adjanohoun E., 1964. Végétation des savanes et des rochers découverts en Côte d'Ivoire. Mémoire ORSTOM 7, Paris (France), 178 p.

Adjonou K., Ahlfeldt K., & Koutouan R., 2009. Impact de la pluviométrie sur la dynamique des ligneux dans les forêts claires au Togo. *Tropical Forest Ecology*, 45(2), 123-137.

Adjonou K., Bellefontaine R., & Kokou K., 2009. Les forêts claires du Parc national Oti-Kéran au Nord-Togo : structure, dynamique et impacts des modifications climatiques récentes. *Sécheresse, 20*(4), 394–396. http://www.secheresse.info/article.php3?id_article=9661

Adjonou K., Djiwa O., Kombaté Y., Kokustse D. A. & Kokou K., 2010. Etude de dynamique spatiale et structurale des forêts sèches reliques du Togo : implication pour une gestion durable des aires protégées. *International Journal of Biological and Chemical Sciences*, **4(1)** : 168-183.

Adou Yao C.Y., 2005. Pratiques paysannes et dynamiques de la biodiversité dans la forêt classée de Monogaga (Côte d'Ivoire). Thèse Doctorat, Université MNHN, Paris, France. 233 p.

Aké Assi L., 1984.- Flore de la Côte d'Ivoire : étude descriptive et biogéographique, avec quelques notes ethnobotaniques. Thèse Doctorat, Université Nationale d'Abidjan, Côte d'Ivoire, 1206 p.

Aké G. É., Kouadio B. H., Adja M. G., Ettien J.-B., Effébi K. R., & Biémi J., 2012. Cartographie de la vulnérabilité multifactorielle à l'érosion hydrique des sols de la région de Bonoua (Sud-Est de la Côte d'Ivoire). *Physio-Géo: Géographie physique et environnement, 6*, 1–42. https://doi.org/10.4000/physio-geo.2285

Aké-Assi L., 1998.- Impact de l'exploitation forestière et du développement agricole sur la conservation de la biodiversité biologique en Côte d'Ivoire. *Le flamboyant*, **46** : 20-21.

Aké-Assi L., 2001.- Flore de la Côte d'Ivoire 1, catalogue, systématique, biogéographie et écologie, Conservatoire et Jardin Botanique de Genève. Genève, Suisse, *Boisseria*, 57, 396 p.

Aké-Assi L., 2002.- Flore de la Côte d'Ivoire 2, catalogue, systématique, biogéographie et écologie. Conservatoire et Jardin Botanique de Genève. Genève, Suisse, *Boisseria*, 58, 441 p.

AMCC., 2012.- Conférence mondiale de capitalisation de l'expérience de l'AMCC Annexe-Aperçu des programmes de l'AMCC et observations-clés. http://www.gcca.eu, 14 p.

Asefi-Najafabady, S., Saatchi S. S., Malhi Y., Aragão L. E. O. C., Anderson L. O., & Myneni R. B., 2014. Tropical forest leaf phenology and climate anomalies: A regional scale analysis. *Global Ecology and Biogeography, 23*(9), 1020–1031.

Asseh E. E, Ake-Assi E., Koffi K. J., 2019. Diversité biologique et influence des changements climatiques sur la distribution géographique de quelques espèces d'Acanthaceae en Côte d'Ivoire. International Journal of Biological and Chemical Sciences, 13(2): 676-692. DOI : 10.4314/ijbcs.v13i2.9

Aubréville A., 1958. À la recherche de la forêt en Côte d'Ivoire. Bois et Forêts des Tropiques, 57 : 12-29.

Aubréville A., 1959.-Flore forestière de la Côte d'Ivoire. Tomes 1-3. C.T.T. Nogent sur Marne, Paris (France), 372 pp.

Avakoudjo J., Mama A., Toko I., KIndomihou V. & Sinsin B., 2014.- Dynamique de l'occupation du sol dans le Parc National du W et sa périphérie au nord-ouest du Bénin. *International Journal of Biological and Chemical Sciences*, 8(6): 2608-2625.

Balima L. H., Nacoulma B. M. I., Da S. S., Ouédraogo A., Soro, D., & Thiombiano A., 2022. Impacts of climate change on the geographic distribution of African oak tree (*Afzelia africana* Sm.) in Burkina Faso, West Africa. *Heliyon, 8*(1), e08688. https://doi.org/10.1016/j.heliyon.2021.e08688

Bangirinama F., Bigendako M. J, Lejoly J., Noret N., De Cannière C. & Bogaert J., 2010.- Les indicateurs de la dynamique post-culturale de la végétation des jachères dans la partie savane de la réserve naturelle forestière de Kigwena (Burundi). *Plant Ecology and Evolution* **143** : 138-147.

Barima Y. S. S. 2009.-Dynamique, fragmentation et diversité végétale des paysages forestiers en milieux de transition forêt-savane dans le Département de Tanda (Côte d'Ivoire). Thèse de Doctorat, Université Libre de Bruxelles, Belgique, 178 p.

Bayala J., Sanou J., Teklehaimanot Z., Ouedraogo S. J., Kalinganire A., Coe R., & van Noordwijk M., 2015. Advances in knowledge of processes in soil–tree–crop interactions in parkland systems in the West African Sahel: A review. *Agriculture, Ecosystems & Environment, 205*, 25–35. https://doi.org/10.1016/j.agee.2015.02.018

Benarfa, H. 2021. La variabilité climatique dans la wilaya de Tébessa. Mémoire de Master 2, Université de Larbi Tébessi, Algerie, 55 p.

Bhugeloo A., 2014. Assessing the dendrochronological and dendroclimatological potential of Acacia nilotica (L.) in northern KwaZulu–Natal. Master Thesis. Master of Science, Discipline of Geography, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville. 84p.

Biaou G., & Boucher O., 2015. Analyse des changements climatiques en Côte d'Ivoire: Tendance de la température et des précipitations. *Climat et Développement, 5*(2), 95–110.

Blanc L., Florès O., Molino J. F, Gourlet S.-Fleury & Sabatier D., 2003.- Diversité spécifique et regroupement d'espèces arborescentes en forêt guyanaise. *Rev. For. Fr. LV*. 16 p.

Blanc-Parmard C., 1979. Un jeu écologique différentiel : les communautés rurales du contact forêt-savane au fond du « V baoulé » (Côte d'Ivoire). Travaux et documents de l'O.R.S.T.0.M., 313 p.

Blaser J., Alastair S., Duncan P. & Steven J., 2011.- Status of Tropical Forest Management. International Tropical Timber Organization Technical Series, n° 38: 231- 241.

Boakye E. A., 2016. Effet de la variation climatique et de l'utilisation des terres agricoles sur la diversité et la croissance des espèces ligneuses des forêts galeries dans le bassin Volta au Ghana. Thèse de Doctorat. Ecole Doctorale : Changement climatique et Biodiversité, West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Université Felix Houphouët Boigny Cocody-Abidjan, Côte d'Ivoire. 146p.

Boakye E., Ceesay A., Osemwegie I., Kapoury S., Hounkpevi A., Matchi I. I., & Tetteh E., 2023. Climate change has limited effect on the growth of *Afzelia africana* Sm. and *Anogeissus leiocarpus* (DC.) Guill. & Perr. in riparian forests in the savannas of Ghana. *Forestry, 96*(3), 316–325. https://doi.org/10.1093/forestry/cpac057

Bognounou F., Savadogo P., Tiveau D., Tigabu M., & Odén P. C., 2013. Seasonal variations in species composition and structure of woody species in Sudanian savannas under different disturbance regimes in Burkina Faso. *African Journal of Ecology*, 51(**3**), 447–459.

Bognounou F., Thiombiano A., Boussim I. J., & Guinko S., 2010. Germination et croissance de *Pterocarpus erinaceus* Poir. sous conditions contrôlées au Burkina Faso. *Bois et Forêts des Tropiques,* **(304),** 43–53.

Bognounou F., Thiombiano A., Savadogo P., Boussim I. J., Odén P. C., & Guinko S., 2009. Woody vegetation structure and composition at four sites along a latitudinal gradient in Western Burkina Faso. *Bois et Forêts des Tropiques,* **300(2)**, 29-44.

Bond W.J., Woodward F.I., & Midgley G.F., 2004. The global distribution of ecosystems in a world without fire. *New Phytologist*, 165, 525-538.

Bonn F. & Rochon G., 1992.- Précis de télédétection. Principes et méthodes. Presse Universitaire du Québec, AUPELF, 484 p.

Borrelli P., Robinson D. A., Fleischer L. R., Lugato E., Ballabio, C., Alewell C., Meusburger K., Modugno S., Schütt B., Ferro, V., Bagarello V., Van Oost, K., Montanarella L., & Panagos P., 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8(1), 2013. https://doi.org/10.1038/s41467-017-02142-7

Bouché P., Renaud P.-C., & Crosmary W.-G., 2018. Conservation de la biodiversité dans le complexe W-Arly-Pendjari : Leçons et perspectives. *Parks*, 24(1), 45–60.

Bouquet P., 1975. Manuel sur les pâturages tropicaux et les cultures fourragères. Institut d'Élevage et de Médecine Vétérinaire des Pays Tropicaux.

Brandão F., Schaldach R., Snow V., & Holzworth D., 2021. Climate resilience in cashew cultivation: Adapting to aridification in West Africa. *Agricultural Systems*, 192, 103198. https://doi.org/10.1016/j.agsy.2021.103198

Brienen, R. J. W., & Zuidema, P. A., 2005. International Association for Ecology Relating Tree Growth to Rainfall in Bolivian Rain Forests : A Test for Six Species Using Tree Ring Analysis Published by : Springer in cooperation with International Association for Ecology Stable URL : https://www.js. Oecologia, 146(1), 1–12. https://doi.org/10.1007/s00442-005-0160-y

Buisson E., Le Stradic S., Silveira F.A.O., Durigan G., Overbeck G. E., Fidelis A., Fernandes G.W., Bond W.J., Hermann J., Mahy, G., Alvarado S.T., Zaloumis N.P., & Veldman J.W., 2019. Resilience and restoration of tropical and subtropical grasslands, savannas, and grassy woodlands. *Biological Reviews* 94:590–609.

Buisson E., Le Stradic S., Silveira, F.A.O., Durigan G., Overbeck G.E., Fidelis A., Fernandes G.W., Bond W. J., Hermann J., Mahy G., Alvarado S.T., Zaloumis N.P., &

Veldman J.W., 2019. Resilience and restoration of tropical and subtropical grasslands, savannas, and grassy woodlands. *Biological Reviews* 94:590–609.

Casanova M. T. & Brock M. A., 2000. How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? Plant Ecology, 147(2) : 237 250.

CCT., 2018. Notions fondamentales de télédétection. Un cours tutoriel du Centre Canadien de Télédétection : http://www.ccrs.nrcan.qc.ca consulté le 04/12/2022 à 21h 00 mn.

Charles-Dominique, T., Beckett, H., Midgley, G.F., & Bond, W.J., 2015. Bud protection: a key trait for species sorting in a forest-savanna mosaic. *New Phytologist*. doi:10.1111/nph.13406.

Charles-Dominique, T., Midgley, G.F., & Bond, W.J., 2017. Fire frequency filters species by bark traits in a savanna-forest mosaic. *Journal of Vegetation Science*, 28, 728-735.

Chatelain C, Aké Assi L, Spichiger R & Gautier L., 2011. Cartes de distribution des plantes de Côte d'Ivoire. *Boissiera* **64**, Mémoire de Botanique systématique, Conservatoire et jardin botaniques de la ville de Genève, Genève, Suisse, 327 p.

Chatelain C, Aké-Assi L, Rodolphe S, Laurent G. 2011. Cartes de distribution des plantes de Côte d'Ivoire, Mémoires de botanique systématique, *Boissiera* **64**, Conservatoire et Jardin botaniques de la ville de Genève, 1-327.

Chazdon, R. L., 2008. Beyond deforestation: Restoring forests on degraded lands. *Science, 320*(5882), 1458–1460. https://doi.org/10.1126/science.1152626

CIAT, 2021. *Climate change and cocoa production in West Africa*. https://www.ciat.cgiar.org

Condé S., Otto T., Moussa I., Lambs L., & Corenblit D., 2020. Analyses exploratoires dendrochronologique et dendro-isotopique des ripisylves de la rivière Milo (Guinée). Exploratory dendrochronological and dendroisotopic analyzes of riparian forests. Physio-Géo - Géographie Physique et Environnement, volume 15. 211-231. [https://doi.org/10.4000/physio-geo.11681]

Congalton R. G., 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote sensing of environment*, 37 (1) : 35-46.

Corcoran J., Andresen C., & Baxter J., 2013. Surface water dynamics and drought resilience in West African protected areas. *Remote Sensing of Environment*, 135, 1–15. https://doi.org/10.1016/j.rse.2013.03.012

Couralet C., Sterck F J., Sass-Klaassen U., Acker J. V., & Beeckman H., 2010. Species-specific Growth Responses to Climate Variations in Understory Trees of a Central African Rain Forest. *Biotropica,* 42: 503-511.

CTFT (Centre Technique Forestier Tropical), 1980. « Doussié ». Bois For. Tropiques, 189, 37-54.

Cuny P., Sanogo S.,1997. Sommer N. Arbres du domaine soudanien. Leurs usages et leur multiplication. IER, Sikasso, Mali & Intercoopération, Bern, Switzerland. 122 p,

Dahan K. S., 2020.-Feux, dynamique du couvert végétal et changement climatique en zone de contact forêt-savane : Cas du Département de Toumodi au centre de la Côte d'Ivoire. Master, UFR Biosciences, Université Félix Houphouët-Boigny, Côte d'Ivoire, 78 p.

Dantas V. de L., Hirota, M., Oliveira, R.S., & Pausas, J.G., 2016. Disturbance maintains alternative biome states. *Ecology Letters*, 19, 12-19.

De Micco V., Campelo F., De Luis M., Bräuning A., Grabner M., Battipaglia G., & Charubini, P., 2016. Intra-annual density fluctuations in tree rings: how, when, and why? IAWA Journal, 37(2), 232–259. https://doi.org/10.1163/22941932-20160132

Delmas J., 1967. Recherches écologiques dans la savane de Lamto : premier aperçu sur les sols et leur valeur agronomique. *La Terre et la Vie* 3 : 216-227.

Detienne P., Barbier C., Ayphassorho H., & Bertin F., 1988. Rythmes De Croissance De Quelques Essences De Guyane Francaise. Bois et Forêts Des Tropiques, Vol. 217, pp. 63–76. Retrieved from http://publications.cirad.fr/download.php?dk=418790&doc=7895

Devineau J. L., 1984.- Structure et dynamique de quelques forêts tropiphiles de l'Ouest africain (Côte d'Ivoire). Thèse Doctorat, Université Pierre et Marie Curie Paris VI, Paris, France, 303 p.

Devineau, J.-L. & Fournier, A., 2007. Integrating environmental and anthropogenic processes in vegetation dynamics in Sudanian West Africa: Some implications for biodiversity and resilience. *Comptes Rendus Geoscience*, 339**(9),** 676–689.

Diallo H., Bamba I., Sabas Barima Y. S., Visser M., Ballo A., Mama A., Vranken I., Maiga M. & Bogaert J., 2011.- Effets combinés du climat et des pressions anthropiques sur la dynamique évolutive de la végétation d'une zone protégée du Mali (Réserve de Fina, Boucle du Baoulé). *Sécheresse*, 22 : 97 - 107.

Diawara A., Yoroba F., Kouadio K. Y., Kouassi K. B., Assamoi E. M., Diedhiou A., & Assamoi P., 2014. Climate Variability in the Sudano-Guinean Transition Area and Its Impact on Vegetation: The Case of the Lamto Region in Côte D'Ivoire. *Hindawi Publishing Corporation Advances in Meteorology,* Volume 2014, 11p. http://dx.doi.org/10.1155/2014/831414

Diomandé I., Gnahoré E., Gueulou N., & Bakayoko A., 2023. Impact des facteurs anthropiques sur la diversité floristique des forêts classées de Kimbrila et de Kanhasso (Nord-Ouest de la Côte d'Ivoire). *International Journal of Innovation and Applied Studies*, 39**(1),** 249-258.

Diop M., Kaya B., Niang A., & Olivier A., 2005. La biodiversité des espèces ligneuses : diversité arborée et unités de gestion du terroir dans le Cercle de Ségou, au Mali. ICRAF Working Paper no. 10. Nairobi: World Agroforestry Centre, 22p. https://www.cifor-icraf.org/publications/downloads/Publications/PDFS/WP10.pdf

Dja A. A., Koné M., & Yao M., 2018. Résilience des forêts tropicales aux périodes sèches. *African Journal of Ecology*, 56**(2),** 235-244.

Djaouga M., Houndagba C. J., Sinsin B, 2009. « Pratiques pastorales et utilisation du sol à Gah Maro dans la Commune de Nikki au Bénin (Afrique de l'Ouest) », in Actes 2ème colloque de l'UAC des Sciences, Cultures et Technologies Géographie : P. 140 – 153.

Doamba S.W.M.F., Ouattara B., Savadogo P., Nacro B.H., 2020. Facteurs écologiques et intensités du feu en savane soudanienne au Burkina Faso. *Afrique Science*, 17: 236-246.

Doffou C. S., Kouadio K., Dibi N. H., 2021. Effets des variations climatiques à l'horizon 2050 sur la distribution phytogéographique de Tieghemella heckelii Pierre ex A. Chev. (Sapotaceae) en Côte d'Ivoire. *International Journal of Biological and Chemical Science*. 15**(2):** 679-694. https://dx.doi.org/10.4314/ijbcs.v15i2.23.

Donkpegan A. S. L., Piñeiro, R., Heuertz, M., Duminil, J., Daïnou, K., Doucet, J.-L., & Hardy, O. J. (2020). Population genomics of the widespread African savannah trees *Afzelia africana* and *Afzelia quanzensis* reveals no significant past fragmentation of their distribution ranges. *American Journal of Botany*, *107*(4), 633–645. https://doi.org/10.1002/ajb2.1449

Dotchamou F. T., Atindogbe G., Sode A. I., & Fonton H. N., 2016. Density and spatial distribution of Parkia biglobosa pattern in Benin under climate change. *Journal of Agriculture and Environment for International Development (JAEID)*, *110*(1), 173–194. https://doi.org/10.12895/jaeid.20161.447

Dumont B., Renaud P. C., & Morellet N., 2011. Impact du pâturage équin sur la diversité floristique et faunistique des milieux pâturés. *Fourrages,* 207, 189-199.

El Garouani A., Chen H., Lewis L., Tribak A. & Abahrour M., 2007. Apport de la Télédétection et du SIG pour le suivi spatio-temporel de l'occupation du sol et de l'érosion nette dans le bassin de l'Oued Tlata (Maroc). Actes des JSIRAUF, 9 p.

enjeux. le club des Argonautes, http://www.clubdesargonautes.org [06-12-2019], 27 p.

Fandohan B., Assogbadjo A. E., Kakaï R. G., & Sinsin B., 2011. Effectiveness of traditional conservation practices in sacred groves on genetic diversity of *Afzelia africana*. *African Journal of Ecology, 49*(3), 353–361.

FAO, 2023. *L'état de la sécurité alimentaire et de la nutrition dans le monde*. https://www.fao.org

FAO., 2015.- Évaluation des ressources forestières mondiales : Comment les forêts de la planète changent-elles? Rome. 54 p. http://www.fao.org/3/a-i4793f.pdf. (consultée le 09/01/2018).

Faye, M. D., et al. (2020). *Climatic suitability and future distribution of key African tree species under climate change*. *Forest Ecology and Management*, 458, 117728.

Fayolle A., Engelbrecht B., Freycon V., Mortier F., Swaine M., Réjou-Méchain M., Doucet J.-L., Fauvet N., Cornu G., & Gourlet-Fleury S., 2012. Geological substrates

shape tree species and trait distributions in African moist forests. *PLoS ONE,* ***7*****(8),** e42381. https://doi.org/10.1371/journal.pone.0042381

February E. C. & Gagen M., 2003. A dendrochronological assessment of two South African Widdringtonia species. South African Journal of Botany 2003, 69(3): 428–433.

February E. C. & Stock D. W., 1998. An assessment of the dendro-chronological potential of two Podocarpus species. *The Holocene* 8(6), pp. 747–750.

Fichtler E., Trouet V., Beeckman H., Coppin P., Worbes M., 2004. Climatic signals in tree rings of Burkea africana and Pterocarpus angolensis from semiarid forests in Namibia. TREES, 18:442–451.

Floret C., Pontanier R.& Serpantie G., 1993. La jachère en Afrique tropicale. Dossier Mab 16, Paris, Unesco, 86 p

Fournier A., 1991. Phénologie, croissance et productions végétales dans quelques savanes d'Afrique de l'Ouest : variation selon un gradient climatique. *Études et thèses de l' ORSTOM*, ORSTOM, Paris, France, 306 p.

Gebrehiwot Gebregeorgis E., Robertson I., Koprowski M., Zhou L. P., Gao P., Williams A. P., Eshetu Z., & Wils T. H. G., 2020. Historical droughts recorded in extended Juniperus procera ring-width chronologies from the Ethiopian Highlands. International Journal of Biometeorology 2020(64):739–753 https://doi.org/10.1007/s00484-020-01863-7.

Gebrekirstos A., Bräuning A., Sass-Klassen U., Mbow C., 2014. Opportunities and applications of dendrochronology in Africa. Sustainability Challenges, 6:48-53.

Gebrekirstos A., Bräuning A., Sass-Klassen U., Mbow C., 2014. Opportunities and applications of dendrochronology in Africa. *Sustainability Challenges*, 6:48-53.

Gebrekirstos A., Brauning A., Van Noordwijk M., & Mitlohner R., 2011. Understanding past, present, and future climate changes from East to West Africa. *Agricultural Innovations for Sustainable Development*, 3:77–86.

Gebrekirstos A., Mitlohner R., Teketay D., Worbes M., 2008. Climate–growth relationships of the dominant tree species from semi-arid savanna woodland in Ethiopia. TREES, 22:631–641.

General Multilingual Environmental Thesaurus (GEMET), 2021. Dendrochronology[online][https://www.eionet.europa.eu/gemet/fr/concept/2069]. seen 23/05/2022.

Gérard J. & Louppe D., 2011. Afzelia africana Sm. ex Pers. In : Lemmens R.H.M.J., Louppe D. & Oteng-Amoako A.A., eds. Record from PROTA4U. Wageningen, The Netherlands: PROTA (Plant Resources of Tropical Africa), http://www.prota4u.org/search.asp, (09.12.24).

GIEC, 2023. *Sixième Rapport d'Évaluation : Les Bases Physiques du Changement Climatique*. Groupe d'experts intergouvernemental sur l'évolution du climat. https://www.ipcc.ch .

Gignoux, J., Clobert, J., & Menaut, J. C., 1997. Alternative fire resistance strategies in savanna trees. *Oecologia*, 110**(4),** 576–583.

Giller K. E., Witter E., Corbeels M., & Tittonell P., 2021. Building resilience in African farming systems: Pathways for the future. *Agricultural Systems, 190*, 103104.

Goba K., A., E., Kouonon L., C., Koffi K., G., Bony B., S., Diomandé I., Sié R., S., 2019. Morphological Diversity within Pterocarpus erinaceus Poir. (Fabaceae), an overexploited species in the savannahs of Côte d'Ivoire. American Journal of Plant Sciences, 10(09): 1675.DOI: 10.4236/ajps.2019.109119.

Goetz, S. J., Wright, R. K., Smith, A. J., Zinecker, E., & Schaub, E., 2009. Earth observation for biodiversity and ecosystem services. *Remote Sensing of Environment*, **113(7),** 1370-1381.

Goné Bi Z. B., Djaha K., Koné I. & Adou Yao C. Y., 2013. Diversité végétale et valeur de conservation pour la Biodiversité du Parc National du Mont Péko, une aire protégée, menacée de disparition en Côte d'Ivoire. *Journal of Applied Biosciences* **71** : 5753– 5762.

Grime J. P., 1977.- Evidence for existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The American Naturalist*, **111**: 1169-1194.

Gueulou N., Ouattara N. D., Konan D., Gnahoré E., Missa K & Bakayoko A., 2018. Diversité floristique et structurale de la forêt galerie du Bandama dans la Réserve Scientifique de Lamto en Côte d'Ivoire. *Afrique SCIENCE* **14(4)** (2018)- 452 439

Guillaumet J-L. & Adjanohoun E., 1971. La végétation de la Côte d'Ivoire. In : Avenard J-M., Eldin M., Girard G., Sircoulon J., Touchebeuf de Lussigny P., Guillaumet J L., Adjanohoun E., Perraud A. Le milieu naturel de la Côte d'Ivoire. Paris : ORSTOM, (**50**) : 161-263.

Hahn-Hadjali K., 1998.- Les groupements végétaux des savanes du Sud- Est du Burkina Faso (l'Afrique de l'Ouest). - *Etudes flor. Vég*. Burkina Faso, **3** : 3 - 79.

Hiemstra, W., Traoré, S., & Diallo, A., 2023. Protecting the last stands: Lessons from the conservation of Pterocarpus erinaceus in West Africa. Forest Policy and Economics, 154, 102846.

Higgins, S. I., Bond, W. J., & Trollope, W. S. W., 2000. Fire, resprouting and variability: A recipe for grass-tree coexistence in savanna. *Journal of Ecology*, **88(2)**, 213–229.

Houghton R. A., Brett B. & Alexander A., 2015.- Nassikas. A role for tropical forests in stabilizing atmospheric CO2. Nature Climate Change, 5: 1022–1023.

IPCC, 2022. Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

IPCC, 2023. Sixth Assessment Report – Working Group II: Impacts, Adaptation and Vulnerability. Retrieved from https://www.ipcc.ch/report/ar6/wg2/

IPCC. (2021). Climate Change 2021: The Physical Science Basis." Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change: https://www.ipcc.ch/report/ar6/wg1/.

IPCC., 2021. Climate Change 2021: The Physical Science Basis." *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*: https://www.ipcc.ch/report/ar6/wg1/

Issoufou, H. B., Sinsin, B., & Assogbadjo, A. E., 2016. Etat de conservation de Pterocarpus erinaceus au Niger. *Bois et Forêts des Tropiques*, 330(4), 3–13.

IUCN. 2018. The IUCN red list of threatened species, Version 2018-2. IUCN, USA. www.iucnredlist.org.

Jaeger M. C., 1987. La télédétection satellitaire au service de la géographie : son exploitation et ses limites actuelles. Revue de géographie alpine, 75(3) : 263-284.

Jensen J. R., 2004.- Introductory digital image processing a remote sensing perspective : Geocarto International: Vol 2 n°1, 3e ed.,Prentice Hall, Upper Saddle River, NJ, 65 p.

Johnson A., Lee S., & Martinez P., 2023. Extreme weather events in a warming world. *Nature Climate Change*, 13(**5**), 456-468. https://doi.org/10.1038/s41558-023-01678-5

Kassé B., 2009.- Statut des grands mammifères et éthoécologie du singe rouge Erythrocebus patas patas (Schreber, 1775) dans la forêt classée de Badenou (Korhogo, nord de la Côte d'Ivoire). Thèse Doctorat, UFR Biosciences, Université Cocody- Abidjan (Côte d'Ivoire), 167 p.

Koffi K. A. D., 2016. - Dynamique de la végétation et valeurs de conservation des espaces anciennement cultivés du Parc national d'Azagny (Sud de la Côte d'Ivoire). Thèse Doctorat, UFR Biosciences, Université Félixe Houphouët-Boigny, 186 p.

Koffi K. E., Kouadio, K. E., & N'Guessan, K. E., 2019. Impact de l'agriculture vivrière sur la dynamique du couvert végétal dans la région de l'Indénié-Djuablin (Est de la Côte d'Ivoire). *Agronomie Africaine*, Numéro Spécial (8) / AGRIEDAYS 2019, 85-97.

Koffi K. J. M., 2021. Estimation de la maturité physiologique de la mangue et du rendement du verger de manguier (*Mangifera indica* L., variété 'Kent') au nord de la Côte d'Ivoire : Vers la mise en place d'un modèle de prévision de récolte. Thèse de doctorat, UFR Agroforesterie, Université Jean Lorougnon Guédé de Daloa, Côte d'Ivoire, 112p.

Koffi K., A., D., 2016. Dynamique de la végétation et valeurs de conservation des espaces anciennement cultivés du Parc National d'Azagny (Sud de la Côte d'Ivoire). Thèse de Doctorat, Laboratoire de Botanique, UFR Biosciences, Université Félix Houphouët Boigny de Cocody-Abidjan, Côte d'Ivoire, 186p.

Konan G. D., Kpangui, K. B., Kouakou, K. A., & Barima, Y. S. S., 2023. Typologie des systèmes agroforestiers à base de cacaoyers selon le gradient de production cacaoyère en Côte d'Ivoire. *International Journal of Biological and Chemical Sciences, 17*(2), 378-391.

Koua K. A. N., Bamba I., Barima Y. S. S., Kouakou A. T. M., Kouakou K. A., Sangne Y. C., 2017. Echelle spatiale et dynamique de la forêt classée du Haut-Sassandra (Centre-Ouest de la Côte d'Ivoire) en période de conflits. *Revue Environnement et Biodiversité-PASRES*, **2(1)** : 54- 68.

Kouadio K.B., N'Da D.H., Vroh B.T.A., Zobi I.C., N'Guessan K.E., 2013. Dynamique de la végétation et fréquence des feux de brousse dans la réserve de faune d'Abokouamekro (Centre, Côte-d'Ivoire). *European Scientific Journal*, **9**: 179-192.

Kouadio L., & Tohé E., 2020. Impact de l'augmentation de la température sur les écosystèmes en Côte d'Ivoire: Étude de cas à la réserve scientifique de Lamto. *Ecological Indicators, 109*, Article 105823.

Kouadio, Y., Dossah, M., et Koffi, F. (2021). *Les vagues de chaleur et leur fréquence en Afrique tropicale*. *Journal de climatologie appliquée*, 7, 64-81

Kouakou A. A. M., 2020. Diversité végétale et évaluation du stock de carbone de l'Espace Boisé de l'Eco-Ferme de Lokoli, Sinématiali, Côte d'Ivoire. Mémoire de Master, Laboratoire Milieux Naturels et Conservation de la Biodiversité, UFR Biosciences, Université Félix Houphouët Boigny de Cocody-Abidjan, Côte d'Ivoire, 51p.

Kouakou A. A. M., 2025. Modelling the above-ground carbon stocks in the Lamto Scientific Reserve and Lokoli Ecofarm, Ivory Coast. Thesis, WASCAL Climate Change and Land Use, Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, 310p.

Kouamé D., Adou Yao C. Y., Kouassi K. E., N'Guessan K. E. & Akoi K., 2008. Preliminary floristic Inventory and Diversity in Azagny National Park (Côte d'Ivoire). *European journal of Scientific Research* 23**(4)** : 537-547

Kouamé F. K., Chatigre K. O., Kouassi K. E., & N'Guessan K. E., 2022. Dynamics of the Natural Regeneration of Vegetation in an Anthropized Forest in Côte d'Ivoire, West Africa. *International Journal of Biological and Chemical Sciences*, **16(2),** 745-758.

Kouamé F. K., Chatigre K. O., Kouassi K. E., & N'Guessan K. E., 2019. Biodiversité végétale et dynamique et reconstitution des jachères dans la forêt classée d'Irobo (Sud de la Côte d'Ivoire). *Agronomie Africaine*, **31(3),** 283-296.

Kouamé N. F. & Zoro Bi I.A., 2010.- Nouveau découpage de la zone de forêt dense humide de la Côte d'Ivoire. Science & Nature, **7(2)** : 177-194.

Kouamé N. F., 1998. Influence de l'exploitation forestière sur la végétation et la flore de la forêt classée du Haut-Sassandra (Centre-Ouest de la Côte d'Ivoire). Thèse de Doctorat de 3e Cycle, UFR Biosciences, Université Cocody- Abidjan. 227 p.

Kouao J.-M., Tagnon B., Koffi B., Kouassi A. M., Kouassi K. A., & Gone, D. L. 2024. Variabilité Climatique et Tendances Interannuelles Récentes du Climat en Afrique de l'Ouest : Cas de la Côte d'Ivoire. *ESI Preprints.* https://doi.org/10.19044/esipreprint.10.2024.p235

Kouassi A.M., Kouamé K. F., Ahoussi K. E., Oularé S. & Biemi J., 2012.-Impacts conjugués des changements climatiques et des pressions anthropiques sur les modifications de la couverture végétale dans le bassin versant du N'zi-Bandama (Côte d'Ivoire), Revue Ivoirienne des Sciences et Technologie, 20 : 124-146.

Koulibaly A. V., 2010. Caractéristiques de la végétation et dynamique de la régénération, sous l'influence de l'utilisation des terres, dans des mosaïques forêts-savanes, des régions de la réserve de Lamto et du parc national de la Comoé, en Côte d'Ivoire. Pour l'obtention du Doctorat en Botanique, Option Aménagement et Ressources Naturelles à l'UFR Biosciences, Laboratoire de Botanique de l'Université de Cocody (Abidjan). 137 p.

Koulibaly A., Kouamé D., Groga, N., Kouassi E. K., Bakayoko, A., & Porembski S., 2016. Floristic characteristics of the mosaic and how forest progress on savanna in the Lamto reserve region (Côte d'Ivoire). *International Journal of Development Research*, *6*(5), 7792–7799.

Koumoi Z., Alassane A., Djangbedja M., Boukpessi T. & Kouya A-E., 2013.-Dynamique spatio-temporelle de l'occupation du sol dans le Centre-Togo. Revue de Géographie Ahoho, **10 (7)** : 163-172.

Kpangui K. B., 2015. -Dynamique, diversité végétale et valeurs écologiques des agroforêts à base de cacaoyers de la Sous-préfecture de Kokumbo (Centre de la Côte d'Ivoire). Thèse de Doctorat, Université Félix Houphouët-Boigny, UFR Biosciences, 194 p.

Kpangui K. B., Kouakou A. A., Kouassi K. A., & Barima, Y. S. S., 2021. Impacts de l'installation des cacaoyères en zone de contact forêt-savanes de Biankouma en Côte d'Ivoire. *Agronomie Africaine,* ***33*****(2),** 57-68.

Kusserow H., 2017. Desertification, Resilience and Re-greening in the African Sahel – A matter of the observation period? *Earth System Dynamics Discussions*, **8(1),** 1-22.

Lauginie F., 2007. La Station d'Ecologie de Lamto : une mosaïque de galeries forestières et de savanes à palmier rônier. In: Conservation de la nature et aires protégées en Côte d'Ivoire (Eds Lauginie F) 299–316 (CEDA/NEI Abidjan & Afrique Nature Abidjan).

Le Stradic S., & Buisson E., 2020. Restaurer les savanes et les écosystèmes herbacés tropicaux. *Encyclopédie de l'Environnement*. http://www.encyclopedie-environnement.org/?p=11420

Lepousez V. & Aboukrat M. 2022. *Les scénarios SSP : décryptage et recommandations d'utilisation pour une démarche d'adaptation au changement climatique*. Pôle Résilience et Adaptation aux Impacts du Changement Climatique, 17p.

Liang J., Crowther T. W., Picard N., Wiser S., Zhou M., Alberti G., Schulze E.-D., McGuire A. D., Bozzato F., Pretzsch H., de-Miguel S., Paquette A., Hérault, B., Scherer-Lorenzen M., Barrett C. B., Glick H. B., Hengeveld G. M., Nabuurs G.-J., Pfautsch S., & Reich P. B., 2022. Diversity–productivity relationships in forest ecosystems under climate change. *Global Ecology and Biogeography, 31*(1), 88–101. https://doi.org/10.1111/geb.13389

Lobreau-Callen, D., Darchen R. & Delage-Darchen B., 1994. Etude comparative du comportement du butinage de deux espèces de Trigona du genre Africain

Liotrigona (Hymenopterae, Trigoninae) à partir de la composition pollinique des rations alimentaires des larves. 133-143.

Lompo D., Vinceti B., Konrad H., Gaisberger H., & Geburek T., 2018. Phylogeography of African locust bean (*Parkia biglobosa*) reveals genetic divergence and spatially structured populations in West and Central Africa. *Journal of Heredity*, *109*(7), 811-824.

Maârouhi I. M., Mahamane A., Saadou M. & Bachmann Y., 2011. Dynamique spatio temporelle des forêts claires dans le Parc national du W du Niger (Afrique de l'Ouest). *Sècheresse*, 22 : 97-107.

Malhi, Y., Meir, P., & Brown, S., 2011. Forests, carbon and global climate. *Philosophical Transactions of the Royal Society A, 366*(1885), 3625–3645. https://doi.org/10.1098/rsta.2008.0195

Mbow C., Brandt M., Ouedraogo I., de Leeuw J., & Marshall M., 2015. What four decades of earth observation tell us about land degradation in the Sahel? *Remote Sensing*, 7(4), 4048-4067.

McCarroll D., Loader N.J., 2004. Stable isotopes in tree rings. *Quaternary Science Reviews*, 23:771–801.

Merle J., Voituriez B. & Dandonneau Y., 2014.- Le changement climatique : histoire et enjeux. le club des Argonautes, http://www.clubdesargonautes.org [06-12-2019], 27 p.

Meyer C., Arbonnier M., Lhoste P., Huguenin Jo., Letenneur L., Roberge G., Tacher G., Vall E., (Eds), 2022. Dictionnaire des Sciences Animales. [On line]. Montpellier : CIRAD,France,.[consulté le 23/05/2022].<url:http://dico-sciences-animales.cirad.fr/>dendrochronologie.].

Mikwa J-F. N., 2010.- Evaluation par télédétection des effets de la déforestation et de la dégradation des forêts à Kisangani (cas de la région forestière de Masako). Thèse Doctorat, Université de Kisangani (République Démocratique du Congo), Mémoire Online, 81 p.

Monnier Y., 1968. Les effets des feux de brousse sur une savane préforestière de Côte d'Ivoire. Etudes Eburnéennes 9, Direction de la recherche scientifique de l'éducation nationale, Abidjan, Côte d'Ivoire, 260 p.

Monnier Y., 1983.- Carte de la végétation de la Côte d'Ivoire. In : Vennetier, P. & Laclavère, G. (eds) : Atlas de Côte d'Ivoire. 2e éd., Jeune Afrique, Paris, 72 p.

Moran E. F., Brondizio E. S., Tucker J. M., Da Silva-Forsberg M. C., McCracken S. & Falesi I., 2000. Effects of soil fertility and land-use on forest succession in Amazonia. *Forest Ecology and Management*, 139 : 93-108.

Moundzeo L., Kiangabene F., Loutete-Bahouamio D. & Itoua-Daporet Y., 2016.- Déterminisme de l'albédo dans la dynamique de productivité des agrosystèmes du Bassin du Congo, Science de la Vie, de la Terre et Agronomie Rev. Cames - 4 (02): 2424-2435.

N'Da D. H., 2008. Etude et suivi par Télédétection Système d'informations géographiques d'une aire protégée soumise aux pressions anthropiques : cas du Parc National de la Marahoué, Thèse de doctorat de l'Université de Cocody, Abidjan, Côte d'Ivoire, 181 p.

N'da D. H., Adou Y. C. Y., N'Guessan K. E., Koné M. & Sangne Y. C., 2008. Analyse de la Diversité floristique du Parc National de la Marahoué, Centre-Ouest de la Côte d'Ivoire. *Afrique Science*, **4 (3)** : 552–579.

N'Dja J. K., Tuo Y., & Zo-Bi I. C., 2017. Diversité floristique et infiltration humaine de la forêt classée de la Besso (Côte d'Ivoire). *Journal of Applied Biosciences*, *114*, 11299–11308. https://doi.org/10.4314/jab.v114i1.3

N'Dri J. K., Koné M., Kouassi K. P., & Traoré D., 2018. Variabilité climatique et dynamique de la végétation à la Station de Recherche Écologique de Lamto (Côte d'Ivoire). *Journal de la Recherche Scientifique de l'Université de Lomé, 20*(2), 141–153.

N'Guessan A. E., 2016. Diversité floristique et valeur de conservation d'une forêt privée à Ouahiéré dans le Département de Dianra (Nord-Ouest, Côte d'Ivoire). Mémoire de Master de Biodiversité et Valorisation des Écosystèmes, Laboratoire de Botanique, Université Félix HOUPHOUËT- BOIGNY, 47 p.

N'Guessan A. E., 2018.- Dynamique de la végétation et facteurs de reconstitution de la biomasse des forêts secondaires dans la forêt classée d'Agbo 1 (Côte d'Ivoire), Thèse de Doctorat Université Félix Houphouët- Boigny, 179 p.

N'Guessan A. E., Kouadio K. E., & Kassi, J., 2019. Cartographie de la dynamique du couvert végétal de la forêt classée d'Agbo 1 (Côte d'Ivoire). *Agronomie Africaine, 31*(1), 1-14.

N'Guessan K. E. et N'Da D. H., 2005. Caractérisation et cartographie par télédétection satellitaire de la végétation de la forêt classée de Bouaflé (Côte d'Ivoire). *Rev Ivoir. Sci. Technol.*, 06. pp. 161-172.

N'Guessan K. É., Dibi N'Da H., Bellan M. & Blasco F., 2006.- Pression anthropique sur une réserve forestière en Côte d'Ivoire. *Télédétection*, **5(4):** 307-323.

Nacoulma B. M. I., Schumann K., Traoré, S., Bernhardt-Römermann M., Hahn K., & Thiombiano, A., 2011. Impacts of land-use on West African savanna vegetation: A comparison between protected and communal area in Burkina Faso. *Biodiversity and Conservation,* **20(14),** 3341-3362. https://doi.org/10.1007/s10531-011-0114-0

Nanan K. K. N., Akaffou S. E. V., Pagny, F. P. J., Tiébré M. S., & Ouattara D., 2024. Anthropogenic Pressures and Dynamics of Land Use Change in the Rural Area of Béoumi and the Upper Bandama Wildlife Reserve (North-Central Côte D'Ivoire), From 1989 to 2020. *IOSR Journal of Pharmacy and Biological Sciences (IOSR-JPBS,* **19(2),** 57–72.

NASA, 2023. *Climate change: Evidence and causes*. National Aeronautics and Space Administration. https://climate.nasa.gov .

Nasi R., Dennis R., Meijaard E., Applegate G., Moore P., 2002. Les incendies de forêt et la diversité biologique. *Revue internationale des forêts et des industries forestières*, 36-40.

Ndiaye D., Sagna M. B., Diallo A., Diatta S., Peiry J. L., & Guisse A., 2020. Analyse de la Structure Morphologique des Cernes de Croissance et Détermination Des Âges de Deux Espèces Sahéliennes : Acacia Tortilis (Forsk.) Hayne Ssp. Raddiana (Savi) Brenan, Acacia Senegal (L.) Willd. European Scientific Journal (ESJ), European Scientific Institute, 16 (6), pp.168-187. 10.19044/esj.2020.v16n6p168 . hal-02568639.

Niang I., Ruppel, O. C., Abdrabo M. A., Essel A., Lennard C., Padgham J., Urquhart P., 2014. Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth

Assessment Report of the Intergovernmental Panel on Climate Change [Barros VR, Field CB, Dokken DJ and 13 others (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Nicholson S. E., 2013. The West African Sahel and the Sudan: Climate and Context. *Annual Review of Earth and Planetary Sciences*, 41, 177-199.

Noufé D., Mahé G., Kamagaté B., Servat E., Tié A. G. B., & Savané I., 2015. Climate change impact on agricultural production: The case of Comoé River Basin in Ivory Coast. *International Journal of Climatology*, **35**(13), 4589–4605. https://doi.org/10.1002/joc.4246

O'Neill B. C., Kriegler E., Ebi K. L., Kemp-Benedict E., Riahi K., Rothman D. S., van Ruijven B. J., van Vuuren D. P., Birkmann J., Kok K., Levy M., & Solecki W., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

Oldeman R. A. A., 1979.- Quelques aspects quantifiables de l'arborigénèse et de la sylvigénèse. *Oecologia Plantarum,* 14 : 289-312.

Olofsson P., Foody G. M., Stehman S. V., & Woodcock C. E., 2014. Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, 42-57.

Organisation météorologique mondiale (OMM)., 1979. *Première Conférence mondiale sur le climat : Genève, février 1979*. Genève : OMM. Disponible sur : genevemonde.ch [Consulté le 4 décembre 2024].

Oszwald J., 2005. Dynamique des formations agroforestières en Côte d'Ivoire (des années 1980 aux années 2000) suivi par télédétection et développement d'une approche cartographique. Thèse de Doctorat, UFR de Géographie et d'aménagement, Université des sciences et technologies de Lille (Lille, France), 304 p.

Ouattara D., Kouame D., Tiebre M-S, Cisse A. & N'Guessan K. E., 2016. Diversité floristique et usages des plantes dans la zone soudanienne du Nord-ouest de la Côte d'Ivoire. *Journal of Animal &Plant Sciences*, Vol.**3(11)**: 4815-4830

Ouédraogo A., Mortier F., Gourlet-Fleury S., Freycon V., & Picard N., 2014. Slow-growing species cope better with drought: Evidence from long-term monitoring in a tropical semi-deciduous forest. *Journal of Ecology, 102*(4), 964–973.

Ouédraogo B. W., Schumann K., Hahn K., & Thiombiano A., 2015. Morphological variation of the threatened species Pterocarpus erinaceus Poir. (Fabaceae) in Burkina Faso (West Africa). *South African Journal of Botany***, 100**, 156-164.

Pagney P., 1988. Le climat de Lamto (Côte d'Ivoire). In: Le climat de la savane de Lamto (Côte d'Ivoire) et sa place dans les climats de l'Ouest africain (Eds Lamotte M & Tireford JL) 31–79 (Travaux de recherche des chercheurs de Lamto, Station d'écologie tropicale de Lamto, Université d'Abidjan).

Pagny F. P. J., Mevanly O. & Tiébre M. S. 2020. Prediction of the potential invasion of Lantana Camara L. (Verbenaceae) an exotic plant species in Côte d'Ivoire from a modelling approach. *International Journal of Biological and Chemical Sciences*, 14(4), 1241-1261. DOI:10.4314/ijbcs.v14i4.7

Pain-Orcet M., Lo See D., Fauvet N., Trebuchon J-F. & Diapapoundji B. (1998). Les cartes, la télédétection et les SIG, des outils pour la gestion et l'aménagement des forêts tropicales d'Afrique Centrale. Rapport CIRAD-Forêt, 31 p.

Pan Y., Birdsey R.A.; Fang J.; Houghton R., Kauppi P.E., Kurz W.A., Phillips O.L., Shvidenko A., Lewis S.L., Canadell J.G., Ciais P., Jackson R.B., Pacala S., McGuire A.D., Piao S., Rautiainen A., Sitch S. & Hayes D., 2011.- A large and persistent carbon sink in the world's forests. *Science*, 333: 988-993.

Pan Y., Birdsey, R. A., Fang J., Houghton R., Kauppi P. E., Kurz W. A., Phillips O. L., Shvidenko A., Lewis S. L., Canadell J. G., Ciais P., Jackson R. B., Pacala S. W., McGuire A. D., Piao S., Rautiainen A., Sitch S., & Hayes D., 2011. A large and persistent carbon sink in the world's forests. *Science, 333*(6045), 988–993. https://doi.org/10.1126/science.1201609

Perraud A. 1971. Les sols. In : Le milieu naturel de la Côte d'Ivoire. Mém. ORSTOM. Paris 50 : 265-392.

PNUE, 2023. *West Africa's changing climate and human security*. https://www.unep.org

Poorter L., Bongers F., & Bongers F., 2004. Biodiversity of West African forests: An ecological atlas of woody plant species. CABI Publishing.521 pages.

Poorter L., Craven D., et al. (2021). Multi-dimensional resilience of tropical forests. *Science, 372*(6538), 97–102. https://doi.org/10.1126/science.abh3629

Poorter L., Craven D., Jakovac C. C., van der Sande M. T., Amissah L., Bongers F., Chazdon R. L., Farrior C. E., Kambach S., Meave J. A., Muñoz R., Norden N., Rüger N., van Breugel M., Almeyda Zambrano A. M., Amani B., Andrade J. L., Brancalion P. H. S., Broadbent E. N., de Foresta H., Dent D. H., Derroire G., DeWalt S. J., Dupuy J. M., Durán S. M., Fantini A. C., Finegan B., Hernández-Jaramillo A., Hernández-Stefanoni J. L., Hietz P., Junqueira A. B., Kassi N'dja J., Letcher S. G., Lohbeck M., López-Camacho R., Martínez-Ramos M., Melo F. P. L., Mora F., Müller S. C., N'Guessan A. E., Oberleitner F., Ortiz-Malavassi E., Pérez-García E. A., Pinho B. X., Piotto D., Powers J. S., Rodríguez-Buriticá S., Rozendaal D. M. A., Ruíz J., Tabarelli M., Teixeira H. M., Sampaio E. V. de Sá B., van der Wal H., Villa P. M., Fernandes G. W., Santos B. A., Aguilar-Cano J., Almeida-Cortez J. S. de, Alvarez-Davila E., Arreola-Villa F., Balvanera P., Becknell J. M., Cabral G. A. L., Castellanos-Castro C., de Jong B. H. J., Nieto J. E., Espírito-Santo M. M., Fandino M. C., García H., García-Villalobos D., Hall J. S., Idárraga A., Jiménez-Montoya J., Kennard D., Marín-Spiotta E., Mesquita R., Nunes Y. R. F., Ochoa-Gaona S., Peña-Claros M., Pérez-Cárdenas N., Rodríguez-Velázquez J., Sanaphre Villanueva L., Schwartz N. B., Steininger M. K., Veloso M. D. M., Vester H. F. M., Vieira I. C. G., Williamson B., Zanini K., & Hérault B., 2021. Multidimensional tropical forest recovery. *Science, 374*(6573), 1370-1376. https://doi.org/10.1126/science.abh3629

pour l'UNICEF, http//www.my [20-07-2019] UNICEF.fr, 7 p.

Quattrochi D. A. & Pelletier R. E. (Eds.) 1990. Remote sensing for analysis of landscapes : an introduction. In : Quantitative methods in landscape ecology : the analysis and interpretation of landscape heterogeneity (Ecological Studies). Edition Springer-Verlag, New York : 51-76.

Quesada C. A., Lloyd J., Schwarz M., Patiño S., Baker T. R., Czimczik C. I., Fyllas N. M., Martin S. T., & Mercado L. M., 2012. Basin-wide variations in Amazon forest structure and function are mediated by both soils and climate. *Biogeosciences, 9*(6), 2203–2246. https://doi.org/10.5194/bg-9-2203-2012

Rabiou H, Bationo B A, Adjonou K, Kokutse AD, Mahamane A, Kokou K. 2017. Perception paysanne et importance socioculturelle et ethnobotanique de Pterocarpus erinaceus au Burkina-Faso et au Niger. *Afrique Science*, 13(5): 43-60.

Rabiou H., Diouf A., Bationo B. A., Segla K. N., Adjonou K., Kokutse A. D., Radji, R., Kokou K., Mahamane, A., Saadou, M. (2015) : Structure des peuplements naturels de *Pterocarpus erinaceus* Poir. dans le domaine soudanien, au Niger et au Burkina Faso. *Bois et Forêts des Tropiques*, 325(3) : 71-83. DOI:10.19182/bft2015.325.a31274

Rammig A., Jupp, T., Thonicke K., Tietjen B., Heinke J., Ostberg S., & Cox P., 2010. Estimation du risque de dépérissement de la forêt amazonienne. *New Phytologist, 694–706*.

Rathore P., Roy A. & Karnatak H. 2019. Modelling the vulnerability of Taxus wallichiana

Reside A. E., Butt N., & Adams V. M., 2018. Adapting systematic conservation planning for climate change. *Biodiversity and Conservation*, 27(**1**), 1–29. https://doi.org/10.1007/s10531-017-1442-5

Richards P. W., 1996. *The tropical rain forest: An ecological study* (2nd ed.). Cambridge University Press, 575p.

Riou G., 1974. Les sols de la savane de Lamto. In: Analyse d'un écosystème tropical humide : la savane de Lamto (Côte d'Ivoire), fascicule 1: les facteurs physiques du milieu. *Bulletin de Liaison des Chercheurs de Lamto* 3-43.

Robin M., 1998. La Télédétection : Des satellites aux systèmes d'information géographiques. Faculté de Géographie, Université de Nantes, France, 319 p.

Roth H. H., Hoppe-Dominik B. & Koffi Yoa P., 2002. Le marché de la viande de gibier à Toumodi en Côte d'Ivoire. *Revue Internationale pour la conservation de la nature en Afrique*, 1-24.

Rozendaal D. M. A., & Zuidema P. A., 2011. Dendroecology in the tropics: A review. Trees,25(1), 3–16. https://doi.org/10.1007/s00468-010-0480-3

Rutherford E., & Tohé E., 2022. Climate Change and Ecosystem Responses in the Lamto Research Reserve, Côte d'Ivoire. *African Journal of Ecology, 60*(3), 299–310.

Rutherford S., et Tohé A., 2022. Les effets des variations climatiques sur les réserves forestières de Côte d'Ivoire. *Journal ivoirien des sciences de l'environnement*, 56, 121-137.

Sanogo K.,Gebrekirstos A., Bayalac J.,Villamor G. B., Kalinganirec A., & Dodiomon S., 2016. Potential of dendrochronology in assessing carbon sequestration rates of Vitellaria paradoxa in southern Mali, West Africa. Dendrochronologia, Elsevier 2016(40) 26–35. http://dx.doi.org/10.1016/j.dendro.2016.05.004

Sanon H. O., Bationo B. A., & Ambouta K. J. M., 2007. Diversité floristique et dynamique des peuplements ligneux dans une savane soudanienne protégée (Burkina Faso). *Sécheresse*, **18(4)**, 283–291

Sanon K., 2007. Dynamique des formations végétales dans les zones de transition forêt-savane en Afrique de l'Ouest. Thèse de doctorat, Université de Ouagadougou. 198p.

Sarr B., Mbow C., et Sultan B., 2008. *Impact des fluctuations des régimes de précipitations sur les savanes de l'Afrique de l'Ouest*. *Climatologie régionale d'Afrique de l'Ouest*, 32, 204-217.

Schimper A.F.W., 1898. Pflanzen Geographie auf Physiologischer; Grundlage: Jena, Germany,

Schmidt M., Müller J., Zizka A., Ehrensperger A., Ouédraogo A., Da S. S. & Hahn K., 2017. Changes in plant functional trait composition along land-use and disturbance gradients in forest and savanna vegetation in southwestern Burkina Faso. *Journal of Vegetation Science*, 28**(4)**, 900-911.

Schongart J., Orthmann B., Hennenberg K.J., Porembski S., Worbes M. (2006). Climate-growth relationships of tropical tree species in West Africa and their potential for climate reconstruction. Global Change Biology, 12: 1130-1150.

Schöngart J., Piedade M. T. F., Wittmann F., Junk W. J., & Worbes M., 2006. Wood growth patterns of *Macrolobium acaciifolium* (Fabaceae) in Amazonian floodplain forests. *Trees, 19*(**3**), 327–335. https://doi.org/10.1007/s00468-006-0055-2

Schweingruber F. H.1988. Tree Rings and Environment: Dendroecology; Paul Haupt: Berne, Switzerland, 1996; p. 609.

Shikangalah R., Mapani B., Mapaure I., Herzschuh U., 2022. Responsiveness of Dichrostachys cinerea to seasonal variations in temperature and rainfall in central Namibia, Flora, 286 (2022) 151974. 7p.

Silué P.A., 2018. Etude de la flore, de la dynamique de la végétation et essai de germination de trois espèces couramment exploitées des forêts classées de la Palé et de Pouniakélé, dans la région de la Bagoué (Nord-ouest de la Côte d'Ivoire). Thèse de doctorat, UFR Biosciences, Université Félix Houphouët-Boigny de Cocody-Abidjan, Cote d'Ivoire. 224p.

Slotta F., Helle G., Heussner K. U., Shemang E. & Riedel F., 2017. Baobabs on Kubu Island, Botswana - a dendrochronological multi- parameter study using ring width and stable isotopes (δ13 C δ13 O). Erdkunde vol 71 No. 1., 23-43.

Sokpon N., 1995.- Recherches écologiques sur la forêt dense semi-décidue de Pobe au Sud-Est du Bénin : groupements végétaux, structure, régénération naturelle et chute de la litière. Thèse de doctorat, Université Libre de Bruxelles, Belgique, 350 p.

Soro G., Ahoussi K. E., Kouadio K. E., Soro D.T., Oulare S., Saley M. B., Soro N. & Biemi J., 2014. Apport de la télédétection à la cartographie de l'évolution spatio-temporelle de la dynamique de l'occupation du sol dans la région des Lacs (Centre de la Côte d'Ivoire). *Afrique SCIENCE,* **10(3)** : 146 – 160.

Sosef M. S. M., Dauby G., Blach-Overgaard A., van der Burgt X., Catarino L., Damen T., Engledow H., Figueira R., Gereau R. E., Hardy O. J., Harris D. J., de Heij J., Janssens S., Johnson D. M., Luke Q., Marshall A. R., Micklem T., van Njoh L., Schafer C., Stévart T., Stoffelen P., Svenning J.-C., Sepulchre P., Sonké B., & Couvreur T. L. P., 2017. Exploring the floristic diversity and distribution of the Guineo-Congolian rain forest tree flora. *Journal of Biogeography, 44*(1), 151–163.

Soufouyane Z., Imorou I. T, Omer A. B., Djaouga M. & Ousséni A., 2018.- Application de la télédétection et du SIG au suivi des formations végétales de la forêt classée des trois rivières au Nord-Est du Bénin, European Scientific Journal, Vol.14 (15): 450-469.

Soulama S., Kadeba. A., Nacoulma B. M. I., Traoré S., Bachmann Y. & Thiombiano A., 2015. Impact des activités anthropiques sur la dynamique de la végétation de la réserve partielle de faune de Pama et de ses périphéries (sud-est du Burkina Faso) dans un contexte de variabilité climatique. *Journal of Applied Biosciences*, **87** : 8047– 8064.

Souza B. T., Estrada G. C. D., Soares M. L. G., & Callado C. H., 2016. Occurrence of annual growth rings in rhizophora mangle in a region with low climate seasonality. Anais Da Academia Brasileira de Ciencias, 88(1), 517–525. https://doi.org/10.1590/0001-3765201620150009.

Staver A.C., Archibald S., & Levin S.A., 2011. The global extent and determinants of savanna and forest as alternative biome states. *Science*, 334, 230-232

Stephenson N. L., Das A. J., Condit R., Russo, S. E., Baker P. J., Beckman N. G., Coomes D. A., Lines E. R., Morris W. K., Rüger N., Álvarez E., Blundo C., Bunyavejchewin S., Chuyong G. B., Davies S. J., Duque Á., Ewango C. N., Flores O., Franklin J. F., & Zavala M. A., 2014. Rate of tree carbon accumulation increases continuously with tree size. *Nature, 507*, 90–93. https://doi.org/10.1038/nature12914

Swaine M. D. & Whitmore T. C., 1988.- On the definition of ecological species groups in tropical rain forests. *Plant Ecology* **75**: 81-86.

Tankoano B., 2017.- Contribution de la télédétection et des Systèmes d'Informations Géographiques à l'évaluation de l'impact des activités humaines sur la couverture végétale : cas du Parc National des Deux Balé (PNDB), à l'Ouest du Burkina Faso. Thèse de Doctorat, Université Nazi Boni (Burkina Faso); 111 p.

Tankoano B., Hien M., Sanon Z., Dibi N. H., Yameogo T. J. & Somda I. 2015.- Dynamique spatio-temporelle des savanes boisées de la Forêt Classée de Tiogo au Burkina Faso. International Journal of Biological and Chemical Sciences, 9 (4) : 1983-2000.

Tarhule A., Hughes M. K., 2002. Tree-ring research in semiarid west Africa: Need and potential. Tree-Ring Research 58(1/2):31-46.

Thiombiano A., 1996.- Contribution à l'étude des Combretaceae dans les formations végétales de la région Est du Burkina Faso. Thèse de Doctorat 3ème cycle, Université de Ouagadougou, Burkina Faso, 220 p.

Thuiller W., Lavorel, S., Araújo M. B., Sykes M. T., & Prentice I. C., 2005. Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Sciences*, *102*(23), 8245–8250. https://doi.org/10.1073/pnas.0409902102

Tiho S., Ehouman N. M., & Dagnogo M., 2015. Aggregation and spatial coexistence of earthworm community in grassy savanna of Lamto (Côte d'Ivoire). *Journal of Biology and Life Science, 6*(**1**), 1-13. https://doi.org/10.5296/jbls.v6i2.6975

Timité, N., Koua, K. A. N., Kouakou, A. T. M., & Barima, Y. S. S., 2023. Dynamiques spatio-temporelles des parcs agroforestiers dans la zone soudanienne de la Côte d'Ivoire de 1990 à 2020 dans un contexte d'expansion de l'anacarde. *International Journal of Biological and Chemical Sciences, 17*(**2**), 484-504.

to climate change scenarios T in south East Asia. Ecological Indicators.

Traoré L., Sop, T. K., Dayamba S. D., Traoré S., Hahn K., & Thiombiano A., 2012. Do protected areas really work to conserve species? A case study of three vulnerable woody species in the Sudanian zone of Burkina Faso. *Environment, Development and Sustainability*, **14(6),** 939-956. https://doi.org/10.1007/s10668-012-9399-8

Traoré S., Hiernaux, P., & Guichard F., 2015. Effet du pâturage sur la végétation sahélienne : dynamique des formations végétales et implications pour la gestion des parcours. *Journal of Arid Environments*, **121**, 44-55.

Trenberth, K. E., & Shea, D. J., 2005. Relationships between precipitation and evaporation. *Journal of Climate, 18*(**21**), 4890–4902.

Trouet V., Esper J., Beeckman H., 2010. Climate/growth relationships of Brachystegia spiciformis from the Miombo woodland in south central Africa'. *Dendrochronologia*, **28**: 161-171.

UICN/BRAO., 2008. Évaluation de l'efficacité de la gestion des aires protégées : parcs et réserves de Côte d'Ivoire. 42p.

UNICEF, 2016.- La lutte contre le changement climatique. UNICEF France-Comité français pour l'UNICEF, http//www.my [20-07-2019] UNICEF.fr, 7 p.

Van Breugel M. 2011. Estimating carbon stock in secondary forests: Decisions and uncertainties associated with allometric biomass models. For. Ecol. Manage., 262(8), 1648-1657.

Venter Z. S., Cramer M. D., & Hawkins H.-J., 2017. Bush encroachment reduces plant diversity in a South African savanna. *Journal of Ecology*, 105(3), 1–12. https://doi.org/10.1111/1365-2745.12747

Voldoire, A., Saint-Martin, D., & Cassou, C., 2020. *Modèles climatiques et projections climatiques*. Encyclopédie de l'environnement. Consulté dans « Le climat en questions », Institut Pierre-Simon Laplace. Publication de la DREAL CVL, juin 2023.

Vuattoux, R. 1968. Le peuplement du rônier (Borassus aethiopum Mart.) d'une savane de Côte d'Ivoire. Annales de l'Université d'Abidjan, Serie E: Ecologie, tome I, fascicule 1, 138 p.

Walter H., & Lieth H. 1967. *Klimadiagramm-Weltatlas*. Gustav Fischer Verlag.

Wan J. Z., Wang C. J., Qu H., Liu R. & Zhang Z. X. 2018. Vulnerability of forest vegetation to anthropogenic climate change in China. Science of the Total Environment, 621:1633-1641. https://doi.org/10.1016/j.scitotenv.2017.10.065

Whitmore T.C., 1984. *Tropical Rain Forests of the Far East*; Clarendon Press: Oxford, UK, p. 352.

Wiederkehr E., 2013. Apports de la géomatique pour une caractérisation physique multi-échelle des réseaux hydrographiques : Élaboration d'indicateurs appliqués au bassin du Rhône. Thèse de Doctorat, Université de Lyon, Lyon, France, 287 p.

Worbes M., 1995. How to Measure Growth Dynamics in Tropical Trees a Review. IAWA Journal, 16(4), 337–351. https://doi.org/10.1163/22941932-90001424

Worbes M., 1995. How to Measure Growth Dynamics in Tropical Trees a Review. IAWA

Worbes M., 2002. One hundred years of tree-ring research in the tropics - A brief history and an outlook to future challenges. Dendrochronologia, 20(1–2), 217–231. https://doi.org/10.1078/1125-7865-00018

Yabi C. C., **Idohou J.**, **Ayena K.**, **Biaou S.**, **Adomou S.**, **Houehanou T. D.**, & **Gouwakinnou G. N., 2025.** Climate change-induced shifts in the ecological niches of *Parkia biglobosa* (Jacq.) and *Vitellaria paradoxa* CF Gaertn, two species of agroforestry parks in Benin, West Africa. *Trees, Forests and People, 20*, 100830. https://doi.org/10.1016/j.tfp.2025.100830

Yao N, A., Kouadio, A. Z., Deguy, J. P. A., Hien, A. S., Goula, A. B. T., & Savané, I., 2018. Influence de la dynamique de l'occupation du sol sur la quantité de perte de sol au sud du bassin versant du Sassandra (Côte d'Ivoire). *International Journal of Advanced Research*, 6(**4**), 830-838. DOI: 10.21474/IJAR01/6918

Yao N., O., 2019. Dynamique et valeur écologique de la végétation dans le secteur sub-soudanais ; cas du département. Thèse de Doctorat, Laboratoire de Botanique Université Félix Houphouët-Boigny Cocody -Abidjan, Côte d'Ivoire, 229 p.

Yao, J. C., 2023. Erosion hydrique dans le bassin versant du Gourou (Côte d'Ivoire). Editions universitaires européennes. ISBN: 978-620-6-68922-5. 92p.

Yassi, Y. F. B., 2014. Mise en place d'un Système d'Information Géographique (SIG) pour la gestion de la biodiversité: Cas de la réserve scientifique de Lamto. Diplôme d'Agronomie Approfondie (DAA), Option Eaux et Forêts, Institut Polytechnique Felix Houphouët Boigny de Yamoussoukro. 51p.

Yélémou B., Savadogo P., Traoré S., Millogo-Rasolodimby J., & Hien V., 2015. Floristic diversity of Piliostigma associations in relation to latitudinal gradient, soil and climate variables in Burkina Faso, West Africa**.** *Tropical Ecology,* 56**(1),** 57-76. ISSN 0564-3295.

Zeng X., Lu H., et Zhang J., 2020. Impacts of Climate Change on African Precipitation Patterns. *Climate Dynamics*, **54**, 3951-3965.

Zhou L., Tian Y., Myneni R. B., Ciais P., Saatchi S., Liu Y. Y., Piao S., Chen H., Vermote E., Song C., Hwang T., & Chen J., 2014. Widespread decline of Congo rainforest greenness in the past decade. *Nature, 509*(7498), 86–90. https://doi.org/10.1038/nature13400

APPENDICES

Confusion Matrices

Appendix 1: Confusion matrix for the Landsat TM 1990 image classification at RS Lamto.

Class	GF/DSF	OF/WS	TS	SS	BL/ ST	WB
GF/DSF	**99.90**	0.00	0.00	0.08	0.00	1.92
OF/WS	0.05	**98.41**	1.53	1.71	0.00	0.00
TS	0.00	0.00	**98.47**	0.16	0.00	0.00
SS	0.05	1.59	0.00	**97.93**	0.00	0.00
BL/ ST	0.00	0.00	0.00	0.12	**100.00**	0.00
WB	0.00	0.00	0.00	0.00	0.00	98.08
Total	100.00	100.00	100.00	100.00	100.00	**100.00**
User quality (%) : values in diagonal and bold						
Overall Accuracy : 98.66%						
Kappa : 0.98						

Appendix 2: Confusion matrix of the classification of the Landsat 7 ETM 2002 image at the SR**.**

Class	GF/DSF	OF/WS	TS	SS	BL/ ST	WB
GF/DSF	**99.89**	0.00	0.00	0.00	0.00	0.00
OF/WS	0.05	**100.00**	0.00	0.27	0.00	0.00
TS	0.00	0.00	**100.00**	0.00	0.00	0.00
SS	0.00	0.00	0.00	**99.73**	0.00	0.00
BL/ ST	0.05	0.00	0.00	0.00	**100.00**	0.00
WB	0.00	0.00	0.00	0.00	0.00	**100.00**
Total	100.00	100.00	100.00	100.00	100.00	100.00
User quality (%) : values in diagonal and bold						
Overall Accuracy : 99,83%						
Kappa : 0.99						

Appendix 3: Confusion matrix of the classification of the Landsat ETM 2012 image at the RS Lamto.

Class	GF/DSF	OF/WS	TS	SS	BL/ ST	WB
GF/DSF	**99.76**	0.00	0.37	0.07	0.00	0.42
OF/WS	0.00	**100.00**	0.00	0.14	0.00	0.00
TS	0.00	0.00	**99.06**	0.14	0.00	1.27
SS	0.00	0.00	0.56	**99.30**	0.00	0.00
BL/ ST	0.24	0.00	0.00	0.35	**100.00**	0.00
WB	0.00	0.00	0.00	0.00	0.00	**98.31**
Total	100.00	100.00	100.00	100.00	100.00	100.00

User quality (%) : values in diagonal and bold
Overall Accuracy : 99,27%
Kappa : 0.98

Appendix 4: Confuson matix of the classification of Landsat 9 OLI TIRS 2022 image at Lamto RS.

Class	GF/DSF	OF/WS	TS	SS	BL/ ST	WB
GF/DSF	**97.37**	1.69	0.00	0.00	0.00	0.20
OF/WS	2.58	**98.31**	0.14	0.22	0.00	0.00
TS	0.00	0.00	**99.14**	0.86	0.00	0.20
SS	0.00	0.00	0.73	**98.92**	0.00	0.00
BL/ ST	0.03	0.00	0.00	0.00	**100.00**	0.00
WB	0.03	0.00	0.00	0.00	0.00	**99.60**
Total	100.00	100.00	100.00	100.00	100.00	100.00
User quality (%) : values in diagonal and bold						
Overall Accuracy : 98,32%						
Kappa : 0.97						

GF/DSF : Gallery Forest/Dense Semi-deciduous Forest ; **OF/WS** : Open Forest/Wooded Savanna ; **TS** : Tree Savanna ; **SS** : Shrub Savanna ; **BL/ST** : Bare Land/Settlement ; **WB** : Water/Body.

Appendix 5: Confusion matrix for the classification of Landsat TM 1990 images at FC Badenou.

Class	GF/DDF	OF/WS	TS /SS	LDSS	FL	PC	RL/RO/AD	WB
GF/DDF	**95.36**	0.25	0.00	0.00	0.00	0.00	0.00	0.15
OF/WS	3.87	**93.64**	0.62	0.00	0.00	0.00	0.00	0.20
TS /SS	0.02	2.29	**90.86**	2.70	8.70	0.00	1.07	1.26
LDSS	0.00	2.29	2.76	**97.30**	0.00	0.00	0.00	0.02
FL	0.00	0.25	4.01	0.00	**91.30**	0.00	0.00	0.12
PC	0.75	1.27	0.00	0.00	0.00	**100.00**	0.00	0.00
RL/RO/AD	0.01	0.00	0.00	0.00	0.00	0.00	**98.93**	0.28
WB	0.00	0.00	1.74	0.00	0.00	0.00	0.00	**97.97**
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
User quality (%) : values in diagonal and bold								
Overall Accuracy : 95.98%								
Kappa : 0.93								

Appendix 6: Confusion matrix for the classification of the Landsat 7 ETM 2002 image at FC Badenou.

Class	GF/DDF	OF/WS	TS /SS	LDSS	FL	PC	RL/RO/AD	WB
GF/DDF	**95.37**	3.01	0.27	0.00	0.00	0.00	1.09	0.11
OF/WS	2.30	**94.81**	1.11	0.00	0.00	0.00	0.65	0.20
TS /SS	1.35	1.09	**95.44**	0.00	0.00	0.00	1.52	3.09
LDSS	0.01	0.82	0.15	**100.00**	0.00	0.00	0.00	0.14
FL	0.08	0.00	1.46	0.00	**100.00**	0.00	0.00	0.11
PC	0.24	0.27	0.00	0.00	0.00	**100.00**	0.00	0.00
RL/RO/AD	0.74	0.00	0.00	0.00	0.00	0.00	**96.74**	0.00
WB	0.03	0.00	1.57	0.00	0.00	0.00	0.00	**96.34**
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
User quality (%) : values in diagonal and bold								
Overall Accuracy : 95.60%								
Kappa : 0.91								

Appendix 7: Confusion matrix for the classification of the Landsat 7 ETM 2012 image at FC Badenou.

Class	GF/DDF	OF/WS	TS /SS	LDSS	FL	PC	RL/RO/AD	WB
GF/DDF	**93.54**	1.86	0.74	0.00	0.00	0.00	1.84	0.24
OF/WS	2.42	**88.56**	2.68	0.00	0.00	3.66	0.00	0.41
TS /SS	1.75	4.79	**84.58**	0.00	0.00	0.00	1.57	5.49
LDSS	0.01	0.00	0.94	**100.00**	0.00	0.00	0.00	0.59
FL	0.24	1.06	8.04	0.00	**100.00**	0.00	0.00	0.13
PC	0.74	3.72	0.00	0.00	0.00	**96.34**	0.00	0.00
RL/RO/AD	1.16	0.00	0.27	0.00	0.00	0.00	**96.59**	0.02
WB	0.14	0.00	2.75	0.00	0.00	0.00	0.00	**93.12**
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
User quality (%) : values in diagonal and bold								
Overall Accuracy : 92.65%								
Kappa : 0.87								

Appendix 8: Confusion matrix for the classification of the Landsat 9 OLI TIRS 2022 image at FC Badenou.

Class	GF/DDF	OF/WS	TS /SS	LDSS	FL	PC	RL/RO/AD	WB
GF/DDF	**89.99**	2.26	0.00	0.00	0.23	0.00	0.00	0.00
OF/WS	4.93	**74.82**	2.00	0.00	1.42	0.00	0.00	0.00
TS /SS	0.22	0.71	**95.74**	4.27	0.28	0.00	0.62	0.22
LDSS	0.22	2.26	1.26	**95.74**	2.66	0.00	0.00	0.00
FL	4.14	19.95	0.67	0.00	**95.41**	0.00	0.00	0.00
PC	0.17	0.00	0.07	0.00	0.00	**100.00**	0.00	0.00
RL/RO/AD	0.33	0.00	0.00	0.00	0.00	0.00	**99.17**	0.00
WB	0.00	0.00	0.27	0.00	0.00	0.00	0.21	**99.78**
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
User quality (%) : values in diagonal and bold								
Overall Accuracy : 94,35%								
Kappa : 0.87								

GF/DDF : Gallery Forest/Dense Dry Forest ; **OF/WS** : Open Forest/Wooded Savanna ; **TS/SS** : Tree Savanna/Shrub Savanna ; **LDSS** : Low Density Shrub Savanna ; **FL** : Fallow Land ; **PC** : Perennial Crops ; **BL/RO/AD** : Bare Land/Rock Outcrop/Agriculture Development ; **WB** : Water/Body.

Transition Matrices

Appendix 9: Land use/land cover transition matrix in the Lamto Scientific Reserve (LSR) from 1990-2002

Lamto		1990					
2002	**Class (%)**	**GF/DSF**	**OF/WS**	**TS**	**SS**	**BL/ ST**	**WB**
	GF/DSF	**89.88**	8.37	3.74			0.99
	OF/WS	6.77	**40.34**	7.99	5.70		
	TS	1.44	36.63	**63.42**	8.34	1.23	
	SS	1.18	14.62	24.85	**85.93**	73.48	
	BL/ST	0.10	0.03		0.01	**25.29**	
	WB	0.64	0.01		0.01		**99.01**
	Total	**100**	**100**	**100**	**100**	**100**	**100**
	Total (Ha)	**663.11**	**649.59**	**85.94**	**1289.47**	**7.34**	**150.12**

Appendix 10: Land use/land cover transition matrix in the Lamto Scientific Reserve (LSR) from 2002-2012

Lamto		**2002**					
2012	**Class (%)**	**GF/DSF**	**OF/WS**	**TS**	**SS**	**BL/ST**	**WB**
	GF/DSF	**83.83**	22.52	8.13	1.41	0.96	0.00
	OF/WS	7.93	**47.21**	13.85	0.83	3.16	0.08
	TS	4.04	13.58	**51.55**	32.19	6.32	
	SS	2.96	16.63	23.88	**63.74**	3.95	
	BL/ST	0.01	0.06	2.60	1.84	**85.61**	
	WB	1.23			0.00		**99.92**
	Total	100	100	100	100	100	100
	Total (Ha)	**698.95**	**387.15**	**171.42**	**1474.29**	**2.85**	**107.33**

Appendix 11: Land use/land cover transition matrix in the Lamto Scientific Reserve (LSR) from 2012-2022

Lamto		**2012**					
2022	**Class (%)**	**GF/FDS**	**OF/WS**	**TS**	**SS**	**BL/ST**	**WB**
	GF/DSF	**71.51**	3.47	2.54	0.25	0.00	0.00
	OF/WS	17.20	**72.22**	10.50	13.10	1.31	
	TS	6.00	13.00	**75.53**	37.03	49.28	0.05
	SS	2.04	10.74	8.41	**47.66**	25.69	
	BL/ST	1.16	0.52	2.95	1.95	**23.72**	
	WB	2.10	0.05	0.07			**99.94**
	Total	**100**	**100**	**100**	**100**	**100**	**99.99**
	Total (Ha)	**746.54**	**197.16**	**592.78**	**1160.81**	**33.16**	**113.03**

Appendix 12: Land use/land cover transition matrix in the Lamto Scientific Reserve (LSR) from 1990-2022

Lamto		1990					
	Class (%)	**FG/FDS**	**OF/WS**	**TS**	**SS**	**BL/ST**	**WB**
2022	**GF/DSF**	**71.77**	10.81	6.93	1.47	11.55	0.00
	OF/WS	20.56	**33.63**	15.79	9.30	10.41	0.00
	TS	3.65	26.29	**54.47**	46.76	23.57	0.10
	SS	1.54	28.82	16.78	**39.46**	3.37	
	BL/ST	0.53	0.44	5.14	3.00	**51.09**	
	WB	1.96	0.00	0.89	0.01		**99.90**
	Total	**100**	**100**	**100**	**100**	**100**	**100**
	Total (Ha)	**661.29**	**649.09**	**85.63**	**1288.05**	**7.23**	**149.30**

Appendix 13: Land use/land cover transition matrix in the Badenou Classified Forest (BCF) from 1990-2002

Badenou		1990							
2002	**Class (%)**	**GF/DDF**	**OF/WS**	**TS/SS**	**LDSS**	**FL**	**PC**	**BL/ ST**	**WB**
	GF/DDF	**65.22**	13.76	4.41	0.00	6.74			
	OF/WS	16.53	**63.64**	14.93		8.13			
	TS/SS	15.66	19.34	**68.82**	38.83	67.31	11.82	54.75	
	LDSS	0.24	0.85	1.56	**51.19**	0.86	0.17	0.96	
	FL	0.61	0.45	4.42	0.79	**8.32**	0.14	5.30	
	PC	0.21	0.11	0.00		0.01	**76.52**		
	BL/ST	1.54	1.87	5.84	9.20	8.63	11.34	**38.76**	
	WB							0.22	**100.00**
	Total	100	100	100	100	100	100	100	100
	Total (Ha)	**5245.91**	**3776.38**	**14076.48**	**812.94**	**3032.10**	**103.24**	**5752.63**	**183.55**

Appendix 14: Land use/land cover transition matrix in the Badenou Classified Forest (BCF) from 2002-2012

Badenou		2002							
	Class (%)	**GF/DDF**	**OF/WS**	**TS/SS**	**LDSS**	**FL**	**PC**	**BL/ST**	**WB**
	GF/DDF	**55.67**	10.19	3.71	1.86	2.31	0.00	0.00	0.00
	OF/WS	9.85	**57.44**	15.95	26.86	4.00	0.00	0.00	0.00
	TS/SS	23.11	23.03	**65.84**	52.54	82.89	26.22	58.05	0.00
	LDSS	1.04	0.87	1.08	**8.31**	0.35	0.00	2.32	0.00
2012	**FL**	1.43	1.65	5.15	1.53	**5.59**	1.07	3.46	0.00
	PC	0.25	0.52	0.07	0.02	0.01	**63.25**	0.35	0.00
	BL/ST	8.65	6.31	8.20	8.88	4.85	9.46	**35.81**	10.89
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**89.11**
	Total	100	100	100	100	100	100	100	100
	Total (Ha)	**5119.92**	**6218.81**	**16809.15**	**371.76**	**1224.05**	**5.37**	**3083.36**	**91.58**

Appendix 15: Land use/land cover transition matrix in the Badenou Classified Forest (BCF) from 2012-2022

Badenou		2012							
	Class (%)	**GF/DDF**	**OF/WS**	**TS/SS**	**LDSS**	**FL**	**PC**	**BL/ST**	**WB**
	GF/DDF	**65.09**	20.38	9.48	2.02	0.00	0.00	0.00	0.00
	OF/WS	6.85	**22.27**	4.98	4.45	27.41	0.00	0.00	0.00
	TS/SS	21.95	47.97	**65.73**	47.45	0.00	0.00	34.21	0.00
	LDSS	0.22	0.74	0.76	**1.99**	4.42	3.36	0.83	0.00
2022	**FL**	2.39	1.70	4.62	1.56	**29.74**	0.00	1.82	0.00
	PC	0.58	1.28	0.89	3.58	3.95	**84.45**	2.05	0.00
	BL/ST	2.92	5.66	13.54	38.95	34.48	12.19	**61.08**	21.96
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.01	**78.04**
	Total	100	100	100	100	100	100	1000	100

	Total (Ha)	**5115.22**	**6967.86**	**16650.61**	**382.11**	**365.89**	**27.68**	**3322.52**	**92.52**

Appendix 16: Land use/land cover transition matrix in the Badenou Classified Forest (BCF) from 1990-2022

Badenou		**1990**							
	Class (%)	**FG/FDS**	**OF/WS**	**TS/SS**	**LDSS**	**FL**	**PC**	**BL/ST**	**WB**
2022	**GF/DDF**	**60.37**	21.08	11.21	9.56	13.99	26.18	4.75	0.00
	OF/WS	8.40	**25.92**	7.23	14.33	7.71	29.47	2.18	0.00
	TS/SS	16.06	36.72	**65.27**	50.05	62.04	10.64	50.91	0.00
	LDSS	0.37	0.88	0.73	**1.69**	0.97	1.24	0.85	0.00
	FL	2.98	1.72	3.97	1.68	**6.12**	0.00	3.78	0.00
	PC	1.06	1.22	0.76	2.13	0.93	**27.98**	1.93	0.00
	BL/ST	10.74	12.47	10.82	20.56	8.25	4.49	**35.57**	3.08
	WB	0.00	0.00	0.00	0.00	0.00	0.00	0.03	**96.92**
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**1000**
	Total (Ha)	**5251.43**	**3752.65**	**14119.24**	**766.84**	**3047.24**	**89.78**	**5750.69**	**146.65**

PUBLICATIONS

ABSTRACT

Forests are important for carbon sequestration and biodiversity preservation, but they remain vulnerable to climate change. This study aims to analyse the impact of climate on the carbon sequestration capacity and spatial distribution of two ecologically and economically important species, *Afzelia africana* and *Pterocarpus erinaceus*, in the Lamto Scientific Reserve and the Badenou Classified Forest in Côte d'Ivoire. The study began with an analysis of the influence of climatic variables on land use dynamics between 1990 and 2022, using Landsat images, as well as an evaluation of the correlations between these variables and the areas of the different land use classes. A botanical inventory was then conducted on 1000 m² plots to catalogue the species and monitor regeneration. Stem discs were collected and analysed to measure the rings, then converted into carbon stocks using allometric equations, allowing for the evaluation of the spatiotemporal evolution of sequestration. Finally, the Maximum Entropy (MAXENT) algorithm was used to model the future distribution of the two species. The results revealed a gradual densification of the vegetation, marked by a transition from savannas to forest formations, more pronounced at Lamto. Temperatures and drought indices appear as the main factors of these changes. Lamto exhibits a richer biodiversity than Badenou, with 292 species (179 genera, 66 families) compared to 242 species (137 genera, 55 families). *Afzelia africana* is associated with 46 species with special status, compared to 12 for *Pterocarpus erinaceus*. *Afzelia africana* stores more carbon and shows greater resistance to climatic variations, particularly at Lamto, while *Pterocarpus erinaceus* is more vulnerable to drought, especially at Badenou. The modelling indicates that under moderate warming (+2°C), *Afzelia africana* could expand its range, while *Pterocarpus erinaceus* would remain stable. On the other hand, under an extreme scenario (+4.4°C), *Afzelia africana* would maintain its habitat, but *Pterocarpus erinaceus* would lose its favourable habitats, threatening its regeneration and survival.

Keywords: Climate change, Carbon sequestration, Biodiversity, *Afzelia africana* and *Pterocarpus erinaceus*, Climate modelling.

RESUME

Les forêts sont essentielles pour la séquestration du carbone et la préservation de la biodiversité, mais elles restent vulnérables face aux changements climatiques. Cette étude vise à analyser l'impact du climat sur la capacité de séquestration du carbone et la distribution spatiale de deux espèces d'importance écologique et économique, *Afzelia africana* et *Pterocarpus erinaceus*, dans la Réserve Scientifique de Lamto et la Forêt Classée de Badenou, en Côte d'Ivoire. L'étude a débuté par l'analyse de l'influence des variables climatiques sur la dynamique des occupations du sol entre 1990 et 2022, à partir d'images Landsat, ainsi que par l'évaluation des corrélations entre ces variables et les superficies des différentes classes d'occupation. Un inventaire botanique a ensuite été réalisé sur des parcelles de 1000 m² pour inventorier les espèces et suivre la régénération. Des disques de croissance ont été prélevés et analysés pour mesurer les cernes, puis convertis en stocks de carbone grâce à des équations allométriques, permettant d'évaluer l'évolution spatiotemporelle de la séquestration. Enfin, l'algorithme Maximum Entropy (MAXENT) a été utilisé pour modéliser la distribution future des deux espèces. Les résultats ont révélé une densification progressive de la végétation, marquée par une transition des savanes vers des formations forestières, plus prononcée à Lamto. Les températures et les indices de sécheresse apparaissent comme les principaux facteurs de ces changements. Lamto présente une biodiversité plus riche que Badenou, avec respectivement 292 espèces (179 genres, 66 familles) contre 242 espèces (137 genres, 55 familles). *Afzelia africana* est associée à 46 espèces à statut particulier, contre 12 pour *Pterocarpus erinaceus*. *Afzelia africana* stocke plus de carbone et montre une plus grande résistance aux variations climatiques, notamment à Lamto, tandis que *Pterocarpus erinaceus* est plus vulnérable à la sécheresse, surtout à Badenou. La modélisation indique que sous un réchauffement modéré (+2°C), *Afzelia africana* pourrait étendre son aire de distribution, tandis que *Pterocarpus erinaceus* resterait stable. En revanche, sous un scénario extrême (+4,4°C), Afzelia africana maintiendrait son habitat, mais *Pterocarpus erinaceus* perdrait ses habitats favorables, menaçant sa régénération et sa survie.

Mots-clés : Changement climatique, Séquestration du carbone, Biodiversité, *Afzelia africana* et *Pterocarpus erinaceus*, Modélisation climatique.