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DABRE Zaïnabou

Biology, Ecology and Dynamics of African Hackberry [*Celtis toka* (Forssk.) Hepper & J.R.I. Wood] in two Climatic Zones in Burkina Faso (West Africa)

Public defence on March 31st, 2023

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Spécialité : Changement Climatique et Biodiversité

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Biologie, Ecologie et Dynamique du Micocoulier Africain [*Celtis toka* (Forssk.) Hepper & J.R.I. Wood] dans deux zones climatiques au Burkina Faso (Afrique de l'Ouest)

Soutenance publique, le 31 mars 2023

Membres du jury

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DEDICATIONS

I dedicate this thesis to:

- The memory of my late mother. Mom, you passed away in early 2022 as I was nearing the end of my data collection. Thank you for your love, efforts, and sacrifices to ensure that I received the best education possible, that I succeeded, and that I was a reference.

- My daddy

- My siblings and their respective families

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ABSTRACT

Climate change is defined as a change in the weather pattern of a location or region that devastates land, and terrestrial ecosystems and exacerbates human food insecurity. These changes have a significant impact on many people who are thought to be disproportionately vulnerable to the effects of climate change. To cope with and mitigate the effects of climate change, rural communities relied on forests, mainly multipurpose plants such as *Celtis toka*, for goods and services. The current study on *Celtis toka*, a threatened species in Burkina Faso, was conducted in this context. The main goal was to contribute to the best knowledge of *Celtis toka* biology, ecology, and threat factors in order to ensure its conservation and sustainable management under climate change and land use change in the Sudanian region of West Africa. Especially, the study aimed to (i) assess the traditional knowledge and management practices of *Celtis toka*, (ii) to analyse the impacts of land use and climate on the diversity, structure, and regeneration of *Celtis toka* natural stand, (iii) to determine the effects of climate on tree ring growth, wood anatomical patterns, and aboveground carbon stock, (iv) predict the impacts of climate change on the geographical distribution of *Celtis toka.* The method consisted of surveying 405 respondents in a semi-structured interview, forest inventories in 129 plots, tree ring analysis and species distribution modelling. Ethnobotany demonstrated that *Celtis toka* is a multiuse tree overharvested in Burkina Faso for mystic (11.62%), food (27.89%), fodder (18.97 %), and medical (14.92 %) uses. Overall, 290 woody species from 113 genera and 105 families were investigated in *Celtis toka*'s natural stand habitats. The diameter (adult) and the height (juveniles) class distribution showed the populations of *Celtis toka* are unstable due to overexploitation, lack of regeneration, fire, and animal grazing. Tree-ring analysis discovered distinct growth ring boundaries. Tree ring chronology showed that climate change may affect the growth of *Celtis toka*. Aboveground biomass (51.44 ± 6.87 to 69.21 ± 13.38 Mg/ha) and carbon stock (25.72 ± 3.43 to 34.60 ± 6.69 Mg/ha) differ significantly ($P < 0.05$) across the climatic zone and land use type designating that climate and land use type impact the carbon storage. Under current climatic conditions, about 54.77 % of Burkina Faso area was suitable for the conservation of *Celtis toka*. Under both emission scenarios, all climate models predicted a decrease in the extent of suitable habitats of *Celtis toka* at the horizons 2041-2060 and 2081-2100. Suitable areas are predicted to decrease from 20.65 % to 27.81 % under the scenario ssp245 and from 48.07 % to 48.83 % under ssp585 in 2041-2060. By 2081-2100, the ssp245 predicts drastic changes in the species' spatial patterns, with habitat loss ranging from 25.26 % to 47.85 % while the ssp585 projected a loss of suitable area from 53.27 % to 54.37 %.

Keywords: Carbon stock, critically endangered species, distribution modelling, tree-ring analysis, use patterns

RESUME

Le changement climatique est défini comme un changement du régime climatique d'un lieu ou d'une région qui affecte les terres, les écosystèmes terrestres et amplifie l'insécurité alimentaire humaine. Ces changements ont un impact significatif sur de nombreuses personnes considérées comme étant disproportionnellement vulnérables aux effets du changement climatique. Pour faire face et atténuer les effets du changement climatique, les communautés rurales font recours aux forêts, principalement les plantes à usage multiples telle que *Celtis toka*, pour les biens et les services rendus. La présente étude sur *Celtis toka*, une espèce menacée au Burkina Faso, a été menée dans ce cadre. L'objectif principal était de contribuer à la meilleure connaissance de la biologie, de l'écologie et des facteurs de menace de *Celtis toka* afin d'assurer sa conservation et sa gestion durable dans le contexte actuel du changement climatique et du changement d'utilisation des terres dans la zone soudanienne de l'Afrique de l'Ouest. Plus précisément, l'étude visait à (i) évaluer les connaissances traditionnelles et les pratiques de gestion de *Celtis toka*, (ii) analyser les impacts de l'utilisation des terres et du climat sur la diversité, la structure et la régénération du peuplement naturel de *Celtis toka*, (iii) déterminer les effets du climat sur la croissance des cernes des arbres, l'anatomiques du bois, et le stock de carbone aérien et (iv) prédire les impacts du changement climatique sur la répartition géographique de *Celtis toka*. La méthodologie a consisté à interroger 405 répondants sous forme d'entretiens semi-structurés, à faire des inventaires forestiers dans 129 placeaux, à analyser les cernes et à modéliser la distribution de l'espèce. L'étude ethnobotanique a démontré que *Celtis toka* est un arbre à usages multiples surexploité au Burkina Faso pour des usages mystiques (11.62%), alimentaires (27.89%), fourragers (18.97 %) et médicaux (14.92 %). Au total, 290 espèces ligneuses appartenant à 113 genres et 105 familles ont été inventoriées dans les peuplements naturels abritant *Celtis toka*. La distribution des classes de diamètre (adulte) et en hauteur (juvéniles) a montré que les populations de *Celtis toka* sont instables en raison de la surexploitation, du manque de régénération, du feu et du pâturage des animaux. L'analyse des cernes a permis de découvrir des limites distinctes entre ces cernes de croissance. La chronologie des anneaux de croissance des arbres a montré que le changement climatique peut affecter la croissance de *Celtis toka*. La biomasse aérienne (51.44 ± 6.87 à 69.21 ± 13.38 Mg/ha) et le stock de carbone (25.72 ± 3,43 à 34.60 ± 6.69 Mg/ha) diffèrent significativement ($P < 0.05$) selon la zone climatique et le type d'utilisation des terres indiquant que le climat et le type d'utilisation des terres ont un impact sur le stockage du carbone. Dans les conditions climatiques actuelles, environ 54.77 % de la superficie du Burkina Faso est propice à la conservation de *Celtis toka*. Selon les deux scénarios d'émissions, tous les modèles climatiques prévoyaient une diminution de l'étendue des habitats appropriés de *Celtis toka* aux horizons 2041-2060 et 2081-2100. Les zones appropriées devraient diminuer de 20.65 % à 27.81 % selon le scénario ssp245 et de 48.07 % à 48.83 % selon ssp585 en 2041-2060. D'ici 2081-2100, ssp245 prévoyait des changements radicaux dans les schémas spatiaux de l'espèce, avec une perte d'habitat allant de 25.26 % à 47.85 %, tandis que ssp585 prévoyait une perte de zone appropriée de 53.27 % à 54.37 %.

Mots-clés : stock de carbone, espèce en danger critique d'extinction, modélisation, analyse des cernes, mode d'utilisation de *Celtis toka*

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ABBREVIATIONS AND ACRONYMS

AGB: Aboveground biomass

ANAM : Agence Nationale de la Météorologie

AUC: Area Under the receiver operating characteristics Curve

BBCH: Biologische Bunde-sanstalt, Bundessortenamt and CHemical industry

BCZ: Both climatic zone

CCTA/CSA: Technical Co-operation in Africa South of the Sahara /Scientific Council for Africa South of the Sahara

CDR: Carbon dioxide removal

CO_2: Carbon dioxide

CZ: Climatic zones

DBH: Diameter at breast height

DpIR: Dendrochronology program library in R statistical software

FAO: Food and Agriculture Organization of the United Nations

GBIF*:* Global Biodiversity Information Facility

GHGs: Greenhouse gazes

GIS: Geographical Information Systems

GLK: Gleichläufigkeitkoeffizient (Coefficient of Parallel Variation between Tree-ring series)

GLMs: Generalized linear model analysis

GPS: Global Positioning System

HadGEM3-GC31-LL: Third Hadley Centre Global Environment Model in the Global Coupled configuration 3.1

IGB : Institut Géographique du Burkina

IPCC: Intergovernmental Panel on Climate Change

IUCN: International Union for Conservation of Nature

IVI: Importance Value Index

LUT: Land use types

MIROC 6: Sixth version of the Model for Interdisciplinary Research on Climate

NTFP: Non-timber forest products

PA: Protected areas

PI: Permutation index

RCP: Representative concentration pathway

REDD+: Reduction of Emissions due to Deforestation and forest Degradation

RWI: Ring width index

SCD: Size-class distribution

SCZ: Sudanian climatic zone

SDM: Species distribution modelling

SPA: Protected areas of the Sudanian climatic zone

SSCZ: Sudano-Sahelian climatic zone

SSPA: Protected areas of Sudano-Sahelian climatic zone

SSPs: Shared Socioeconomic Pathways

SSUPA: Unprotected areas of the Sudano-Sahelian climatic zone

SUPA: Unprotected areas of the Sudanian climatic zone

TSAP: Time Series Analysis and Presentation

TSS: True Skill Statistic

UICN/PACO : Union Internationale pour la Conservation de la Nature / Programme Afrique Centrale et Occidentale

UPA: Unprotected areas

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

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INTRODUCTION

Non-timber forest products (NTFP) such as wild fruits, vegetables, nuts, edible roots, palm leaves, poisons, bush meats, gums and resins, honey and beeswax, medicinal and aromatic plants, dying and tanning materials and bamboo are wildlife products harvested from forests (Godoy, 1993; Iponga *et al*., 2016; Wagh *et al*., 2010). Otherwise, they are the most important resource of forests in developing countries (Leßmeister *et al*., 2018). The extraction of NTFP is hence very significant to the rural and national economies in the stock of food, material, building, energy, cash income, employment and other benefits for both subsistence and trade remains common and widespread (Chou, 2018). The NTFP are widely used in the domains of pharmaceutic, botanic, cosmetics, medicines, abrasives and industries (Belcher and Schreckenberg, 2007). Indeed, its products play a capital function in sustaining the livelihoods of the needy (Mukul *et al*., 2016) and such NTFP are considered a means of improving the resilience of households during emergencies. In Bangladesh, NTFP are found highly important in the sense that they provide 19 % of households' annual income and 18 % of households as primary (Mukul *et al*., 2016). The production of NTFP can therefore develop the economic value of forests (Shackleton and Pandey, 2013; Wetterwald *et al*., 2004) and benefit the conservation of forests (Belcher *et al*., 2005) in ecological preservation areas worldwide (Steele *et al*., 2014). According to Chou (2018), NTFP might either provide useful effects for forest-dwelling peoples or incentivize forest conservation. In Africa, for several decades, NTFP played a crucial role in the survival of a rural and urban population. They, therefore, contribute to the reduction of poverty and food security for the population living nearby the forests (Mohammed, 2015; Moupela *et al*., 2011). Sunderlin *et al*. (2005) highlighted that six hundred (600) million people over two-third of the continent rely on forest products and this reliance can be either in the form of subsistence uses or as cash income derived from a wide range of timber and non- timber forest products. For instance, in Sub-Saharan Africa, NTFP plays a socioeconomic role in rural livelihoods (Timko *et al*., 2010). In Tanzania, NTFP are considered a source of conservation (Ndangalasi *et al*., 2006) and they provide an estimated value of USD 42 million per year which is an important source of additional income for local communities, particularly the poorest who mainly depend on subsistence agriculture. In Ethiopia, NTFP interfere with sustainable forest management and its implication on carbon storage and biodiversity conservation (Melese, 2016). In Zimbabwe, NTFP is a kind of means for people to cope with climate variability (Woittiez *et al*., 2013). In addition, NTFP help reduce the rise of GHG concentrations in the atmosphere by increasing the carbon removed and stored in forests (Gorte, 2009).

Burkina Faso, a country characterized by the increased population, rely upon the natural forest (Sawadogo, 2006; Sop *et al*. 2012) like most African countries where local communities depend strongly on forests and plants for their goods and services (Belem *et al*., 2007; Bognounou *et al*., 2013; Hahn *et al*., 2014; Nacoulma *et al*., 2011; Mbayngone *et al*., 2008; Thiombiano *et al*., 2011). The most important needs for most rural communities in Burkina Faso are food, medicine, wood, fodder, fuel, shade, soil fertilization or reclamation, ornamentation and practices of rituals and customs (Belem *et al*., 2007). According to Ouédraogo *et al*. (2013); wild plants contribute 12 % to the total household income in the south-west part of the country. For instance, in Kompienbiga, Gourmantche shared 44 % of non-timber forest products as income while Mossi shared 41 % (Leßmeister *et al*., 2018). In the eastern part of the country, baobab bark's decoction is used as ‘‘vitamins’’ to strengthen babies and to heal wounds (Schumann *et al*., 2012). This is also the case with shea butter which interferes with cosmetic industries (Elias and Carney, 2004) in the country. Plants underpin ecosystem services and functions (Thiombiana *et al*., 2012). The services of the ecosystem are the set of functions of the ecosystem that are useful to a human being. These services make the planet inhabitable by supplying and purifying the air we breathe and the water we drink (Sekercioglu, 2010). Hence, Sop *et al*. (2012) stated that some natural species are declined mainly due to drought, regeneration failure, population ageing and humans. Moreover, Storch *et al*., 2015 stressed that biodiversity has declined. According to Briggs, 2014, the gain of global biodiversity is concurrent with declining population sizes.

Celtis toka, is a woody plant belonging to the family of *Cannabaceae* (Thiombiano *et al*., 2012). *Celtis toka* is either rare, threatened, critically engendered or even extinct in some temperate regions and the Sahelian region in Africa (Hahn-hadjali and Thiombiano, 2000; Garzuglia, 2006; Al-Khulaidi, 2018; Alfaifi *et al*., 2021; Tchobsala *et al*., 2022). Nevertheless, *Celtis toka* seems to be lacking in Uganda, Guinea Sudan, and Senegal (Hauman, 1942). Also, *Celtis toka* is threatened in northern Cameroon, Benin, and the Sahelian region of Africa (Gonzalez *et al*., 2012; Dansi *et al*., 2013; Moksia *et al*., 2019). *Celtis toka* is either extinct or endangered in Chad (Tchobsala *et al*., 2022). Although *Celtis toka* is crucial in Yemen, it is presently rare and must be evaluated and monitored regularly (Al-Khulaidi, 2018). *Celtis toka* is thus a very rare and threatened species in Saudi Arabia (Alfaifi *et al*., 2021).

In the world, the genus *Celtis* is about 60-70 species of deciduous trees (Mahre *et al*., 2017). In Africa, the genus *Celtis* is about 12 species (Sattarian and van der Maesen, 2005). Among the 12 species, only one (*Celtis toka*) is present in Burkina Faso. Unfortunately, this species is threatened, and it is about to disappear in Burkina (Thiombiano *et al*., 2010; Savadogo et al., 2017). In Burkina Faso, several empirical pieces of evidence from the previous years have shown that *Celtis toka* is either a rare or threatened even disappeared species (Bayala *et al*., 2011; Hahn-hadjali and Thiombiano, 2000; Savadogo, 2013; Thiombiano *et al*., 2010). Vodouhe *et al*. (2007) also reported that *Celtis toka* has been on the verge of extinction in Burkina Faso since 2007. Bayala *et al*. (2010) stated that *Celtis toka* was the most threatened species in the agroforestry parkland of Burkina Faso. Additionally, Savadogo and Thiombiano, (2010) highlighted that *Celtis toka* is endangered in the Northern and Southern Sudanian zones of Burkina Faso. More recently, studies by Savadogo *et al*. (2017) have demonstrated that *Celtis toka* is rare in communities in the strict, southern, and northern Sahelian regions of Burkina Faso. The International Union for Conservation of Nature (IUCN) red list has classified *Celtis toka* as the least concern (IUCN, 2019). Garzuglia has argued that since 2006, *Celtis toka* is one of the critically endangered species in Burkina Faso. In contrast with Burkina Faso, the species is widespread in West-Central Africa (Blench, 2000) and South-eastern Nigeria (Annah, 2016).

A species may therefore be absent in its biotope if its natural habitat has been disturbed by human interference (Scheldeman and Van Zonneveld, 2010). Moreover, several researchers mentioned that the major threat to any species is to modify it to secondary stands or other species types due to the harvesting of selective species (Giriraj *et al*., 2008). The impact is the removal of the species in their natural stands for agriculture by maintaining the most useful species (Bayala *et al*., 2010). Effectively, the legume tree *Celtis toka* is a species subject to strong human pressure in some areas of Burkina Faso because of the domestic use of its wood, roots and its importance in the traditional pharmacopoeia (Arbonnier, 2019; Blench, 2000; Höhn and Neumann, 2016) which may contribute to the heterogeneity in the distribution. In Chad, for instance, most of the stands' natural species have been replaced by the cultivation of dry-season sorghum (Klee *et al*., 2000).

The scarce literature information on the structure, production and reproduction dynamics, indigenous knowledge, aboveground carbon sequestration, dendrochronology, and future geographic distribution of plant species *Celtis toka* in those regions hampers our understanding of regional vegetation dynamics and prevents effective conservation actions. Most of the studies on

Celtis toka have emphasized the toxicity (Fall *et al*., 2017; Geidam and Adole, 2014; Mahre *et al*., 2017) and nutrient content, amino acid composition and proteins (Abah *et al*., 2018; Kubmarawa *et al*., 2011) of its leaves. However, the lack of reliable information is the greatest obstacle to effective conservation planning in Burkina Faso. This study will provide baseline information to guide stakeholders and policy makers to promote the valorisation of the species for efficient conservation and sustainable use. Furthermore, this study was integrated into the reduction of emissions from deforestation and forest degradation (REDD) mission. This supports countries' efforts to minimize emissions from deforestation and forest degradation through national REDD+ strategies that convert their forest zones to contribute to human well-being and meet climate change mitigation and adaptation aspirations (Neufeldt, 2015). To fill this gap, data such as the diameter of the hight breast (DBH) stem discs, occurrence, and environmental data of *Celtis toka* were used.

The main research question of this study: Will climate change have any significant influence on the structure, ring growth and geographical distribution of *Celtis toka* and what information is necessary to promote the conservation and sustainable use of *Celtis toka* in Burkina Faso?

The specific research questions are:

- **i.** What are the use patterns and use values of *Celtis toka*? What is the current state of *Celtis toka* in the local perception? What are local practices and their influences on the species' survival? What are the potential local solutions to the threat?
- **ii.** What are the biological life forms of *Celtis toka*? What are the human pressures, environmental disturbances, and sanitary state of *Celtis toka*? What is the impact of climate and land use type on the stand diversity, the population structure, and the regeneration of *Celtis toka*? What are the regeneration mechanisms of the species?
- **iii.** What are the tree ages and radial growth rates of *Celtis toka*? What is the xylem anatomical responses to land use and climate variation? Will climate have an impact on the growth and anatomical features of *Celtis toka* in Burkina Faso? What is the impact of climate and land use type on the carbon stock of *Celtis toka*?
- **iv.** What are the current and the future potential suitable areas for the conservation of *Celtis toka*? Which environmental factor impacts the spatial and temporal distribution of *Celtis toka*?

The hypotheses tested in this study were:

i. The use value of *Celtis toka* differs between ethnolinguistic groups,

ii. Land use types and climate impact the stand floristic diversity and structure of *Celtis toka* population,

iii. The growth rate of *Celtis toka* rises with increasing rainfall,

iv. Climate change will cause changes in the geographic distribution of *Celtis toka,*

The main goal of the study is to contribute to the best knowledge of *Celtis toka* biology, ecology, and threat factors to ensure its conservation and sustainable management in the context of climate change in Burkina Faso.

The specific objectives of this study can be summarized in four points:

- ❖ To assess the traditional knowledge and management practices of the species *Celtis toka* in Burkina Faso
- ❖ To evaluate the stand floristic diversity, the structure, and the natural regeneration of *Celtis toka* in Burkina Faso
- ❖ To analyse the effect of climate on tree ring width growth and wood anatomical patterns of *Celtis toka* under changing climate in Burkina Faso
- ❖ To predict the potential impact of climate change on the geographical distribution of *Celtis toka* in Burkina Faso

The outline of the thesis consists of four main chapters, besides the general introduction and conclusion. The first chapter is based on a literature review relevant to the topic. In this section, we described the literature review, the study site, and the species from the genus *Celtis*, with a focus on *Celtis toka*. Moreover, this chapter presents a review of previous findings on *Celtis toka* and knowledge gaps related to ethnobotany, dendrochronology, biomass quantification and distribution modelling.

In addition, this chapter provides a review of previous findings on *Celtis toka* as well as knowledge gaps in ethnobotany, dendrochronology, carbon stock, and distribution modelling.

The second chapter of the thesis develops the materials and methods. It explained the materials and methods used to conduct each research activity. The third chapter presented the results of every single activity. They consisted of four main subsections: the first subsection provided insight into the assessment of the traditional knowledge and management practices of the species *Celtis toka* in Burkina Faso while the second subsection highlighted the floristic composition, diversity, regeneration, and population structure of *Celtis toka* in Burkina Faso. The third subsection emphasised the effect of climate on tree ring width growth, wood anatomical patterns, and aboveground carbon stock of *Celtis toka* under the changing climate in Burkina Faso. Lastly, the fourth subsection of the results treated the potential impact of climate change on the geographical distribution of *Celtis toka* in Burkina Faso. Finally, the fourth chapter consists of a discussion of the results.

CHAPTER I: LITTERATURE REVIEW

1. 1. GENERALITIES ON STUDY SITE

1.1.1. Abiotic factors

1.1.1.1.Climate

The Sudanian climatic zone is established by the fluctuation of the dry and rainy seasons. The rain begins in mid-Mars and closes in early November. The dimension of the increasing period fluctuates from 70 days in the northern areas to nearby 100 days in the extra-southern province. The mean yearly temperature is about 27.72 °C (Figure 1 A) or 27.9 °C (Figure 1 B) along with the mean annual wind speed of 2.85 m/s (Meteorological Direction of Ouagadougou, station of Bobo Dioulasso (1984-2015) and Gaoua (1984- 2021)). In the Sudano-Sahelian climatic zone, the annual precipitation varies between 652.1 and 1149.2 mm over 4 to 5 calendar months while the annual temperature comprises between 25 and 35 C. The mean annual rainfall is about 812.46 mm/year with a dry period lasting from 5 to 6 months. The rainy time starts in late April and finishes at the beginning of October. Maximum precipitation is recorded between July and August. The mean monthly temperature and annual wind speed are respectively 29.03°C (Figure 1 C) and 2.47 m/s (Meteorological Direction of Ouagadougou, station of Dédougou (1984- 2015)).

1.1.1.2.Geomorphology and hydrology

In the Sahelian climatic zone, the rainy period lasts from July to September and the dry season from October to June. Precipitation is characterized by an irregular distribution, with a mean precipitation of 467mm per year, of which about 90 % falls between July and August. The mean annual rainfall over the last 30 years is 467 mm, although mean temperatures for a similar period reached 29 ◦C (Bayen *et al*., 2015). The main rivers of the Sudanian climatic zone are Mouhoun, Comoé and Léraba (Boussim *et al*., 2004) and the key soil types are leptosols, vertisols, regosols, cambisols, and luvisols (FAO, 2006). In the Sudano-Sahelian climatic zone, rainfall ranges between 600 and 900 mm over 4 to 5 months. Temperatures are generally moderate (between 20 and 30 °C) according to Nacoulma *et al*. (2018); Thiombiano *et al*. (2010). The types of soils are poorly developed, and this includes lithosols and hydromorphic soils. The hydrographic network is made up of tributaries of streams and rivers such as Sourou, Nakambé, Nazinon, and Sissili (Kagambega *et al*., 2010).

1.1.2. Biotic factors

1.1.2.1. Vegetation

The flora of the Sudanian climatic zone is conquered by Sudanian and Guinean species (Savadogo and Adjima, 2010) like *Chlorophora excelsa* (Welw.) Benth. & Hook.fil., *Elaeis guineensis* Jacq., *Antidesma venosum* E. Mey. ex Tul., *Dialium guineense* Willd., *Cola laurifolia* Mast., *Antiaris africana* Engl., *Carapa procera* DC., *Manilkara multinervis* (Baker) Dubard. The vegetation of the Sudano-Sahelian climatic zone is a mosaic of various savannah types (wood savannahs, shrubs, and trees) and forests. The vegetation is considered Sudanian and some Sahelian species: *Crateva adansonii* DC., *Pterocarpus santalinoides* L'Hér. ex DC., *Mitragyna inermis* (Willd.) Kuntze, *Acacia seyal* Del., *Vitex chrysocarpa* Planch. ex Benth., *Adansonia digitata* L., *Sclerocarya birrea* (marula), *Parkia biglobosa* R.Br. ex G. Don, *Lannea macrocarpa* Engl. & K. Krause, *Azadirachta indica* A. Juss., *Vitellaria paradoxa* C.F. Gaertn., *Grewia bicolor* Juss., and *Faidherbia albida* (Delile) A.Chev. etc., as most common species.

1.1.2.2. Human

1.1.2.2.1. Population

In the Sudanian climatic zone, the population of the study area is made up of native socio-linguistic groups: Bobo (dominant), Bozo, Turka, Bambara, Sambla, Senoufo, Bwaba, Dafing, Tièfo and Toussian and of migrants which are essentially Mossi (from our ethnobotanical investigation). The Sudano-Sahelian zone is comprised of Bobo, Dafing, Mossi, Fulani (Peul-Rimaibe) Bisa, Gourmatché, Gourounssi and Bwaba. People from both climatic zones (BCZ) are farmers, hunters, and traders except Fulani who are mostly cattle breeders (from our ethnobotanical investigation).

1.1.2.2.2. Socio-economic activities

Higher rainfall enables the population of the Sudanian climatic zone to harvest cotton and various other export crops.

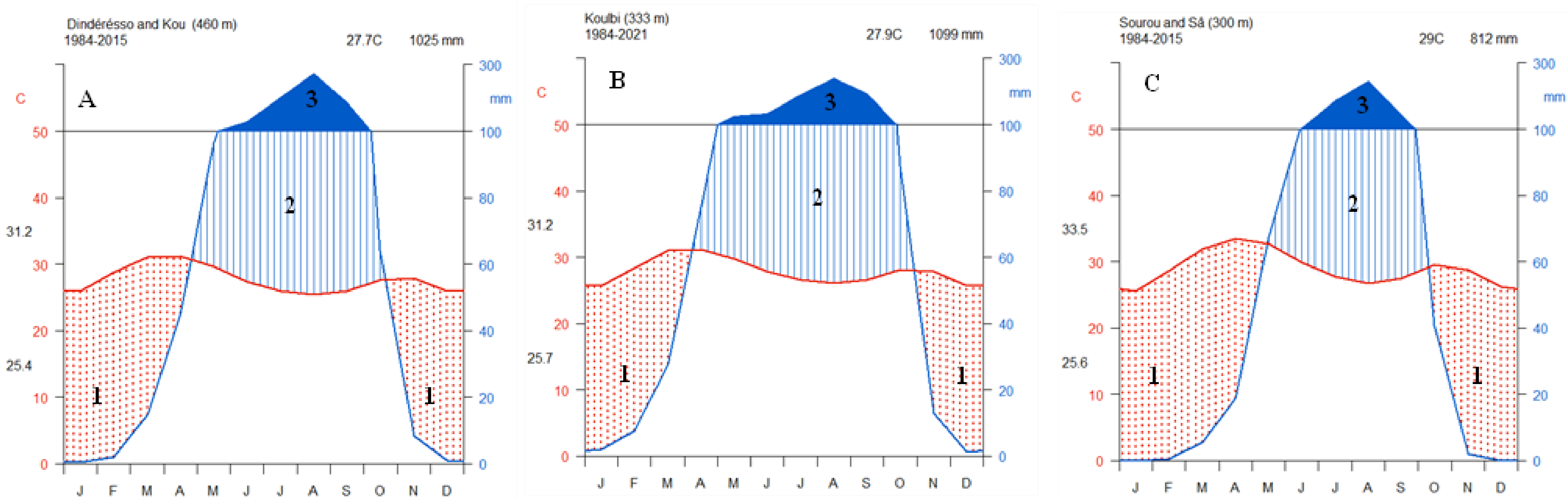

Figure 1: Climate diagrams of the study sites in Burkina Faso.

Dindérésso and Kou (A), Koulbi (B), and Sourou and Sâ classified forests (C) according to Walter and Lieth (1960) from synoptic meteorological stations of Bobo Dioulasso (1984-2015), Gaoua (1984 -2021) and Dédougou (1984 – 2015) in Burkina Faso. 1: dry season, 2: rainy season and 3: major seasonal precipitation

Mossi farmers and Fulani livestock herders immigrate from the Northern provinces, increasing the already high levels of cultural diversity in this province. Farming, non-timber forest products exploitation and livestock farming are the local revenue generation activities (Lankoandé *et al*., 2016).

The population of the Sudano-Sahelian climatic zone practices agriculture, hunting, and trade (RGPH, 2022).

Farming is the chief subsistence activity, and it makes up about 88 % of the total occupation of people in the above-mentioned areas (IOM, 2014).

1.2. GENERALITIES ON THE SUBJECT OF THE STUDY

1.2.1. Systematic and biosystematics of the genus *Celtis*

Celtis is a genus belonging to the Rosales order and the *Cannabaceae* family (IUCN, 2019). Genus which has been discovered in 1753 and is widespread in the world (Asia, America, and Africa). *Celtis* is found in tropical and temperate regions of the world (Sattarian, 2006). *C. philippensis, C. tetrandra, C. hildebrandii, C. latifolia, C. luzonica, C. paniculata, C. rigescens C. rubrovenia, C. timorensis*, and *C. philippensis* var. wightii are species found in Asia (Soepadmo, 1977). America species are *C. ehrenbergiana, C. chichape, C. brasiliensis, C. orthocanthos, C. loxensisi* and *C. orthocanthos* (Elias, 1970). Africa species are twelve (12) in number such as: *C. adolfi-friderici* Engl., *C. africana* Burm. f., *C. australis* L, C. bifida J.-F. Leroy, *C. gomphophylla* Baker, *C. malagasica* Sattarian nom. nov., *C. mildbraedii* Engl., *C. prantlii* Priemer ex Engl, *C. tessmannii* Rendle., *Celtis toka* (Forssk.) Hepper & J. R. I. Wood, *C. wightii* Planch. and C. *zenkeri* Engl (Sattarian, 2006).

1.2.1.1. Ecology of *Celtis* species

Celtis, is a widespread genus whose natural distribution is found in Africa, the Mediterranean region, North and South America, northern Australia, and Asia. Asia's *Celtis* species are mainly in lowland forests and moist areas (Sattarian, 2006; Soepadmo, 1977). According to America's *Celtis*, they are found either in a dry forest or in a humid forest (Elias, 1970). Africa's *Celtis* species occupied different ecological settings from tropical to various temperate regions. For instance, *C. tessmannii, C. mildbraedii* are tree species which colonized the rainforest; *Celtis adolfi- friderici*, *C. prantlii*, *C. zenkeri* are settled in semi-deciduous forest; *C. africana* is found occasionally in hill forest; *C. gomphophylla* is shrubs or small trees of rain forest undergrowth. Only one species (*Celtis toka*) is a fairly giant tree with a compact crown, exists beside streams or is planted in villages in the Sudano-Sahelian zone (Sattarian, 2006).

1.2.1.2. African *Celtis*' Wood

The bark of African *Celtis* is smooth and whitish to grey; buttresses are present. *Celtis* harvests lightweight to heavy hard wood with a density of 400-960 kg/m3 at 15 % humidity content (Soerianegara and Lemmens 1993). The hardwood is habitually pale brown to pale yellow- brown, rarely with dark streaks, temperately separate to unclear from the wide, white, or pale sapwood, grain generally inter-locked, occasionally straight, texture good to moderately good at times moderately coarse.

1.2.2. Generality on *Celtis toka* (Forssk.) Hepper & J.R.I. Wood

1.2.2.1. Description

Ficus toka Forssk (1775) also known as *Celtis integrifolia* Lam. (1797), *Celtis toka* (1983), (Arbonnier, 2019; Sattarian, 2006), Micocoulier Africain, African Hackberry (Kagambega *et al*., 2010) or nettle tree (Mahre *et al*., 2017) is discovered in 1775 by Pehr Forsskål (1732-1763), a naturalist Forsskål (World Flora online). The wild plant *Celtis toka* is a species belonging to the Rosales order and the *Cannabaceae* family (Table 1) with a height which is between 15-20 m and sometimes 25 m, its larger diameter (Kindt *et al*., 2008; Bayala *et al*., 2010) stands for 1.5 m.(Arbonnier, 2019, Alfaifi *et al*., 2021).

Celtis toka belongs in riparian areas (Fousseni *et al*., 2014), galleries forests, berg of water bodies, dense dry forests or savanna frameworks (Rabeil, 2003; Sambaré *et al*., 2010; Sambaré *et al*., 2011; Akoegninou *et al*., 2006; Höhn and Neumann, 2016; Arbonnier, 2019;). At times, it appears on the rocky hill of Sahelian – Sudanian to Guinean, on deep and well-drained soil (Arbonnier, 2019). This wild plant has at times occurred in sacred groves (Shepherd, 1992). Species from Sahelo-Sudanian to Guinean zones but colonized along rivers and streams in the drier savanna areas (Neumann, 1992; Höhn and Neumann, 2016). According to Watrin *et al*. (2007), *Celtis toka* growths in zones with both low rainfall (110–960 mm $yr.^{-1}$) and high temperature (26–30°C). In contrast, some others stated that the annual cumulative rainfall of the species is about 500 to 1400 mm per year (Julier, 2018). Species with multiple local names in Africa (Table 2), are associated with *Diospyros mespilifomris* (Mahamane, 2005; Mahamane *et al.*, 2008). It is also found in *Tamarindus indica-Anogeissus leiocarpa* community (Awas, 1997). According to the agroforestry parkland, *Celtis toka* is found in cereal and cotton farming systems (Bayala *et al.*, 2010).

Researchers have emphasized that *Celtis toka* is a phanerophyte (Thiombiano *et al.*, 2012) which may be deciduous (Mahre *et al*., 2017), moist semi-deciduous (Adomou *et al.*, 2013; Julier, 2018) or evergreen to semi-deciduous species (Diémé *et al.*, 2018). Moreover, *Celtis toka* is parasitized by *Tapinanthus globiferus* (Boussim *et al*., 2004)**.** *Celtis toka* is a monoecious tree whose linear stipulate leaves (Alfaifi *et al.,* 2021) are alternates, more or less strong on both sides, oval with acuminate or attenuated peak (Arbonnier, 2019; Fall *et al*., 2017). *Celtis toka* provides a diversity of products used for medicine (flowers, leaves, bark, seeds and roots); food (leaves, fruit); construction (wood); firewood (wood) and charcoal for human culinary activities; and fodder (leaves) for animals; and handicrafts (Blench, 2000; Lykke *et al.,* 2004; Teklehaymanot and Giday,2010; Seignobos, 2014; Höhn and Neumann, 2016; Piqué *et al.*, 2016; Arbonnier, 2019; Badiane *et al.*, 2019). Leaves and fruits are edible in Sudan (Arkell, 1947), Ghana (Irvine, 1961), Senegal (Lericollais, 1990), Nigeria (Kiee *et al.*, 2000; Harris and Mohammed, 2003; Kubmarawa *et al.*, 2011), Cameroon (Nakagawa, 2008; Neba, 2009; Betti and Yemefa, 2011), and Benin (Djègo-Djossou *et al.,* 2015). According to Mballow *et al*. (2020), *Celtis toka* is the most used species by communities in east and west Africa. In addition, all organs of *Celtis toka* are used to cure ailments such as malaria, back pain, measles, chickenpox, mental diseases ringworm, mycosis, headache, sore, fever, and eye pain (Hahn-hadjali and Thiombiano, 2000; Betti *et al.*, 2011; Arbonnier, 2019; Diatta *et al.*, 2019). For instance, leaves, roots, and bark of *Celtis toka* were used in Nigerian traditional medicine to treat various diseases, including epilepsy (Muazu and Kaita, 2008). In Cameroon, the bark was also used to heal epilepsy (Tsabang *et al*., 2016). Moreover, the plant parts of *Celtis toka* were used to treat trypanosomiasis (Osue *et al*., 2018). The medicinal use of *Celtis toka* was also emphasized in Mali (Bizimana *et al*., 2006) and Senegal (Badiane *et al*., 2019). In Ethiopia, *Celtis toka* provides an important economic service, as it is preferred for hanging beehives (Bareke, 2018), for timber and for making local boats (Rolkier and Abebe, 2015). In Burkina Faso, *Celtis toka* has mystical value (Savadogo and Thiombiano, 2010).

Furthermore, glycosides, saponins, alkaloids, phenols, tannins, flavonoids, coumarins, triterpenoids, mucilage, and steroids are phytochemicals taken out from leaves of *Celtis toka* (Fall *et al*., 2017; Abba Idris and Halima Mohammed, 2020). Many studies have shown that the leaves content Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Copper (Cu), Zinc (Zn), Lead (Pb), Iron (Fe), Manganese (Mn) and Cadmium (Cd) (Abah *et al.*, 2018; Kubmarawa *et al.*, 2011; Tadzabia and Dimas, 2020) as mineral elements. It contents 8.20 % as protein and seventeen amino acids which are Lysine, Threonine, Cysteine, Valine, Methionine, Isoleucine, Leucine, Tyrosine, and Phenylalanine (Kubmarawa *et al.*, 2011). Coumarins, flavonoids, mucilage, triterpenoids and steroids are phytochemical constituents of the leaf of *Celtis toka* (Fall *et al*., 2017).

Inflorescences are pubescent and branched panicles (Arbonnier, 2019)

Male flowers are sessile, and female are pedicellate (Arbonnier, 2019). Flowers are without petals (Alfaifi *et al.*, 2021).

Drupe fruits are brown, and they contain white seeds. Seeds measure 5 mm in length. They are ovoid-ellipsoid (A-Magid, 2003). Studies have shown that seeds possess oil (Seignobos, 2014).

Barks are smooth light grey with cavities (Arbonnier, 2019, Alfaifi *et al*., 2021).

Ecological (Gilbert *et al.*, 2017) and socio-economically multipurpose tree species that offer various products for diverse uses (Diémé *et al.*, 2018). In addition to the information on its biotope, *Celtis toka* is a high-value species which is mainly exploited for food (leaves, fruit), medicine (leaves, roots), building (wood), firewood or charcoal, livestock or fodder (leaves and branches) and handicraftsman purposes (Arbonnier, 2019; Blench, 2000; Höhn and Neumann, 2016; Seignobos, 2019).

1.2.2.2. Distribution

In America, the species is in Brazil (GBIF, 2023) and in Asia, *Celtis toka* is found in Saudi Arabia (Alfaifi *et al.*, 2021) and Yemen (Al-Khulaidi, 2018). In Africa, the species is distributed from Senegal to Uganda and Sudan (Sattarian, 2006) whereas in Burkina Faso, it originated from the north to the south (Ouédraogo, 2006; Ganaba, 2008). Benin, Burkina Faso, Cameroon, Chad, Ethiopia, Eritrea, Gambia, Ghana, Guinea (Conakry), Ivory Coast, Niger, Nigeria, Mali,

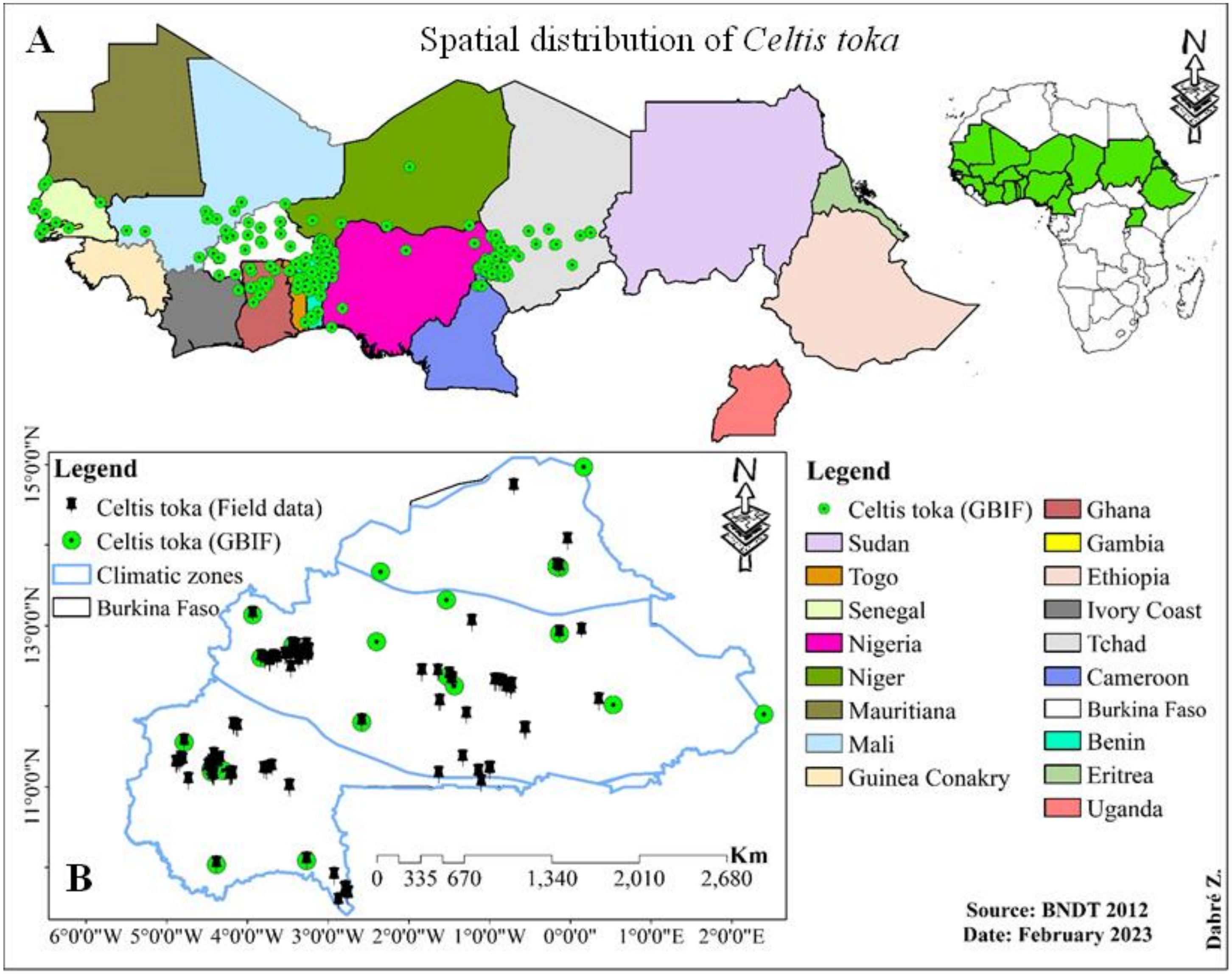

Figure 2: Spatial distribution of *Celtis toka* occurrence data.
A: Africa and B: Burkina Faso. Source: GBIF, literature review and field data

Mauritania, Senegal, Sudan, Togo, and Uganda are the 18 Africa countries where *Celtis toka* are present (Figure 2). Hence, in Senegal, almost all its plant parts (60%) except its seeds and bark are useful to the population (Ndiaye *et al.,* 2017). For instance, plant parts of *Celtis toka* treat a lot of diseases such as sore, mycosis, oedema, abscess, headache, and retention of the placenta (Arbonnier, 2019). The flaking hard barks cure rheumatism. Bark and stem are even sold in the north of Cameroon. The roots are also used to cure rheumatism, paralysis, epilepsy, sterility and mental disease (Arbonnier, 2019; Awas, 1997). Also, the species is appreciated for its yellow wood because it is easy to handle, has little resisting to ants, and is used in the construction of canoes and mortar. Magical species, in Cameroon, the stew (kwetefe) based on the leaves are consumed as a sacrifice for those who do not kill bulls (Seignobos, 2014). Also, the species is appreciated for its yellow wood because it is easy to handle, has little resistance to ants, and is used in the construction of canoes and mortar (Arbonnier, 2019). Based on the observation in the field, *Celtis toka* species is mostly pollinated by bees and wasps (Table 3). Its dispersal aspect is done by rainwater, some birds, and small ruminants.

1.2.3. Causes of biodiversity loss

In West Africa, plant diversity is threatened either by human activities (Da *et al.*, 2018; Dunn, 1997; Garbelotto and Pautasso, 2012; Kokou *et al.,* 2008; Newmark, 1999) or by future climate, land use change, biological invasions, deforestation etc. (Bomhard *et al.,* 2005; O'Connor, 2005; Heubes *et al.,* 2013; Brévault *et al.,* 2014; Riordan and Rundel, 2014; Dimobé *et al*., 2015; Zhang *et al.,* 2017). The transformation of land to human uses, such as agriculture, infrastructures, and dams, has destroyed, fragmented, and knocked out natural habitats, driving species declines towards extinction and reducing the ability of species to move across the landscape (IPCC, 2014). Moreover, the change in climate conditions would make forests vulnerable to illness and insect predation (Gribovszki *et al.*, 2019). The decline of global biodiversity is triggered by the expansion of modern agriculture (Lanz *et al*., 2017) by habitat loss (Elmqvist *et al.,* 2016) which is caused by the acceleration of climate change and human direct impact (Pereira *et al.,* 2010). According to the Food and Agriculture Organization of the United Nations (FAO) 2010, around 13 million hectares of forest were transformed for other purposes or lost through natural causes each year between 2000 and 2010.

Table 1**:** Classification of *Celtis toka*.

(Source: IUCN, 2019)

Kingdom	Plantae
Phylum	Tracheophytes
Class	Magnoliopsida
Order	Rosales
Family	*Cannabaceae*
Genus	*Celtis*
Species	*Celtis toka*
Scientific name	*Celtis toka* (Forssk.) Hepper & J.R.I.Wood

Common name: in French: Micocoulier Africain; in English: nettle tree (Thiombiano *et al*., 2010; Mahre *et al.,* 2016).

Table 2: Some local names of *Celtis toka* in Africa.

Countries	**Language**	**Vernacular name**	**Source**
Benin	Dendi	Séékossou	Dansi *et al*., 2013
	Yoruba	Afoufè	Djègo-Djossou *et al*., 2015
	-	Bousamsambou	Achigan-Dako *et al*., 2010
Burkina Faso	Mooré	Pargandé	Thiombiano *et al*., 2012
	Mooré	Silsaka	Thiombiano *et al*., 2012
Cameroon	Arabe	Ngouso	Betti and Yemefa 2011
		Aboum gatou	Vivien, 1990
		Hala	
	Fulfuldé	Djiho	
	Haoussa	Douki	
	Toupouri	Likan	
		Loubour	
	Kanouri	Ngouzo	
	Mofu	Sabak	
	Mafa	Shéshébé	
		Wanka	
	Fulfuldé	Ganki	Gilbert *et al*., 2019
	Fulfuldé	Wanko	(Gilbert *et al*., 2019; Seignobos and Tourneux, 2002)
	Mofou	Mebed	Gilbert *et al*., 2019
	Arabe	Falmaro	Betti *et al*., 2011
Ethiopia	Anywaa	Laero,	Awas, 1997
	Kara (people)	Zuguay,	Teklehaymanot and Giday, 2010
	Kwego (people)	Lompo	Teklehaymanot and Giday, 2010
Nigeria	-	Aápe	Ogungbenro *et al*., 2018
Mali	Bambara	Kamaua, Gamya	Bizimana *et al*., 2006
Senegal	Wolof	Mbul	Gonzalez, 2001
	Diola	Busingilit	Diatta *et al*., 2019
	Sereer	ngan	Lericollais,1990
South Sudan	Mabanese	Shaw	Bloesch, 2014
	Arabe	Tekey	Bloesch, 2014
South Kordofan Sudan	-	Mohagria	Ismail and Elawad, 2015
Sudan	-	Mohagria, Lipingo	Hamid and Kordofani, 2015

Figure 3: Descriptive characteristics of *Celtis toka.*

Pictures: Dabré, 2020 (B, D), 2021(A, G) and 2022 (C, E, F, G).

Whole tree in agroforestry farmland (A), young (B) and old (C) trunks, Leaves (D), Flowers (E) fruits (F) and seeds (G) of *Celtis toka*. Seeds were harvested from ripened fruits between November 2021 and January 2022.

Table 3 : Environment, observation, and taxonomic description of *Celtis toka*.

Characters	**Descriptions**
Habitat	Protected areas (woodland, savannah, forests), gallery forests (bank or inside of some rivers, bank of streams), farmlands, rocky areas (hill, slope), sacred forests and fallows
Propagation approaches	Sexual (seeds) and asexual (root suckers, seeding sprouts, water sprouts or coppices)
Dispersal agents	rainwater, bats, ruminants, wind, birds
Pollinators	Bees, bats, wasps.
Tree	Height (up to 25 m) and diameter at breast height (up to 220 cm) with a huge canopy (Figure 3)
Leaves	Petiolate (5mm long), simple alternate light green (savannah, rocky areas) to dark green (gallery areas, dense forests). The limb is occasionally toothed with the peak at the top.
Flowers	Yellow-green colour, five (5) green sepals.
Fruits	Drupe, bright yellow, orange, purple, red, or brown, single of pair with from 9 to 16 mm long. Yellow or orange pulp.
Seeds	White spheric seeds, 7 mm long with seven basal veins ended by a peak at the top.
Trunk and barks	Light grey, dark or ashy stunk with smooth or scaled bark

Furthermore, urbanization affects also ecosystem services (Elmqvist *et al*., 2016). According to Gonzalez *et al. (*2012), the density of trees and species declined in the African Sahel attributable to climate.

Several studies from previous years stated that the climate may either have a repercussion on the biodiversity and ecosystem performance (Erisman *et al.*, 2013; Glass *et al*., 2009; Nagelkerken *et al.,* 2016; Xiao *et al*., 2018) or a decline in ecosystem services (Bohensky *et al*., 2011), disappearance of some species (Kijazi *et al.,* 2012) even their extinction (Brook *et al.*, 2008). However, some authors stressed that global change has been identified either as the biggest threat to the resilience of ecology (Bohensky *et al*., 2011) or a major threat to conservation and even as the current and future threat to conservation (McCarty, 2001).

For instance, Cameroon and Ghana's forest areas declined dramatically due to harvesting and degradation, averaging 0.6 and 1.3 % each year, respectively during the last 20 years (Dixon *et al.*, 1996). Some researchers demonstrated that biodiversity loss by human activities is around 1000 times faster than natural 'background' rates (Roe *et al.,* 2019). Climate change will increase biodiversity loss and cause reductions in harvest and livestock productivity, threatening food security (Climate Analytics, 2021). Hence, biodiversity has declined mainly due to drought, regeneration failure, population ageing, habitat loss and human (Sop *et al*., 2012; Storch *et al*., 2015). The diversity and structure of tropical gallery forests are under threat from fire (Armenteras *et al*., 2021). In agreement with this study, FAO, 2017 and Climate Analytics, 2021 reported that climate change will increase biodiversity loss. The risks of climate change are intensifying, and without immediate action, the consequences will be devastating (Quiggin *et al*., 2021). Climate change has had widespread negative consequences, including losses and damage to nature (IPCC, 2023).

1.2.4. Ethnobotany

Indigenous knowledge plays a key role in biodiversity conservation (CBD, 1994). However, the incorporation into biological and ecological studies of local, social, and institutional backgrounds that guide the relationship between people and wildlife, has led to a greater understanding of the association between social and ecological dynamics (Ghimire *et al*., 2005). Plant use extremely depends on social features and differs significantly between diverse ethnic groups and locations (Zizka *et al*., 2015). In Africa, numerous studies on ethnobotany have been done. In Ethiopia for instance, an ethnobotany study has been done on wild edible plants (Teklehaymanot and Giday, 2010; Gurashi *et al*., 2021); on woody plants in Cameroon (Gilbert *et al*., 2019); on wood in Senegal (Ndiaye *et al*., 2017), wild fruits (Gueye *et al*., 2014) and on shea tree in Ivory Coast (Diarassouba *et al*., 2008). In Burkina Faso, several traditional knowledge studies have been done not only on woody plant species (Belem *et al*., 2007, Lykke *et al*., 2004; Sop *et al*., 2012) but also on single species such as *Sarcocephalus latifolius* (Kaboré *et al*., 2014), *Anogeissus leiocarpa* (Schumann *et al*., 2011), *Combretaceae* plant species (Bognounou *et al*., 2008), *Afzelia africana* Sm. (Balima *et al*., 2018), *Gardenia erubescens* Stapf & Hutch (Ouédraogo *et al*., 2019) and *Bombax costatum* (Zerbo *et al*., 2022). In the east part of Burkina Faso, study on the perception on species which were about to disappear has been realized and *Celtis toka* was among them (Hahn-hadjali and Thiombiano, 2000). The ethnobotany of *Celtis toka* has never been studied either specifically or in other parts of the country.

1.2.5. Aboveground biomass and carbon stock

Forests and plants are central carbon sinks. They capture carbon dioxide from the atmosphere and store it by way of carbon (FAO, 2010) and the carbon can remain stored in any wood products made from the harvested trees (Malmsheimer *et al*., 2008). However, forests are indispensable for carbon dioxide removal (CDR) and the CDR rate needs to grow rapidly to remain within the 1.5 or 2.0°C range (Soest *et al*., 2018). Furthermore, forests yearly sequester huge quantities of atmospheric carbon dioxide (CO2), and stock carbon above and below ground for long periods (Moomaw *et al*., 2019). Indeed, current research in the tropics demonstrates that natural forests hold 40 times more carbon than plantations (Lewis *et al*., 2019). Carbon can be sequestered by several means such as dendrochronology (Sanogo *et al*., 2016), non-destructive allometric model (Okoh *et al*., 2019) or destructive allometric model (Bayen *et al*., 2015). In Burkina Faso, several studies have been done on carbon stock (Dayamba *et al*., 2016; Dimobé *et al*., 2019) and allometric models have been developed to estimate the aboveground carbon sequestered by fruit yields of *Vitellaria paradoxa* C.F. Gaertn (Bondé *et al.,* 2019) or by some single species such as *Jatropha curcas* L (Bayen *et al*., 2015), *Afzelia africana* Sm. (Balima *et al*., 2019), *Tamarindus indica Pterocarpus erinaceus Poir* (Ganamé *et al*., 2020) and *Diospyros mespiliformis* (Ouédraogo *et al*., 2020). The allometric equation has never been developed to estimate the aboveground carbon of

Celtis toka either in Burkina Faso or in another part of the world. Our study aims to assess the density of *Celtis toka* and then use the specific allometric equation of some species to estimate the ability of *Celtis toka* to sequester the carbon dioxide from the atmosphere.

1.2.6. Dendrochronology

Dendrochronology is the discipline of dating tree rings during their annual formation and using accurately dated tree rings to distinguish environmental signals (Gebrekirstos *et al*., 2014). Like long-living organisms, trees record ecologically pertinent information in their annual rings and hence represent vital natural archives for the study of global changes for the last millennium (Trouet *et al*., 2009). Ring width or maximum latewood density constitutes tree-ring variables which are strongly influenced by environmental conditions, specifically where temperature or rainfall limits tree growth. They then play a protuberant role in the reconstruction of climate variation (Jones *et al*., 2009) or the reconstruction of past environmental conditions. In Africa, dendrochronological work is still in its beginning (Gebrekirstos *et al*., 2014). Nevertheless, the study has realized the potential of dendrochronology in assessing carbon sequestration rates of *Vitellaria paradoxa* in southern Mali (Sanogo *et al*., 2016).

1.2.7. Species distribution

To address the threat of change in climate to biodiversity, it is necessary to enhance our knowledge of species' geographic distributions and the elements that govern their spatial patterns. We are all aware that physical factors and climatic influence the geographic distributions of species at different spatial scales (Soberón and Peterson, 2005). Pearson and Dawson (2003) stressed that at huge spatial scales, the climate is considered more relevant than biotic interactions in determining species’ geographic distributions. Nevertheless, climate change might engender either favourable or unfavourable spatial dynamics in the geographic distribution of some species (Hannah *et al*., 2002). Some studies showed that climate change can modify tree physiology and tree defence mechanisms (Kirilenko and Sedjo, 2007). However, the effects of climate extreme events such as high wind events can damage trees through branch breaking, crown loss, trunk breakage, or complete stand destruction, especially caused by the faster build-up of growth stocks in a warmer climate (Kirilenko and Sedjo, 2007). Climate change aggravates desertification through the alteration of spatial and temporal patterns of temperature, precipitation, winds, and solar insolation (Gonzalez, 2001). In Benin for instance, Ganglo *et al*. (2017) have highlighted the distribution of *Dialium guineense* Willd. (Black velvet) has decreased to 17 and 34 % both under RCP 4.5 and RCP 8.5 at the horizon of 2055. Fandohan *et al.* (2013) argued that the increase in rainfall may decrease the suitable conservation area of the species *Tamarindus indica* L. at the horizon of 2050. In addition, Vos *et al*., 2008 mentioned also that climate change will force some species to shift their geographic ranges, or face extinction. There is some scientific evidence that climate change impacts biodiversity and that it threatens individual species as well as whole ecosystems (Campbell *et al*., 2009). Range limited of *Celtis toka* can be expected to be at a higher risk of extinction under current land use dynamics coupled with the climate change threat.

CHAPTER II: MATERIAL AND METHODS

2.1. MATERIAL

There are two categories of materials in the study: biological materials and technical equipment. The biological materials of this study are *Celtis toka* (stem discs) and species associated with *Celtis toka*. As for the technical equipment, this includes the following items:

- **GPS**

The Global Positioning System (**GPS**) is a tool which has been developed to allow accurate determination of geographical locations. This instrument was used:

- ✓ to determine the positions of plots located anyhow in the three climate zones,
- ✓ to localize trees chosen for the assessment of allometric equations and dendroecology,
- ✓ to localize different interview villages.

- **Tape meter**

Tape is a common measuring tool. It was used for realizing the diverse sizes (1000 m^2, 500 m^2 and 2500 m^2) of the plots during forest inventories. A maximum of four tapes were used for this purpose.

- **Diameter tape**

A diameter tape is a measuring tape used to estimate the diameter of the stem of a tree. It was used specifically to assess the diameter at breast height (DBH) of *Celtis toka* and related species destined either for the inventories or carbon sequestration.

- **Clinometer**

A clinometer is an instrument used for measuring the angles of the tree concerning gravity's direction. It was used to get the height of *Celtis toka* and associated species.

- **Pruner**

Pruners or secateurs are a type of scissors for use on plants. They were used to cut a sample of the branch of each unknown species encountered in *Celtis toka* natural stand for identification at the laboratory of Plant Biology and Ecology of University Joseph KI-ZERBO, Burkina Faso.

- **Digital camera**

A digital camera is an instrument used to capture images digitally. This tool was used to snap the vegetation (different plots) during either the inventory, survey, or germination test (sexual reproduction).

- **Rain suit**

A rain suit, raincoat or slicker is a waterproof or water-resistant coat worn to protect the body from rain. It was used during different activities (inventory, germination test and survey) on the field when it was raining.

- **Fieldboots**

Fieldboot is a hybrid of the classic work boot. The boot is designed to go up against ice, mud, and grass. It was used for the different data collection on the field.

- **Calliper**

It is a tool used to assess the collar diameter of juveniles of *Celtis toka* in the field.

- **Scotch tape**

Tape is used to stick the unidentified plant specimens before putting them in the empty rice bag.

- **Empty bag of rice**

It is used to put the reference specimen of unidentified species.

- **Herbarium press**

In a herbarium, plant specimens are dried in a forced-air plant dryer that approaches temperatures of 100°C.

- **Computer**

It was used either in data analysis of the surveys, inventories, and geographical distribution or in dendrochronology analysis.

- **Microscopes**

They were used to assess the wood's anatomical characteristics.

2.2. METHODS

2.2.1. Study Area

The study was conducted in Burkina Faso which is in the heart of West Africa and lies between latitude 09 ° 02 ’and 15 ° 05’ north, and longitude 02 ° 02 ’east and 05 ° 03’ west. It was carried out from November 2020 to January 2022 on *Celtis toka* natural habitats in two climatic zones (CZ) and different land use types (LUT): protected areas (PA) such as five classified forests namely Kou, Dindérésso, Koulbi, Sâ and Sourou (Figure 4) and unprotected areas (UPA) (farmlands, fallows, rocky areas, sacred areas). Kou, Dindérésso, and Koulbi are localized in the

Sudanian climatic zone (SCZ) and Sâ, Sourou within the Sudano-Sahelian climatic zone (SSCZ). The study sites were selected based on the occurrence and accessibility of the plant species. Table 4 shows the characteristics of these sites.

2.2.2. Assessment of the traditional knowledge and management practices of *Celtis toka* in Burkina Faso

2.2.2.1. Sampling performance and data collection

The surveys were conducted in 2020 where Covid-19 spread throughout the world. To prevent the spread of the Corona virus in the study area, the prospection and survey were conducted while maintaining social distance and other precautions (wearing a nose mask and using hand sanitiser). Before the survey, a prospection was conducted to confirm the presence of *Celtis toka* in the selected sites, to get the consent of the authorities and villages' leaders, and to adjust the questionnaire. A random sampling scheme was used to select informants. Data was gathered using a semi-structured interview method. The surveys were based on the presence and knowledge of *Celtis toka*. Informants' age, sex, occupation, origin and ethnolinguistic groups were all recorded (Goudégnon *et al*., 2018). We used translators who spoke the informants' native languages and each respondent was requested to provide as much information as possible on:

- Do you know *Celtis toka*? What is its vernacular name?
- What are the use patterns of *Celtis toka* (food, fodder, firewood, etc.)?
- What is the state of *Celtis toka* during the last 30 years (increasing, decreasing, or stable and what reasons for this)?
- What are the reasons for its threat and the management strategies of the species?

2.2.2.2. Data analysis

Overall, 405 consented rural people (146 women (91 in the Sudanian climatic zone and 55 in the Sudano-Sahelian climatic zone) and 259 men (112 in the Sudanian climatic zone and 147 in the Sudano-Sahelian climatic zone)) were interviewed. Before the analyses, informants were grouped into two generations (adult: < 55 and old: ≥ 55 years) followed by Sop *et al*. (2012). Twenty-five ethnolinguistic groups were involved. Ethnolinguistic groups such as Bobo, Bozo and Dioula on the first hand, Dafing, Bwaba, Bobo and Mossi on the other hand were examined respectively in the Sudanian climatic zone and the Sudano-Sahelian climatic zone as major ethnolinguistic groups (Figure 5). Minorities included Sambla, Dafing, Miniankas, Mossi, Samo, Dioula, Tièfo, Toussian and Bwaba in the Sudanian climatic zone and Fulani, Gourounssi, Bissa and Gourmatché in the Sudano-Sahelian climatic zone were grouped as others to perform statistical analysis.

The recorded usages were computed and organized by use patterns to determine the species' uses. Eight use categories (Food, fodder, shade, energy, pharmacopoeia, sacred tree, magic tree, and building) were cited by informants. We focus on food, medicinal, and specific uses because households use them in a variety of ways. Generalized linear models with a Poisson error distribution were used to assess the variation of use patterns across climatic zones, ethnolinguistic groups, sex, generations, and the interaction between factors. For each use pattern, Relative frequency of Use (RF), Fidelity Level (FL), Use Diversity (UD) and Use Equitability (UE) were computed in each climatic zone. UD and UE were used to determine the distribution of knowledge and perceptions regarding the uses, management, and conservation practices of *Celtis toka* within the community (Table 5). Nonparametric tests (Kruskal-Wallis test, Mann–Whitney) at the threshold of significance of 5 % were applied to evaluate significant differences of use diversities between sex, generation and ethnolinguistic groups for each climatic zone (Goudégnon *et al*., 2017). All statistical tests were accomplished using R version 4.1.1 software (R Core Team (2021).

2.2.3. Stand floristic composition, diversity, and structural characteristics of *Celtis toka*

2.2.3.1. Sampling and measurements

Assessment of *Celtis toka* sanitary state and phenological stages according to CZ and LUT

During the prospection and inventory periods, we recorded various life history events in each climatic zone and land use type. From the Greek phainein, which means "to show or appear", phenology is a study of the timing of the life history events of plant species (Fenner, 1998). *Celtis toka* was categorized as leaf development, flowering, young fruits or ripe fruits and old leaves. The phenological growth stages were classified according to the **B**iologische Bunde-sanstalt, **B**undessortenamt and **CH**emical industry (BBCH) scale (Meier *et al*., 2009).

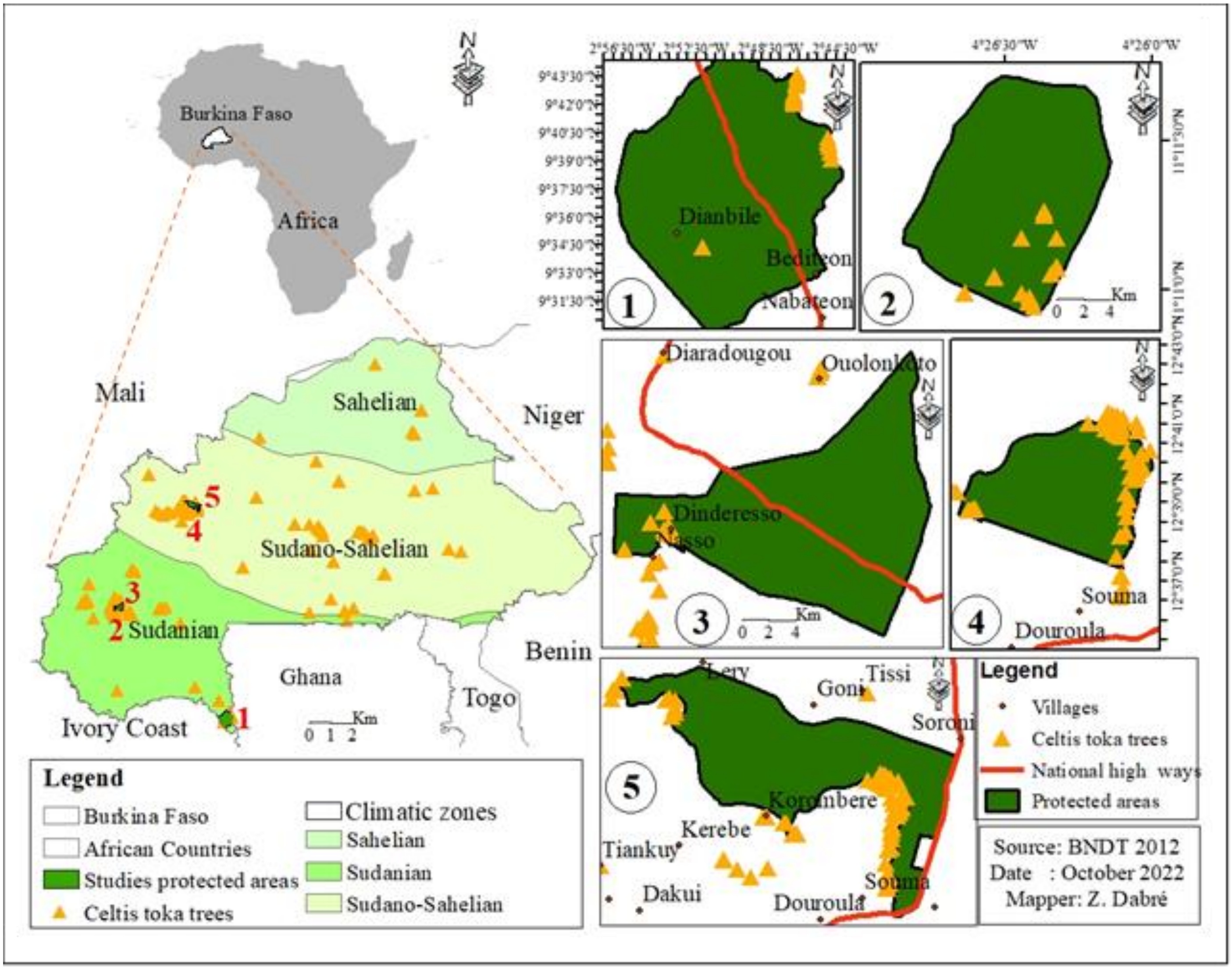

Figure 4**:** Map showing the study sites in Burkina Faso, West Africa

Distribution of *Celtis toka*: Source: GBIF (153 points), and field data and literature (401 points). **1**: classified forest of Koulbi, **2**: classified forest of Kou, **3**: classified forest of Dindérésso, **4**: classified forest of Sâ, and **5**: classified forest of Sourou.

Table 4: Characteristics of the protected areas of the study area.

Protected areas / Characteristics	**Sudanian climatic zone**			**Sudano-Sahelian climatic zone**	
	Kou	**Dindéresso**	**Koulbi**	**Sâ**	**Sourou**
Date of classification	04 /07/1935	27/02/36 and 26/08/41	4 /8/1955	1937/38	1937/38
Areas (ha)	117	8 500	40000	5 400	14 000
IUCN	IV	IV	IV	IV	IV
Rivers	Kou	Kou	Mouhoun	Mouhoun	Mouhoun
Temperature (°C)	27- 28.4	27- 28.4	27.4 – 27.9	28 -29.9	28 -29.9
Rain falls (mm)	775.4 - 1331.6	775.4 - 1331.7	900.8 -1435.6	580.7 - 1149.2	580.7 - 1149.2
Flow rate	Temporary	Temporary	Permanent	Permanent	Permanent
Soil types	Leached ferruginous soils	Leached ferruginous soils	Vertisol and leached ferruginous soils	Hydromorphic soil	Hydromorphic soil
Dominant woody species	*Anogeissus leiocarpa*, *Dialium guineense*, *Diospyros mespiliformis*, *Mitragyna inermis*, *Cordia myxa*, *Ceiba pentandra*, *Flacourtia indica*, *Cola laurifolia*, *Lepisanthes senegalensis*			*Tamarindus indica*, *Grewia bicolor*, *Balanites aegyptiaca*, *Acacia seyal*, *Acacia erythrocalyx*, *Diospyros mespiliformis*. *Combretum micranthum*, *Vitellaria paradoxa*	
Socio-cultural groups	Bobo (71.44%), Dioula (10.34%) and Bosso (8.37 %)			Bwaba (31.68 %), Dafing (23.27%), Bobo (13.86%) and Mossi (12.87)	
Major activities	Farmers (61.44 %), traders (21.61%) and breeders (11.65%)			Farmers (75.98%) breeders (11.35%) and traders (8.74%)	
References	a	a and b	a and c	a and c	a and c

IUCN: International Union for Conservation of Nature; a: Belemsobgo *et al.*, 2010; b: Nikiema *et al.*, 2001, c: UICN/PACO, 2009. Environmental data : Source ANAM (Agence Nationale de la Météorologie) / Socio-cultural groups and major activity (from our ethnobotanical activity), dominant plant species (from phytosociology activity).

The species was considered to process young leaves if leaves in the canopy were new; and old leaves if it was the opposite. It was in flower if it had either buds or open flowers. It was also considered a ripened fruit if they were not green. On each *Celtis toka* individual within a plot, different pressures related to natural hollows, overgrazing, pruning, debarking, fire scars, wind, flood actions and any other disturbances were noted.

Celtis toka was also considered healthy when there were no signs of animal or human exploitation or natural pathogens (hollows, fungi, parasites) or natural calamities (wind, flood etc.,).

Assessment of *Celtis toka* stand diversity, population structure and abundance.

The inventory of *Celtis toka* stand diversity, population structure and abundance were performed from November 2020 to April 2021 in two different types of climatic zones namely the Sudanian climatic zone and the Sudano-Sahelian climatic zone and two land use types using a completely randomized design. The land use types are protected areas (classified forests of Kou, Dindérésso, Sâ, Sourou and Koulbi classified forests) and unprotected areas (farmlands, fallows, rocky areas, and sacred areas). A random forest sampling technic was used. The plot sizes were 50 × 20 m in savannah and rocky areas, 10m x 50m in the gallery forests, and 50 m x 50 m in fallows and farmlands (Thiombiano *et al*., 2016). Plots were settled based on the presence of *Celtis toka*. A total of 339 *Celtis toka* individuals were sampled in 129 plots (64 plots in the protected areas and 65 plots in the unprotected areas). The following variables such as the height and the diameter at breast height (DBH) of individuals with DBH ≥ 5 cm were recorded. To avoid autocorrelation of *Celtis toka* individuals, plots were spaced about 200 m from a random starting point (Sambaré *et al*., 2011). However, individuals of *Celtis toka* with DBH < 5 cm were considered juveniles. The survey of juveniles was carried out into one or two subplots per quadrat with sizes 5m x 5m or 1 × 1 m of each subplot. The size and unbalanced nature of the juvenile subplots were due to the scarcity of juveniles in the study area. Within each subplot, the diameter at the collar, the height, and the regeneration mechanisms were recorded (Bognounou *et al*., 2010 b; Ouedraogo and Thiombiano, 2012; Thiombiano *et al*., 2016). To assess the stand diversity, within each plot, all encountered woody species associated with *Celtis toka* were recorded and their height and the diameter at breast height (DBH) were measured. Moreover, the topography (landscape position, slope) and soil texture were recorded.

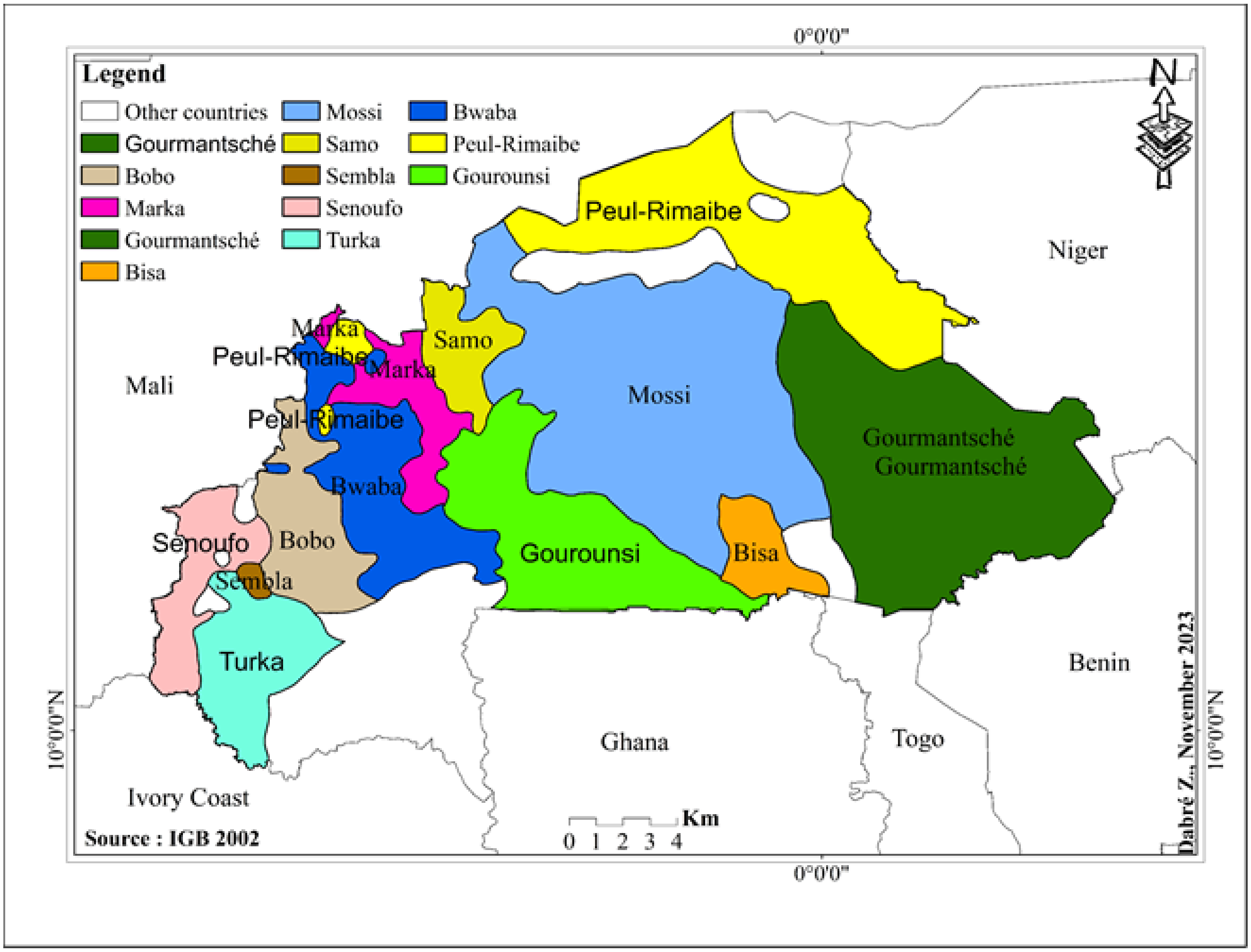

Figure 5: Map of the ethnolinguistic groups interviewed in the study area.

Ethnolinguistic groups such as Bambara, Miniankas and Bozo are immigrants from Mali.

Table 5: Overall formula for the computation of the local knowledge

Measurement of knowledge and perceptions regarding uses, sociodemographic impact, and conservation strategies of *Celtis toka* within communities in the Sudanian climatic zone and the Sudano-Sahelian climatic zone of Burkina Faso.

Index	Computation	Description	References
$\mathbf{RF} = \frac{\mathbf{FU}}{\mathbf{SF}} \boldsymbol{x100}$	Frequency of uses (FU) cited by a given informant divided by the number of total uses times 100.	Measures the ratio of the number of times a pattern of *Celtis toka* occurs in the set of all number of use patterns. The value ranges from 0 to 100.	(Thiombiano *et al*., 2016)
$\mathbf{FL} = \frac{\mathbf{Ip}}{\mathbf{Iu}} \mathbf{x100}$	Number of informants (Ip) related to a specific use divided by the total number of informants (Iu) times 100.	Measures the grade of consensus between informants. FL is considered significant when this is directly above 5 % (FL > 5%).	(Friedman *et al*., 1986)
$\mathbf{UD = U\ cx/U\ ct}$	Number of indications recorded by pattern (U cx) divided by the total number of indications for all the patterns (U ct).	Expresses how many uses patterns *Celtis toka* is used and its contribution to the total usage. The value ranges from 0 to the number of use categories that use it	(Byg and Balslev, 2001; Schumann *et al*., 2012)
$\mathbf{UE = UD/UD\ max}$	Use-diversity value (UD) is separated by the index's maximum value (UD max).	UE measures the contribution of diverse uses to the overall use of a species, regardless of the number of use categories. The range of values is between 0 and 1.	(Byg and Balslev, 2001; Schumann *et al*., 2012)

The determination of the vegetation type (savannah, galleries forests etc.) was done based on the classification of Yangambi (CCTA/CSA, 1956) redone by Aubreville, 1957.

2.2.3.2 Data analysis

Sanitary state and phenology of *Celtis toka*

Mean and standard errors of individuals were computed to assess the biological life forms and disturbances factors of the species. The proportion of trees debarked, pruned, both pruned and debarked, grazed, fired, flooded, fallen branches or the whole tree, hollowed, and parasitized either by fungi or epiphytes was calculated for the different climatic zones and land use types. Non-parametric Kruskal–Wallis' test was used to compare mean overgrazing, debarking, pruning and debarking percentages across climatic zones and land use types.

Woody stands diversity and ecological importance of *Celtis toka* across CZ and LUT

Species richness (S), Shannon's index (H') and Pielou evenness (E), Simpson`s index (D), were hence calculated to assess the stand diversity. Additionally, the Sorenson diversity index (Ss), and Importance Value Index (IVI) were used to evaluate the stand composition and the ecological importance (Table 6). The most important IVI were considered.

Structural parameters of *Celtis toka* populations and stability across CZ and LUT

The following dendrometry parameters: mean diameter of the tree ((Dm, in cm), basal area (G, in m^2/ha), tree height (H_L, in m), and density of populations (D, ha^{-1}) were computed for the species according to the different climatic zones and land use types (Table 6).

Generalized linear model analysis (GLMs) with Poisson error was used to assess the effect of climate and land use type on the dendrometry parameters. The demographic structure of *Celtis toka* population was assessed using height classes and diameter size classes' distribution. The diameter class distribution concerned the adult stratum (DBH $\geq$ 5cm), and the height class distribution, the juvenile stratum (DBH < 5 cm).

To analyse tree size-class distribution (SCD), trees were grouped into six to eighteen size classes, based on diameter (i.e., 5-15 cm, 15-25 cm, 25-35 cm and greater than or equal to 175 cm), and juvenile total height (0-0.5 m, 0.5-1m, 1-1.5 m, 1.5-2 m, 2-2.5 m, and 2.5-3 m). The population structure of *Celtis toka* across land use types in the Sudanian and the Sudano-Sahelian climatic zones was assessed through a bar graph by using the density of individuals of the species (Thiombiano *et al*., 2016; Assogba *et al*., 2020; Lokonon *et al*., 2022). SCD slopes for each climatic zone and land use type were computed. A least-square linear regression was used to show the evolution of the tree density. The shape of the SCD and the level of recruitment were used to predict the demographic structure (Martins and Shackleton, 2017). Negative slopes denote an inverse J-shaped size class distribution curve with the best recruitment, i.e., greater individuals came from smaller size classes and lower individuals came from bigger size classes. A positive slope indicates low recruitment, with lower stem densities in smaller size classes and higher densities in larger size classes, implying a stand with an unimodal size-class curve. A flattened slope denotes the same number of stems in smaller and higher-size classes, indicating populations with flat SCD curves (Venter and Witkowski, 2010; Martins and Shackleton, 2017; Assogba *et al*., 2020). *Celtis toka* population stability was investigated using the permutation index (PI) and the quotient between successive size classes (Venter and Witkowski, 2010). The level of deviation from the monotonic reduction predicted in an undisturbed stand is determined by the PI. To compute the PI, diameter size-classes were organized in increasing order and compared to the ranking of their actual frequency. A PI value close to zero indicates an undisturbed population, while a higher PI shows a disturbed population with discontinuous distribution (Wiegand *et al*., 2000; Helm and Witkowski, 2012). Quotients between successive size classes were graphed, and the shape of fluctuations was examined.

Regeneration mechanisms

To assess the regeneration mechanism, the mean (± standard error) number of juveniles (coppice, water sprout, root sucker, seedling sprout and true seedling) per plot was computed per climatic zone and land use type. Regeneration rate (Table 6), and the density of seedlings were computed (Poupon, 1980; Ngom *et al*., 2013), and Kruskal–Wallis' test was calculated to evaluate the effect of climate and land use types on the natural regeneration. The density in each plot permits us to appreciate the state of the regeneration of *Celtis toka*. All the analyses were performed using R software (R Core Team, 2021). Fluctuating quotients between successive size classes indicate an unstable stand, whereas constant quotients indicate a stable stand.

Table 6: Global formula of the demographic structure and stability of *Celtis toka*

Description of the demographic structure and stability parameters of adults and juveniles of *Celtis toka*.

Parameters	Index	Description	References
Species richness (S)	n	Total number of the species	
Shannon`s diversity index (H')	$H' = -\sum_{i=1}^{s} \frac{Ni}{N} log2 \frac{Ni}{N}$	Sum of the number of plots in which the species occurs (Ni) over the total number of plots (N).	(Shannon and Weaver, 1949)
Pielou evenness index (E)	$E = \frac{H'}{H'max}$ With $H'max$ = $\log_2(S)$	Shannon's diversity over a maximum of Shannon's diversity. S is the total number of the species in the communities	(Whittaker, 1972)
Simpson`s index (D)	$D = 1 - \sum_{i=1}^{n} P_i^2$	Pi stands for the relative importance value of the species i, n the sum of the importance values of all species on a plot where species i is found.	(Simpson, 1949)
Sorenson's index of similarity (Ss)	$Ss = \frac{2C}{(C_j + C_k)}$	C stands for the number of species shared by two LUT in the CZ, Ci is the number in the PA and Ck is the number in UPA	(Whittaker, 1972)
Importance Value Index (IVI, %)	IVI = relative dominance (RD) + relative density (Rd) + relative frequency (RF)	$RD = \frac{basal\ area*100}{Total\ basal\ area}$, $Rd = \frac{number\ of\ individuals\ of\ the\ species*100}{Total\ number\ of\ individuals\ of\ all\ species}$, $RF = \frac{Number\ of\ plots\ where\ the\ species\ occurs*100}{Total\ number\ of\ plots}$	(Curtis and Mcintosh, 1951)
Tree density of populations (D, ha^{-1})	$D = \frac{n}{s}$	The overall number of trees in the plot (n) divided by the area of the plot (s) in hectares	(Philip, 1994)
Mean diameter of the tree (D_m, cm)	$Dm = \left(\frac{1}{n}\sum_{i=1}^{n} d_i^2\right)^{1/2}$	Average of diameter trees in the stand. n is defined as the overall number of trees in the plot and di, the diameter of tree i in each plot.	
Tree height (H_L, in m)	$H_L = \frac{1}{n}\sum_{i=1}^{n} h_i$	Average of the tree height	

Basal area (G, in m^2/ha)	$G = \frac{\pi}{4s}\sum_{i=1}^{n} 0{,}0001 * d_i^2$	Sum of the cross-sectional area at 1.3 m above the ground level of all trees on a plot,	
Permutation index (P)	$P = \sum_{i=1}^{n} \lvert j - i \rvert (i = 1 \text{to } 18 \text{ or } 1 \text{ to } 7)$ n = 18 (adults) n = 7 (juveniles)	J stand of sized classes i (i=1 for small stems), and the first rank (J=1) attributed to the mostly frequent sized class.	(Wiegand *et al.*, 2000)
Quotients (Q) between successive size-class	$Q = \frac{n_{i-j}}{n_i}$	ni: number of individuals in class i. ni-1: number of individuals in preceding class.	(Shen *et al.*, 2013)
Regeneration rate (Rr, %)	$Rr = \frac{young\ individual\ (< 5cm)}{adult\ individual\ (\trianglerighteq 5)} * 100$	Number of individuals with DBH < 5 cm divided by the number of individuals with DBH ≥ 5 cm times 100	(Poupon, 1980; Ngom *et al.*, 2013)

2.2.4. Impact of climate change on the tree ring growth, wood anatomical patterns, and aboveground carbon stock of *Celtis toka* in Burkina Faso

2.2.4.1. Sampling and measurements

Dendrochronology or tree ring analysis can importantly contribute to the study of tropical forest responses to changing climate (Brienen *et al*., 2016). Plots were established according to the vegetation types. Topographic variation, tree size, tree morphological characteristics (diameter and height) and land cover types (shrubs, woodland, and gallery forests) were recorded. In each plot, biometric parameters such as stem DBH (1.3 m above the ground) and tree height (H) for *Celtis toka* living trees and snags (i.e. standing dead trees) using respectively diameter tape and clinometer were measured. The geographic coordinates of each plot and the elevation data from a topographic map were documented. We had limited permission to take wood from living trees. Therefore, we could only collect four cross-sections from either a dead tree or a cutting tree with a chainsaw from both climatic zones (two from each climatic zone and land use type). Concerning the carbon stock, our study aims to assess the density of *Celtis toka* and then use the specific allometric equation of some species to estimate the ability of *C toka* to sequester the carbon dioxide from the atmosphere.

2.2.4.2. Data analysis

Ring-width measurement and cross-dating

To determine the tree age and annual radial increment rate, the 4 stem discs were dried in an open area under shade before being transported to the Laboratory of Dendrochronology of Friedrich Alexander-University of Erlangen-Nuremberg (Germany) for tree-ring analysis. To improve the visibility of the growth ring boundaries, the samples were polished gradually using sandpaper of grit size 80–4000. After the compressed air was used to remove the wood dust. Tree-ring widths (Figure 6 A) were evaluated from two to four radii (from pith to bark) to the nearest 0.02 mm with a LINTAB 6.0 supported by the software TSAP-Win (Rinn *et al.*, 1996 and Sanogo *et al.*, 2016). Tree-ring boundaries (Figure 6 B) were therefore marked under a microscope connected with a LINTAB 6.0 (Sanogo *et al*., 2016) measuring system (Rinntech Inc., Germany). Residual and standard chronologies were assessed on a cross-dated series.

Cross-dating was done both statistically and visually. The visual cross-dating was realized using pointer years (extremely wide or narrow rings) which enabled us to detect and correct errors due to possible missing or false rings (Gebrekirstos *et al*., 2008). Cross-dating was more confirmed statistically through the TSAP which permitted to analyze 'Gleichläufigkeitkoeffizient' (coefficient of parallel dissimilarity between tree-ring series) or GLK (> 65%) and T-value (> 2) that confirmed the authenticity of the degree of resemblance of two curves (Baillie and Pilcher, 1973). Subsamples were cut from CZ, discs were labelled and soaked in water for 72 hours to describe the growth-ring anatomy and identify the features that characterize the growth-ring boundaries. Tangential, radial and transversal thin sections of 10–20 μm thickness were prepared from those samples using a GSL-1 sledge microtome (Gärtner *et al*., 2014). The thin sections were dried with a mixture of Safranin (0.81%) and Asta blue (0.5%) and cleaned with concentrations of ethanol respectively 50%, 95%, and 99%. Microslides were analysed under a digital microscope Zeiss Smartzoom 5 **(**Carl Zeiss Microscopy GmbH 2014, Jena, Germany) to identify features characterizing the growth-ring boundaries. The diameter increment rates and age of each sample were evaluated from tree-ring analyses.

Vessel variables measurements

The tree ring series of all discs (Figure 7A) were used for wood anatomical measurements. Characteristics of vessels were measured using microscopic images (100) captured by the Zeiss Smartzoom 5 digital microscope (Carl Zeiss Microscopy GmbH 2014, Jena, Germany) using a high-resolution image with 100 x magnification (Figure 7B). To improve the visibility of vessel features, image quality had to be improved in some cases through contrast enhancement and manual correction of image errors in the Photoshop program (Figure 7C). The software WinCELL 2012 (Regent Instruments Inc., Québec, Canada) was used for wood cell analysis (Figure 7D). The year of formation was first used to identify tree-ring boundaries on each image. In WinCELL, an analysis region was created in each tree ring by closing the regions delimited by the ring boundary paths. Vessels were measured in each investigated region using the appropriate filters (width, length, length-to-width ratio, area, and form).

Because of the species' diffuse-porous anatomy, we did not distinguish between earlywood and latewood vessels and considered them all together, resulting in one analysis region per tree ring.

IAWA List of Microscopic Features for Hardwood Identification was used (IAWA committee 1989). Vessel variables such as number of Vessels (NV), total vessel area (TVA), total vessel area percentage (TVAp), mean vessel area (MVA), mean vessel tangential diameter (MVTD), mean vessel radial diameter (MVRD), and vessel density (VD) were directly measured by WinCELL except for vessel density (VD) which was calculated by dividing the number of vessels by the size of the analysed area. Vessel features were measured on these cross-dated series.

To assess the link between climate variables and ring width index, Origin software was used to build graphs. Origin is a robust and full-featured data analysis software (Seifert, 2014; Moberly *et al.*, 2018). The chronology construction and data analyses were performed using the dendrochronology Program Library (dplR, treeclim, trader, graphics, utils), COFECHA, and ARSTAN (Holmes, 1983; Cook and Holmes, 1996; Bunn and Korpela, 2018; Waszak *et al*., 2021). Vessel traits were assessed through one sample Wilcoxon test analysis of median values of vessel traits in each ring from the pith to the bark. Pearson's correlation test was used to assess the pairwise relationships between vessel traits at a confidence level of 0.95%. Finally, we used a Principal Component Analysis (PCA) to see how different wood anatomical traits related to one another. All statistical analyses were carried out using R4.05 software (R Core Team (2021).

Historical record of environmental and human effects on *Celtis toka*

Four individual cross-sections were collected from two CZ. After sanding the transversal surfaces of the cross-sections, the year and the season of disturbances were determined visually by employing ring-width boundaries.

Wood density, biomass, and carbon stock measurements

The stem discs harvested for ring analysis were used to determine wood density. Following that, a sub-sample was taken from each stem disk and saturated in water for 30 minutes. The wood-specific density of each sample tree was assessed as the dry weight to fresh volume ratio after 72 hours of drying at 105°C (Nogueira *et al*., 2005; Sanogo *et al.*, 2016). The below formula was used to compute wood-specific density (ρ) for each individual tree and average it across all sites:

$\rho \frac{dw}{V}$; where *dw* equals the dry weight of the sample, and *v is* the fresh volume.

To estimate the aboveground biomass, the allometric equation (Chave *et al*., 2014) was used:

$AGB = 0.0673 \times (\rho \times DBH^2 \times H)^{0.976}$

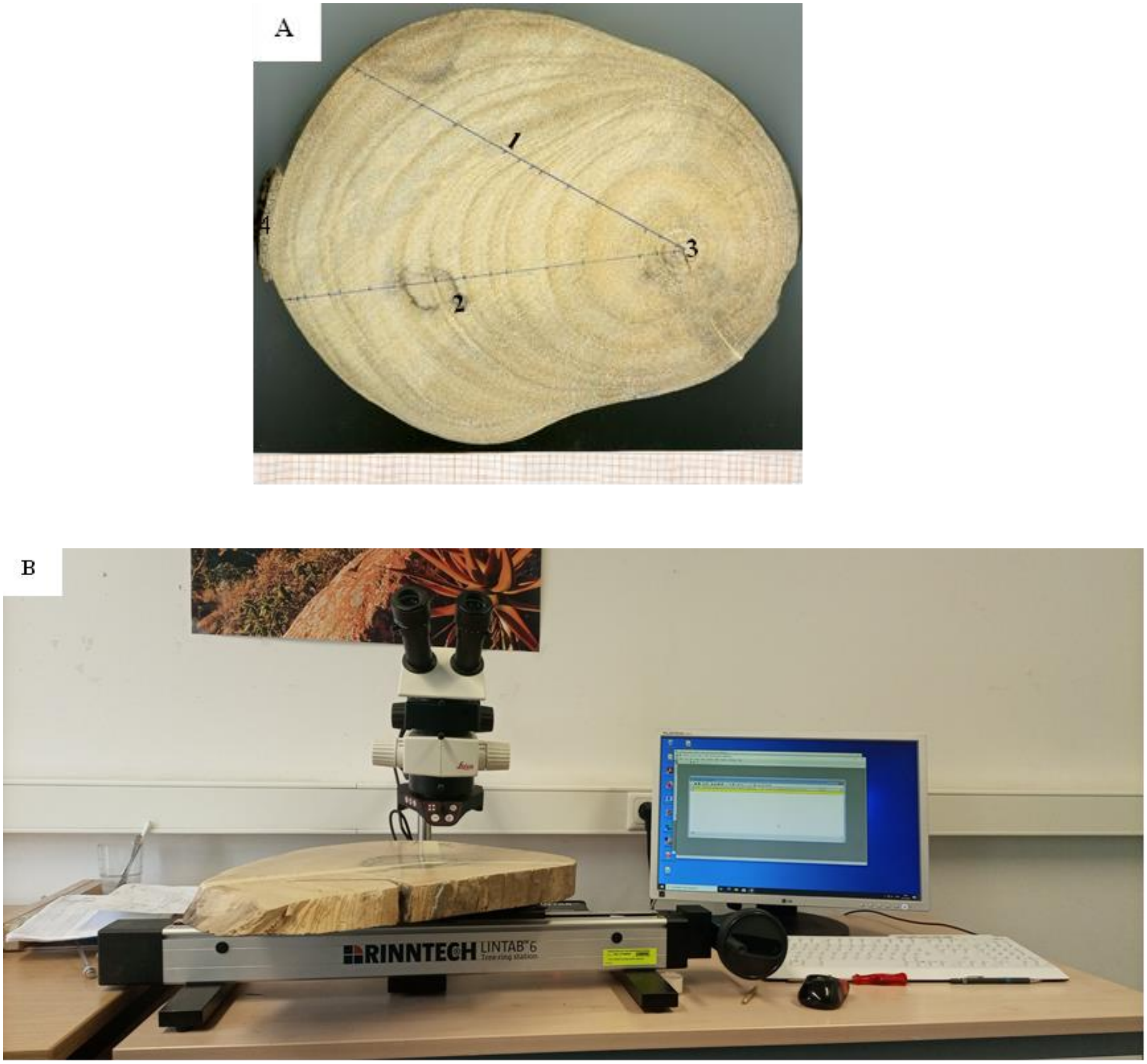

Figure 6: Measurement of ring-width and cross-dating

Pictures: Dabré, 2022.

Stem disc with marked growth-ring boundaries along radii (1: radial 1, 2: radial 2, 3: pith and 4: bark) (A), and tree-ring widths measurement and cross dating using LINTAB 6 supported by TSAP software (B).

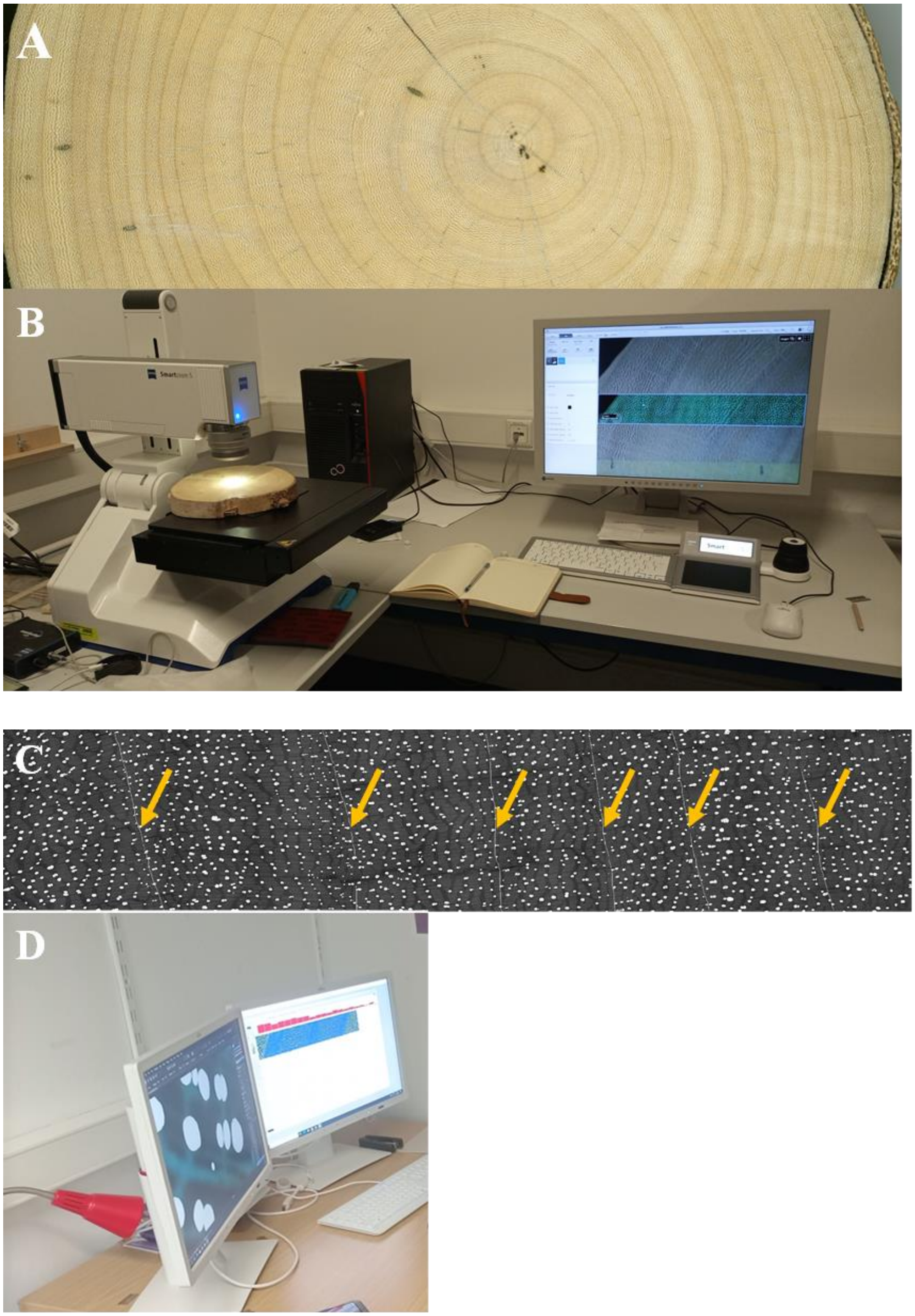

Figure 7: Different steps of the measurements of wood anatomical features.

Pictures: DABRE, 2022.

Polished wood (A) scanned wood image thanks to Smartzoom 5 (B), enhancement of vessel distribution (in white) and tree-ring boundaries materialized by arrows (C), and measurement of vessel features in WinCell (D).

where AGB is the aboveground biomass in kilograms per tree, ρ is wood density in grams per cubic centimetre and DBH is in centimetres and H is the total height of the tree in metres. Aboveground biomass was calculated for each tree and totalled by the plot. Carbon stocks were estimated to be 50 % of the AGB (Redondo-Brenes, 2007). The outcomes were then scaled from Mg $plot^{-1}$ to Mg ha^{-1}.

2.2.5. Assessment of the potential impact of climate change on the geographical distribution of *Celtis toka* in Burkina Faso

2.2.5.1. Sampling and measurements

Occurrence data

Global Positioning Systems (GPS) have improved the spatial accuracy of field sampling relative to plants, and it has been used for geographic coordinate data (latitudes, longitudes). Those data were used to predict the geographic ecological distribution of *Celtis toka* species. In addition to the coordinate data obtained from the fieldwork by random sampling (Table 7), coordinate data of the same species was downloaded free from the Global Biodiversity Information Facility (GBIF) website http://www.gBif. org) for generating the current and future geographic distribution of *Celtis toka* purpose(Fourcade *et al.*, 2014).

Climate data

The potential consequences of projected climatic change upon species can be feigned using models relating their geographical distributions to climatic variables (Huntley *et al*., 2006). The distribution of the species was analysed via an ensemble of environmental data. The climate is a main factor in the distribution of a species at a large scale (Vayreda *et al*., 2013). The current data and the middle future climate (Bioclimatic variables) at the horizon 2080 and 2100 of the 30-second spatial resolution were downloaded from the WorldClim database (Varol *et al*., 2022); http://www.wordclim.org). A total of 22 environmental (Table 8) variables were considered for the use of the species distribution model, including elevation, human influence index, the degree of inclination (decimal degrees), and 19 bioclimatic variables (Nyairo and Machimura, 2020, Xu *et al*., 2022). The third Hadley Centre Global Environment Model in the Global Coupled configuration 3.1 (HadGEM3-GC31-LL) and the sixth Coupled Model Intercomparison Project (CMIP6. MIROC6) are models which were used. SSP245 and SSP585 are two SSPs (Shared Socioeconomic Pathways) which was run in Maxent software. (Climate Analytics, 2021). Those two scenarios were chosen because they are widely used (Ali *et al*., 2023).

2.2.5.2. Data analysis

2.2.5.2.1. Data processing and model calibration

SDMtoolbox 2.0 was used to process occurrence data and bioclimatic variables in ArcGIS 10.8.1 software (Brown *et al*., 2017). However, bias has been reduced using the “spatially rarefy occurrence data” function. The auto-correlated variable removed all duplicate records from each grid using SDMtoolbox's “remove highly correlated variables” function. The forcefully reliable bioclimatic variables were kept for the final map. Occurrence data were transformed into CSV format in Excel and bioclimatic variables into ASCII format in ArcMap 10.8.1. Geographical sampling bias was examined and corrected through background data or ‘‘pseudoabsences” (Syfert *et al*., 2013). Regarding the model calibration, 70 % of the species occurrence points served as training data, while the remaining 30 % served as test data to assess the model's predictive power. We ran 10 replicates of *Celtis toka* using cross-validation/repeat split samples to determine the amount of variability in the model, 5000 iterations, and then averaged the results. The threshold for maps has been reduced to binary to avoid overfitting effects (Peterson, 2007). The threshold was utilized for the collinearity reduction between variables (Ndayishimiye *et al*., 2012). To determine the percentage contributions, the selected variables in the distribution model were subjected to the Jackknife test.

2.2.5.2.2. Model evaluation

In terms of model evaluation, we tested 25 % of the species occurrence records and calibrated 75 %. The model's sensitivity and specificity were determined using the area under the curve (Phillips *et al*., 2006). This area under the curve (AUC) is a discrimination index which represents the probability that a presence will have a further predicted value than an absence (Lobo *et al*., 2008). The translation of AUC values and for model validation was: 0.90-1.00: excellent; 0.80 to 0.90: good; 0.70 to 0.80: average; 0.60 to 0.70: poor; 0.50 to 0.60: insufficient (Linshan *et al*., 2017;

Ndayishimiye *et al*., 2012; Thuiller *et al*., 2003). True Skill Statistics (TSS) was used to validate the models' ability to predict true presence (sensitivity) and true absence (specificity).

TSS = sensitivity + specificity -1.

TSS accuracy in prediction models is evaluated, with a TSS of 0 indicating random prediction and a TSS close to 1 (TSS > 0.5) indicating good predictive power (Allouche *et al*., 2006; Peterson, 2007). MaxEnt logistic probability distributions generated with the 10th percentile training presence logistic threshold were used to assess the species' potential habitat suitability. The suitability of occurrence was determined by areas above the threshold, while areas below the threshold were deemed unsuitable (Idohou *et al*., 2017). ArcGIS 10.8.1 was used to create maps for habitat suitability and unsuitability.

Table 7: Occurrence data of *Celtis toka* in Burkina Faso

GPS data of individual trees	Sources	Dates
401	Fieldwork and literature review	From November 2020 to April 2022 (field work)
153	Global Biodiversity Information Facility (GBIF)	May 2022

Table 8: Description of bioclimatic variables

Variables	Descriptions	Source
Elevation	Height above sea level (m)	WorldClim
HII	Human influence index	a*
Slope	Degree of inclination	WorldClim
BIO1	Annual Mean Temperature	WorldClim
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	WorldClim
BIO3	Isothermality (BIO2/BIO7) (×100)	WorldClim
BIO4	Temperature Seasonality (standard deviation ×100)	WorldClim
BIO5	Max Temperature of Warmest Month	WorldClim
BIO6	Min Temperature of Coldest Month	WorldClim
BIO7	Temperature Annual Range (BIO5-BIO6)	WorldClim
BIO8	Mean Temperature of Wettest Quarter	WorldClim
BIO9	Mean Temperature of Driest Quarter	WorldClim
BIO10	Mean Temperature of Warmest Quarter	WorldClim
BIO11	Mean Temperature of Coldest Quarter	WorldClim
BIO12	Annual Precipitation	WorldClim
BIO13	Precipitation of Wettest Month	WorldClim
BIO14	Precipitation of Driest Month	WorldClim
BIO15	Precipitation Seasonality (Coefficient of Variation)	WorldClim
BIO16	Precipitation of Wettest Quarter	WorldClim
BIO17	Precipitation of Driest Quarter	WorldClim
BIO18	Precipitation of Warmest Quarter	WorldClim
BIO19	Precipitation of Coldest Quarter	WorldClim

a*: NASA socioeconomic data and application centre (SEDAC)

CHAPTER III: RESULTS

3.1. ASSESSMENT OF THE TRADITIONAL KNOWLEDGE AND MANAGEMENT PRACTICES OF THE SPECIES *Celtis toka* IN BURKINA FASO

3.1.1 Diversity of use of *Celtis toka*

3.1.1.1 Local names of the species *Celtis toka*

Among the 405 respondents interviewed in this study, 63.46 % were men. Most of the local communities were farmers and had low education levels. Around 80 % of informants have attended no formal education (Table 9).

The species *Celtis toka* was referred to 49 vernacular names in 25 ethnolinguistic groups across the study area (Table 10). However, for a single ethnolinguistic group, several local names were attributed. The main meaning of the local names was either taboo, fetish, sacred, magic, mystic, fodder, or sweet stew plant. Some names were related to the size and height (gobda, kaa) or the number of *Celtis toka* trees (Kankami (many *Celtis toka* trees*)* or Kankama (Single *Celtis toka* tree)). Nonetheless, a few informants were unable to give a precise sense of the name of the species in their respective dialects (Table 10).

3.1.1.2. Frequencies and fidelity levels of the use categories and plant parts

Celtis toka provides various functions including custom, cultural, ecologic, and socio economical. Custom and cultural values were food (27.89 % of which 29.86 % in the Sudanian climatic zone and 25.92 % in the Sudano-Sahelian climatic zone), fodder (18.97 % of which 23.70 % in the Sudano-Sahelian climatic zone and 14.23 in the Sudanian climatic zone), pharmacopoeia (14.92 of which 16.28 % in the Sudanian climatic zone and 13.56 % in the Sudano-Sahelian climatic zone), energy (11.33 % of which 10 % in the Sudanian climatic zone and 12.66 % in the Sudano-Sahelian climatic zone), shade (16.22 % of which 19 % in the Sudanian climatic zone and 13.56 % in the Sudano-Sahelian climatic zone), Sacred tree (5.24 % of which 6.50 % in the Sudanian climatic zone and 4 % in the Sudano-Sahelian climatic zone) and others indicated in Figure 8. Although eight specific use patterns were recorded across its entire distribution range, seven of them were found to be important (FL> 20 %). Both climatic zones share the same number of usage categories. However, the FL of motivation highlighted the uses of food, fodder, shade, pharmacopoeia, and energy value as the most important (Table 11, Table 12). Almost all respondents of both climatic zones widely expressed that they use *Celtis toka* for food, fodder, shade, pharmacopoeia, and energy purposes. In the Sudano-Sahelian climatic zone, Bobo sociolinguistic groups valued the species in terms of food (FL= 98.62), fodder (FL = 82.76%) and sacred tree (FL: 41.38 %) than Dioula culture (FL: 57.14%). Whereas Bwaba and Dafing cherished the species in food (FL = 100%) and fodder (FL = 95.74%), Mossi culture valued less the species in terms of food (FL: 10.81%) in the Sudano-Sahelian climatic zone. Hence, the motivation for conservation was similar ($p > 0.05$) between ethnolinguistic groups, sexes, and generations in both climatic zones (Table 13). The results of the GLM analysis at the level of

motivation revealed that the conservation of *Celtis toka* for multiuse and sacred trees varied significantly between ethnicity ($p < 0.05$) and sex ($p < 0.05$) see Table 13. The most used plant parts of the multipurpose species were leaves (63.83 % of which 60.35% in the Sudanian climatic zone and 55.95 % in the Sudano-Sahelian climatic zone), roots (19.20 % of which 18 % in the Sudanian climatic zone and 16.99 % in the Sudano-Sahelian climatic zone) and barks (17.11 % of which 16.41 % in the Sudanian climatic zone and 14.78 % in the Sudano-Sahelian climatic zone) (Figure 9). Leaves, flowers, and fruits had various usage patterns. However, leaves were the most widely used plant parts and were used as food, fodder, and pharmacopoeia. In both climatic zones, fruits and seeds were also used as food. Some of the respondents (20.69 % of Bobo culture in the Sudanian climatic zone) highlighted that the pounded leaves were often used to cook tô (it is the national dish (or saghbo in Moré), a dough made from millet, corn or sorghum flour accompanied by a sauce) during hunger period by some of their ancestors. However, pounded leaves were sold in some hamlets (Figure 10 d and e) in both climatic zones.

3.1.1.3. Food uses of *Celtis toka*

Edible plant parts were leaves, fruits, and seeds. Leaves were mostly used in seven ways, followed by fruits and lastly by seeds in both climatic zones. The use of the leaves as the sweet stew was more diverse in the Sudanian climatic zone (7) than in the Sudano-Sahelian climatic zone (4). Fruits were more used in the Sudanian climatic zone (FL = 20.20 %). Furthermore, seeds were mostly consumed more in the the Sudano-Sahelian climatic zone (FL= 14.36%) than in the Sudanian climatic zone (FL =2.46%) as indicated in Table 14.

Table 9**:** Sociodemographic characteristics of informants in the study area

Demographic parameters	**Variables**	**Sudanian climatic zone**		**Sudano-Sahelian zone**	
		n	(%)	n	(%)
Sex	Women	91	40.95	55	27.23
	Men	112	59.05	147	72.77
	Total	203	100	202	100
Status	Autochthon	132	65.02	164	81.19
	Migrant	71	34.98	38	18.81
	Total	203	100	202	100
Generation	adult (< 55)	95	46.80	119	58.91
	old (≥ 55)	108	53.20	83	41.09
	Total	203	100	202	100
Ethnolinguistic groups	Bobo	145	71.44	28	13.86
	Bozo	17	8.37	-	-
	Bwaba	-	-	64	31.68
	Dafing	-	-	47	23.27
	Dioula	21	10.34	-	-
	Mossi	-	-	37	12.87
	Others	20	9.85	26	12.87
	Total	203	100	202	100
School level	None	162	79.59	150	74.26
	Primary	32	15.75	43	21.28
	Secondary	9	4.37	7	3.47
	Tertiary	1	0.29	2	0.99
	Total	203	100	202	100
Main activity	Farming	125	61.44	153	75.74
	Trade	44	21.61	18	8.91
	Breeding	24	11.65	23	11.39
	Handwork	11	5.3	0	-
	Hunt	0	-	8	3.96
	Total	203	100	202	100

Table 10: Local names and meanings of *Celtis toka* in the study zones.

CZ	Localities	Ethnolinguistic groups	Vernacular names	Meaning
	Balé	Bwaba	Kankami, kankama, kankambri	Food, sacred and magic species
		Dafing	Mambi, kamignan	Very useful tree, sweet stew tree, magic tree
		Bambara	Mambri	Useful tree, taboo and magic tree
		Toussain	Kamignan	Useful tree, sacred and magic tree
SCZ	Houet	Bobo	Kamignagua, kanka, Loumou, seideni, sondeyni, bamignan, kamignan, kamygnam	Sweet stew tree, good spiritual tree, sacred species, magic species, fetish, mistic tree
		Bambara	Guamignan, mambri, gamignan, kongnon, djo,	Useful tree, fetish tree, Magic tree, fodder tree, sacred species
		Marka	Yobo	Fetish, magic tree
		Bozo	Djo, djo la la, yobo, gamignan	Fetish, Magic tree, sweet stew tree
		Bwaba	Amignan, kamignan, kamignan	Sweet stew tree, good spiritual tree, sacred species, magic species
		Dioula	Djo, mabri, kamignan, nongon na baa	Fetish, magic tree, sweet stew tree, fodder tree
		Foulga	Riiki	-
		Fulani	Kamignan	Very useful tree, fodder tree, sweet stew tree
		Maranssé	Farangua	Useful tree
		Miniankas	Mambri	Sweet stew tree
		Mossi	Farangua, rickou	Sweet stew tree, fodder
		Sambla	Kaa, gnimini, kamignan, fly	Senior brother of Adansonia digitata, a useful tree
		Samo	Mambri	Sweet stew tree

		Sénoufo	Kamignan	Sweet stew tree
		Tièfo	Kamignan	Sweet stew tree
		Toussian	Mambri, mabri	Sweet stew tree, fodder tree
		Yarsé	Farangua	-
SSCZ	Bazèga	Mossi	Pargandé	Useful tree
	Boulgou	Bissa	Gobda, gobdo, saam, kada	Saam, gobda, gobdo, kada
		Fulani	Ganki	Fodder tree
	Ganzourgou	Mossi	Pargandé	Food tree, useful tree, fodder
	Gnagna	Gourmanché	Tidjerbou	Hunger hunter/ famine hunter
	Gourma		O'ossanssambou, oti, sanssambou	Medicine tree (against itching)
	Kossi	Bobo	Kamignan, kamignan yiri	Useful tree, sacred species, and magic tree
		Dafing	Kamignan	Very useful tree, a sweet stew tree, a sacred tree
		Gourounsis	Douka, kamignan	Sweet stew tree
		Mossi	Dikou, kamignan	Sweet stew tree
	Kourwéogo	Mossi	Yibourougou, yibiligou	Fodder tree, the sacred tree
	Mouhoun	Fulani	Ganignan, kamagnan	Very useful tree, fodder tree, sweet stew tree
		Dafing	Kamagnan	Very useful tree, sweet stew tree, magic tree
		Bwaba	Kamagnan, kamignan	Useful tree, fodder tree
		Dioula	Kamignan	Sweet stew tree, magic tree
		Mossi	Kalguem-tohéga, salguem-tohéga	Sweet stew tree
		Bobo	Kamignan	Sweet stew tree
	Nahouri	Gourounsis	Takara	Useful tree
	Nayala	Dafing	Kamigni, kamignin, kamignin ba	Very useful tree, sweet stew tree, sacred tree
		Fulani	Ganki, yibi, yibini	Very useful tree, fodder tree

3.1.1.4. Traditional medicinal uses of *Celtis toka*

Overall, 29 diseases have been recognized to be healed with *Celtis toka* plant parts. The most common diseases were vitamin deficiency (FL = 8.84%), malaria (FL = 8.44%), cast (FL = 5.84 %), madness (FL = 3.25 %), eye ache (FL = 2.77%) and yellow fever (FL = 2.60%). All plant parts were involved in the composition of medicines.

Roots were the most frequently used plant parts and were used to heal 15 ailments which were mostly ringworm, diarrhoea, backache, toothache, ulcer, measles, and chickenpox followed in decreasing order by bark (12), leaves (12), fruits (3), seeds (3) and flowers (2) according to Table 15. This form of knowledge is generally kept by elders, bozo (Fishermen/women), dosso (hunters) and traditional healers.

3.1.1.5. Specific use of *Celtis toka*

Sacred (37.99%), taboo (25.04%), mystic (11.62%), magic (10.28%), fetish (8.96%) and medico-magic (6.12%) tree are six specific uses of *Celtis toka* in the study sites. The use as sacred remains the most used in both climatic zones. In the Sudanian climatic zone, the local community perceived the species as a taboo (31.91%) species than in the Sudano-Sahelian climatic zone (18.18%). However, mystic (15.46%), magic (13.16%), fetish (10.91%) and medico-magic (9.74%) were more highlighted in the Sudano-Sahelian climatic zone (Table 16). Locals define a sacred tree as a traditional tree under which customs or cultural activities take place. Taboo and fetish have been defined in the same way as sacred trees but with little difference. Sacred, taboo and fetish are almost synonymous. The location determines the name. For example, Bobo, Marka, and Mossi all designated *Celtis toka* as a sacred, fetish, and taboo species, which all refer to cultural and customary activities. The term fetish was used by the Bozo culture because it worships *Celtis toka* as its God. As for the Dafi people, they use the term taboo because in this culture it is forbidden to pass under the species or to point at it. Mystics are evil spirits, demons, and genies who have haunted the species for centuries. Magic is the power that the species (plant parts) must be used to solve problems. For instance, the presence of *Celtis toka* bark or roots in the pirogue protects fishermen/women from ferocious water animal attacks, particularly hippopotami in rivers. Furthermore, a *Celtis toka* plant parts hung in the entrance of a house could protect it from wizards and witches. The ability of *Celtis toka* to cure evil spirit diseases is referred to as medico-magic.

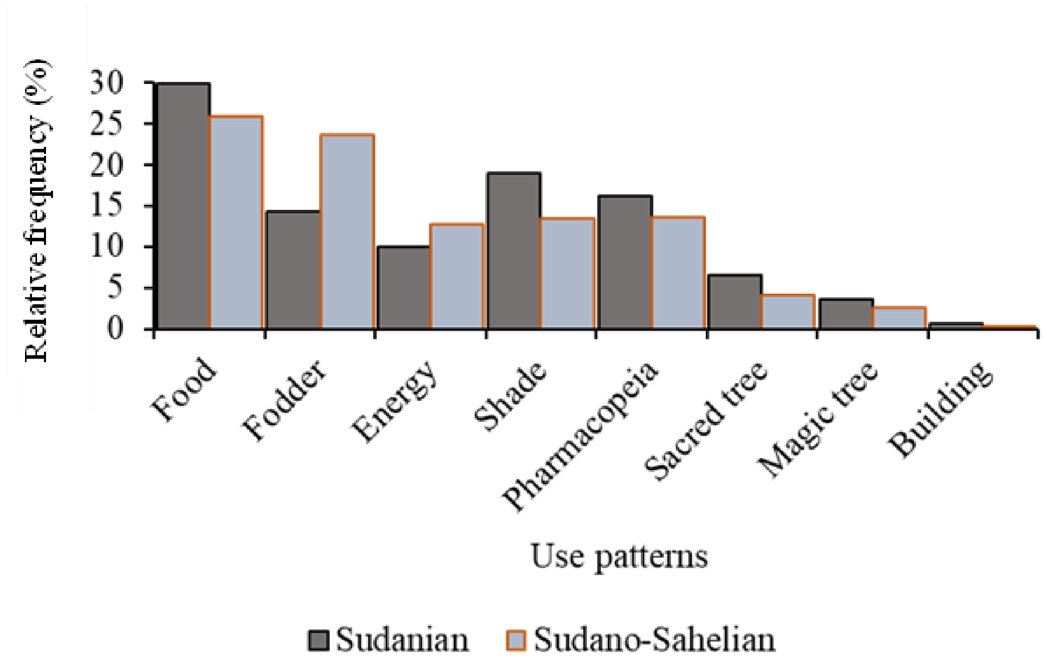

Figure 8: Use patterns of *Celtis toka* by climatic zones

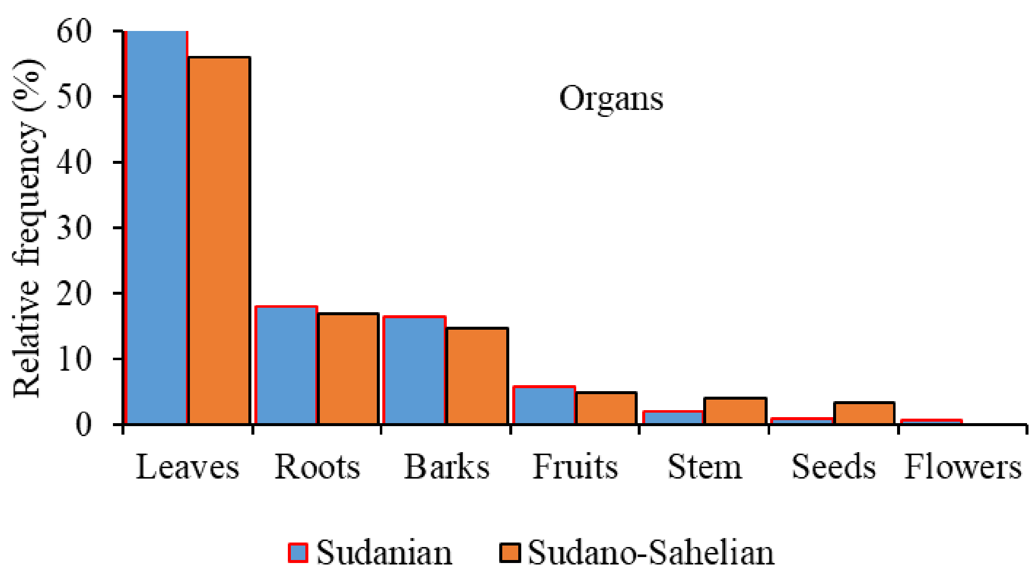

Figure 9: Use report of harvested plant parts in the study sites

Table 11: Variation of local knowledge of *Celtis toka* in the Sudanian climatic zone

Criteria /Patterns	**Variants**	**Bobo (n= 145)**		**Bozo (n=17)**		**Dioula (n=21)**		**Others (n=20)**	
		F	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**
Motivation for conservation	Multiuse tree	61	**42.07**	11	**64.71**	18	**85.71**	11	**55**
	Magic tree	14	9.66	4	23.53	0	0	2	10
	Sacred tree	60	**41.38**	9	**52.94**	3	14.29	4	20
	Agroforest tree	26	17.93	14	**82.35**	4	19.05	4	20
	Shade	29	20	2	11.76	14	**66.67**	9	**45**
	Rare	2	1.38	4	**23.53**	1	4.76	3	15
	ΣF	192	-	44	-	40	-	33	-
Use patterns	Food	143	**98.62**	16	**94.12**	12	**57.14**	19	**95**
	Fodder	120	**82.76**	11	**64.71**	15	**71.43**	18	**90**
	Energy	51	**35.17**	5	29.41	8	**38.1**	13	**65**
	Shade	78	**53.79**	12	**70.59**	17	**80.95**	16	**80**
	Pharmacopeia	57	**39.31**	5	29.41	6	**28.57**	20	**100**
	Sacred tree	60	**41.38**	9	52.94	3	14.29	4	20
	Magic	14	9.66	4	**23.53**	0	0	2	10
	Building	4	2.76	0	0	0	0	0	0
	ΣF	527	-	62		61	-	92	-

n: number of informants per ethnolinguistic groups, F: frequency, FL: fidelity level, ΣF: sum of frequency per ethnolinguistic group, Bold values: FL>20%, unbold value: FL<20%

Table 12: Variation of local knowledge of *Celtis toka* in the Sudano-Sahelian climatic zone

Criteria /Patterns	**Variants**	**Bobo (n=28)**		**Bwaba (n=64)**		**Dafing (n=47)**		**Mossi (n =37)**		**Others(n=26)**	
		F	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**
Motivation for conservation	Multiuse tree	3	10.7	17	**26.6**	15	**32**	24	**64.86**	20	**76.92**
	Magic tree	1	3.57	14	**21.9**	8	17	6	**16.22**	6	**23.08**
	Sacred tree	1	3.57	5	7.81	7	**15**	10	**27.03**	11	**42.31**
	Agroforest tree	11	**39.3**	1	1.56	22	**47**	24	**64.86**	10	**38.46**
	Shade	1	3.57	9	14.1	3	6.4	23	**62.16**	11	**42.31**
	Rare	2	7.14	21	**32.8**	17	**36**	37	**100**	15	**57.69**
	ΣF	19	-	67	-	72	-	124	-	73	-
Use patterns	Food	28	**100**	64	**100**	45	96	4	**10.81**	2	8
	Fodder	5	17.9	64	**100**	33	70	37	**100**	26	**100**
	Energy	1	3.57	47	**73.4**	18	38	24	**64.86**	11	**42.31**
	Shade	1	3.57	34	**53.1**	22	47	16	**43.24**	9	**34.62**
	Pharmacopeia	2	7.14	17	**26.6**	15	32	22	**59.46**	5	19.23
	Sacred tree	1	3.57	5	7.81	16	**34**	10	**27.03**	11	**42.31**
	Magic	1	3.57	14	**21.9**	8	17	6	16.22	**6**	**23.08**
	Building	0	0	1	1.56	0	0	1	2.7	**1**	3.85
	ΣF	39	-	246	-	157	-	120	-	71	-

n: number of informants per ethnolinguistic groups, F: frequency, FL: fidelity level, ΣF: sum of frequency per ethnolinguistic group, Bold values: FL>20%, unbold value: FL<20%

Table 13: Results of GLMs testing for differences in overall use value.

Motivation of conservation	**CZ**	**Ethnolinguistic groups (Eg)**	**Sex (S)**	**Generation (G)**	**CZ x Eg**	**E x S**	**G x S**
Agroforest tree	0.138	0.4464	0.6258	0.3509	0.0984	0.6499	0.672
Magic tree	0.364	0.803	0.717	0.41	0.435	0.374	0.203
Multiuse species	0.34849	0.77754	0.35637	0.8574	0.0592	**0.00476**	0.5796
Rare	0.913	0.94	0.979	0.422	0.83	0.989	0.654
Sacred tree	0.766	0.164	0.345	0.609	0.773	**0.03**	0.51
Shade	0.898	0.263	0.338	0.923	0.123	0.178	0.612

Bold values: $p < 0.05$. Unbold values: $p > 0.05$. Results are broken down by climatic zones, sociocultural groups, sex, and generation

Figure 10: Use categories of *Celtis toka* in Burkina Faso
Pictures: Z. DABRE, 2020 (g), 2021(a, b, c, d, h) and 2022 (f).

Dried leaves of *Celtis toka* for family stew purposes in Sudanian climatic zone (a) and Sudano-Sahelian climatic zone (b); sweet stew cooked with *Celtis toka* pounded dried young leaves and made into powder and taken along with tô in Sudanian climatic zone (c); powder of dried young leaves for trade in villages of Sudano-Sahelian climatic zone (d and e): a bottle of tomato paste (A) was 500 francs CFA and small bottle (B) was 100 francs CFA. Fruits were pounded and seeds (f) were removed from the hull and eaten by children in the Sudano-Sahelian climatic zone. Firewood in both climate zones (g) and charcoal (h) in the Sudanian climatic zone. The promotion and enhancement of *Celtis toka* may provide significant socioeconomic benefits to local communities mainly women.

3.1.2. Impact of sociodemographic factors on the use of *Celtis toka*

3.1.2.1. Diversity and distribution of knowledge according to socio-professional groups

Diversity and distribution of knowledge of different socio-professional groups on the use of *Celtis toka* were not homogeneous (Table 17). However, in both climatic zones, farmers (use diversity: 0.51; use equitability: 1) have a perfect distribution knowledge of the use of *Celtis toka* as food, followed by farmers and traders (in Sudanian climatic zone; use diversity: 0.04; use equitability: 0.23), farmers and blacksmiths (in Sudano-Sahelian climatic zone; use diversity: 0.22; use equitability: 0.43), farmers and finally breeders; and farmers and traditional healers (use diversity: 0.03; use equitability: 0.06). Agriculture, trade, blacksmithing, breeding, and traditional medicine were all activities that had an impact on *Celtis toka* conservation.

3.1.2.2. Effect of sex, age, and ethnolinguistic groups on *Celtis toka* use categories.

Most use patterns were similar among sex, generations, and ethnolinguistic groups ($p > 0.05$). The analysis at the level of uses categories showed that the use of *Celtis toka* for sacred and magic was only dissimilar among sex ($p < 0.05$) in the Sudanian climatic zone. Overall use categories were more important for men than women. In sacred use, for example, men (1.87 ± 0.85) valued the species more than women (1.31 ± 0.63). There is a significant difference in the food use of *Celtis toka* between generations and ethnolinguistic groups ($p < 0.05$) in the Sudano-Sahelian climatic zone. Energy and pharmacopoeia use varied only among ethnolinguistic groups ($p < 0.05$) see Table 18. In the Sudanian climatic zone, the food uses category was more important for Dioula (1.65 ± 0.86), followed by others (1.63 ± 1.02), Bobo (1.59 ± 0.70) and Bozo (1.44 ± 0.63). The food use category was important for Dafing (1.44 ± 0.78) in the Sudano-Sahelian climatic zone, the old generation valued the species for food, sacred and magic use (Table 18).

3.1.3. Effect of sex, age, and ethnolinguistic groups on *Celtis toka* plant parts

Interviewees from various ethnolinguistic groups used most plant parts of *Celtis toka* in different ways. Leaves, roots, and barks (Table 19) were the most used plant parts and leaves were used by all interviewees. Regarding the use of *Celtis toka* plant parts, all plant parts of the species were similar across sex ($p > 0.05$). Therefore, the use of certain plant parts greatly differs among generations, and ethnolinguistic groups ($p < 0.05$).

Table 14: Edible plant parts and recipes of *Celtis toka* in SCZ and SSCZ of Burkina Faso

Plant parts	Recipes	Fidelity Level	
		Sudanian climatic zone (n = 203)	**Sudano-Sahelian climatic zone (n = 202)**
Leaves	Dry fresh leaves of *Celtis toka*, pound and make stew	**67.98**	**49.50**
	Dry fresh leaves of *Celtis toka*, pound and add *Adansonia digitata* powder leaves and make a sweet stew	2.46	-
	Dry fresh leaves of *Celtis toka* pound by mixing with shea butter and make a sweet stew	4.43	0.99
	Dry fresh leaves of *Celtis toka* in the shed, pound and make sweet stew	3.45	2.48
	Dry fresh leaves of *Celtis toka* in the shed, pound by mixing with shea butter and make a sweet stew	**41.38**	3.96
	Dry fresh leaves of *Celtis toka* in the shed, pound by mixing with shea butter add *Adansonia digitata* powder leaves and make a sweet stew	5.91	-
	Dry fresh leaves of *Celtis toka* in the shed, pound, add groundnut paste and make a sweet stew	2.96	-
Fruits	Lick raw ripened fruits	**20.20**	**15.35**
	Lick either fresh or dried ripened fruits	0.99	-
Seeds	Chew dried seeds		0.18
	Chew raw seeds from the dried ripened fruits by breaking the hull	2.46	**14.36**

n: number of informants per climatic zone. The stew should be spiced with ingredients such as locus beans, Maggie, fish, meat, salt, and some other vegetables. Bold values: fidelity levels that were shown to be more important.

Table 15: Plant parts, diseases, and recipes of *Celtis toka* in the Sudanian climatic zone and the Sudano-Sahelian climatic zone of Burkina Faso

Plant parts	Diseases treated	Recipes	Fidelity Level	
			Sudanian climatic zone (n=203)	**Sudano-Sahelin climatic zone (n=202)**
Barks	Diabetes	The decoction of barks is taken as a drink.	0.99	-
	Fungal infection/mycosis (Disease that attacks newborn baby's anus)	The decoction of barks is used to wash the newborn baby's anus and get him/her to drink later.	0.99	-
	Old wound	The decoction of barks is used to wash the old wound and the powder of the barks is used to apply the wound	**1.48**	-
	Backache	-	-	0.65
	Body ache	The decoction of the bark is used to wash the body and drink.	-	0.65
	Eyes ache	The decoction of the bark is used to wash the eyes	-	**1.3**
	Several diseases	The decoction of barks is used to bathe and drink.	-	0.65
	Hemorrhoids	-	-	0.65
	Madness	-	-	0.65
	Malaria	-	-	0.65
	Cast (disease mystically	Powder of the barks added into the charcoal breach and covered	-	**5.84**

	transmitted by humans and evil spirits)	themselves with a blanket to get its smoke.		
	Tiredness	The decoction of the barks is taken as a drink	-	0.65
Inflorescence /flowers	Chest ache	Drink the powder of the flowers added into chilled water	0.99	-
	Malaria	-	**1.48**	-
Fruits	Old wound	The decoction of the fruits is served as a drink and powered fruits are applied to the old wound	0.49	-
	Measles and chickenpox	Powder fruits put into porridge are served as a drink	0.49	-
	Vitamin	lick either fresh or dried fruits	0.99	-
Seeds	Vitamin	Chew dried seeds		0.18
	Chest ache	Powder seeds were added to chilled water and applied to the chest	**1.97**	-
	Diarrhea	Pounded seeds added to salt and licked	0.99	-
Leaves/ leafy branches	Breast ache	Pounded leaves, pressed, and applied the juice on the breast of a new-born mother	-	0.18
	Yellow fever	The decoction of leaves is drunk as a drink	-	**2.6**
	Body ache	Sweet stew made with dried powder leaves added to shea butter, locust beans, salt, Maggie (Cube Jumbo), fish or meat and other vegetables	-	0.65
	Malaria	-	0.49	-
	Baby sicknesses	The decoction of the leaves / leafy	0.49	-

	branches is taken as a drink and later bath the baby with		
Eyes ache	The decoction of the leaves / leafy branches is used to wash the eyes	**1.48**	-
Fungal infection/mycosis	The decoction of the leaves / leafy branches is used to wash the newborn baby's anus and get him/her to drink it.	0.4	-
Malaria	Powder-dried leaves are added to water, or their decoction is drunk and washed. Sweet stew made with the young powder leaves added to groundnut paste, locust beans, fish or meat, Maggie and other vegetables is taken as porridge only or taken with tô. Otherwise, self-covered with the decoction is used	2.96	**8.44**
Appetite	Infusion of leaves / leafy branches added to Dolo (local beer made with red sorghum) or any other drink and drink	0.18	
Old wound	Pressed fresh leaves, remove the juice, and apply it to it	0.4	**1.3**
Measles and chickenpox	A stew cooked with fresh powder leaves added to shea butter is served as a drink (2 or 3 times /day) until the patient gets healed. The leftover from the previous day's stew is thrown away. Otherwise, a decoction of	0.99	-

		leaves is drunk and washed.		
	Vitamin	Sweet stew made with dried fresh (young) powder leaves added to peanut paste, locust beans, salt, Maggie, fish, or meat. Or sweet stew made with the young powder leaves added to locust beans, fish or meat and Maggie. Otherwise, a sweet stew made with the young powder leaves added to *Adansonia digitata powder* leaves, locust beans, fish or meat and Maggie. Or Sweet stew made with dried powder leaves added to shea butter, locust beans, salt, Maggie, fish or meat, salt, and other vegetables. These sweet stews are taken either with tô (traditional food made based on corn or millet flour in Burkina Faso) or other foods.	**10.84**	7.14
Roots	Diarrhoea	Decoction of the leaves is taken as a drink.	-	**1.3**
	Several diseases	Decoction of the leaves is used to bath.	-	0.65
	Hemorrhoids	-	-	0.65
	Madness	-	-	**3.25**
	Malaria	-	-	0.65
	Ringworm	Roots burnt and added to shea butter and applied to the ringworm; later make decoction and drink	-	**1.3**
	Tiredness	The decoction of roots is served as a	-	0.65

		drunk		
	Backache	The decoction of *Celtis toka* roots added to other roots of plants is bathed.	**1.48**	-
	Fungal infection/mycosis	The decoction of roots is used to wash the newborn baby's anus and get him/her to drink.	0.99	-
	Blood pressure	The decoction of the roots is drunk as a drink	0.99	-
	Toothache	The decoction of roots is kept in the mouth for a few minutes	**1.48**	-
	Measles and chickenpox	Dried powder roots are mixed with shea butter and applied to the body	0.99	-
	Old wound /Wound	Powder roots are applied to the wounds of humans and animals to heal them.	0.49	1.62
Roots and Leaves / leafy branches	Fever	Roots and leaves / leafy branches are boiled, drunk and having a shower with	-	**2.6**
Roots and barks	Ulcer	Dried powder roots and bark are put into porridge and drunk. Otherwise, the decoction is served as a drunk by the means of calabash	**1.97**	0.65
Any plant parts	Measles and chickenpox	The decoction of any plant parts of *Celtis toka* is purged.	**-**	0.18

n: number of interviewees per climatic zone. Values in bold: fidelity levels that were shown to be more important.

Table 16: Relative frequencies of the mystical character of *Celtis toka*

Climatic zones	Sacred	Taboo	Mystic	Magic	Medico-magic	Fetish	Total
SCZ	**43.42**	**31.91**	7.78	7.39	2.49	7.01	100
SSCZ	**32.55**	18.18	**15.46**	**13.16**	**9.74**	**10.91**	100

CZ : climatic zones, SCZ : Sudanian climatic zone. SSCZ: Sudano-Sahelian climatic zone. Bold values are values that were shown to be more important.

Table 17: Use diversity and equitability according to the knowledge of socio-professional groups on *Celtis toka*

CZ	Activities	Fo	P	Mt	St	F	B	E	Sh
		Use Diversity							
SCZ	Farmers	**0.16**	0.07	0.02	0.03	0.07	0.00	0.09	0.09
	Farmers and Blacksmith	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Breeders	**0.03**	0.02	0.00	0.01	0.01	0.00	0.02	0.02
	Fishermen/Women	0.02	0.00	0.00	0.01	0.01	0.00	0.01	0.00
	Forest Managers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Hand workers	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Farmers and Housemaids	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00
	Farmers and Hunter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Mechanic	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
	Farmers and Orchard Owner	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Trader	**0.04**	0.01	0.00	0.00	0.02	0.00	0.02	0.02
	Farmers and Traditional healers	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Watchmen	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
SSCZ	Farmers	**0.51**	0.23	0.05	0.11	0.23	0.03	0.30	0.29
	Farmers and Blacksmith	**0.22**	0.05	0.08	0.05	0.16	0.00	0.10	0.09
	Farmers and Breeders	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fisherman/woman	0.02	0.01	0.01	0.00	0.02	0.00	0.01	0.02

	Forest Managers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Hand workers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Housemaids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Hunters	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Mechanics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Orchard Owner	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Traders	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Traditional healers	**0.03**	0.01	0.01	0.01	0.02	0.00	0.01	0.02
	Farmers and Watchmen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Use Equitability							
SCZ	Farmers	**1.00**	0.46	0.10	0.20	0.43	0.03	0.57	0.58
	Farmers and Blacksmiths	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.01
	Farmers and Breeders	**0.18**	0.10	0.02	0.04	0.07	0.02	0.09	0.11
	Fishermen/women	0.10	0.02	0.02	0.06	0.06	0.00	0.06	0.01
	Forest Managers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Hand workers	0.09	0.02	0.00	0.01	0.03	0.00	0.04	0.08
	Farmers and Housemaids	0.06	0.01	0.00	0.01	0.04	0.00	0.05	0.01
	Farmers and Hunters	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00
	Farmers and Mechanics	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.05
	Farmers and Orchard Owners	0.04	0.02	0.01	0.01	0.01	0.00	0.02	0.01
	Farmers and Traders	**0.23**	0.08	0.00	0.01	0.11	0.01	0.12	0.10
	Farmers and Traditional healers	0.04	0.04	0.01	0.02	0.02	0.00	0.03	0.02
	Farmers and Watchmen	0.06	0.04	0.00	0.00	0.02	0.00	0.02	0.03
SSCZ	Farmers	**1.00**	0.46	0.10	0.21	0.45	0.05	0.58	0.56
	Farmers and Blacksmiths	**0.43**	0.10	0.16	0.10	0.32	0.01	0.20	0.17
	Farmers and Breeders	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fishermen /women	0.04	0.02	0.01	0.01	0.03	0.00	0.03	0.03
	Forest Managers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Hand workers	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	Farmers and Housemaids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farmers and Hunters	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Farmers and Mechanics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Farmers and Orchard Owners	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Farmers and Traders	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.01
Farmers and Traditional healers	**0.06**	0.01	0.02	0.02	0.05	0.00	0.02	0.03
Farmers and Watchmen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CZ: climatic zones, SCZ: Sudanian climatic zone, SSCZ: Sudano-Sahelian climatic zone, Fo: Food, P: Pharmacopeia, Mt: Magic tree, St: Sacred tree, F: Fodder, B: Building, E: Energy and Sh: Shade. Bold values are values which been demonstrated to be more important.

Table 18: Sociodemographic parameters effect on the use categories of *Celtis toka* in Burkina Faso

CZ		n	Food	Fodder	Energy	Building	Shade	Pharmacopeia	Sacred tree	Magic tree
	Ethnolinguistic groups									
SCZ	Bobo	145	1.59 ± 0.70	1.86 ± 0.76	1.60 ± 0.70	1.75 ± 0.5	1.69 ± 0.73	2.04 ± 0.71	1.65 ± 0.69	1.55 ± 0.68
	Bozo	17	1.44 ± 0.63	1.5 ± 0.76	1.63 ± 0.74	-	2 ± 0	2 ± 0.71	1.36 ± 0.67	1.60 ± 0.64
	Dioula	21	1.65 ± 0.86	1.67 ± 1	1.44 ± 0.88	-	1.55 ± 0.82	2 ± 0.89	2 ± 0	2 ± 0
	Others	20	1.63 ± 1.02	1.69 ± 1.11	1.69 ± 1.11	-	1.89 ± 1.27	1.91 ± 1.14	2.75 ± 1.5	1.76 ± 1.40
	Kruskal-Walli's test		0.8333	0.3622	0.7833	-	0.6991	0.792	0.1589	0.1395
SSCZ	Bobo	28	1 ± 0	1 ± 0	1 ± 0	0 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0
	Bwaba	64	1.26 ± 0.51	1.26 ± 0.51	1.24 ± 0.52	0 ± 0	1.24 ± 0.49	1.94 ± 0.54	1.36 ± 0.54	1.17 ± 0.42
	Dafing	47	1.44 ± 0.78	1.36 ± 0.70	1.89 ± 0.90	0 ± 0	1.73 ± 0.88	2.44 ± 0.73	1.94 ± 0.90	1.87 ± 0.86
	Mossi	37	1.36 ± 0.6	1.72 ± 1.5	1.32 ± 0.75	1.2 ± 0	1.4 ± 0.55	3.15 ± 1.89	2 ± 1.41	2 ± 1
	Others	26	1.15 ± 0.63	1.82 ± 1.54	1.43 ± 0.79	1 ± 0	1.5 ± 0.76	3.25 ± 1.89	2 ± 1.32	1.31± 0.56
	Kruskal-Walli's test		**0.02837**	0.3889	**0.01699**	NA	0.1321	**0.01337**	0.0817	0.0601
	Generation									
SCZ	Old	108	1.52 ± 0.74	1.68 ± 0.88	1.60 ± 0.81	2 ± 0	1.70 ± 0.79	2.09 ± 0.82	1.81 ± 0.61	1.8 ± 0.91
	adult	95	1.67 ± 0.73	1.88 ± 0.79	1.64 ± 0.72	1.67 ± 0.58	1.73 ± 0.79	2 ± 0.77	1.59 ± 0.69	1.46 ± 0.87
	Mann-Whitney test		0.108	0.1562	0.6208	1	0.891	0.7058	0.4997	0.307
SSCZ	Old	83	1.37 ± 0.66	1.38 ± 0.64	1.46 ± 0.70	1 ± 0	1.48 ± 0.69	2 ± 0.72	1.61 ± 0.74	1.59 ± 0.73
	Adult	119	1.17 ± 0.49	1.24 ± 0.76	1.29 ± 0.65	0 ± 0	1.31 ± 0.67	2.46 ± 1.27	1.4 ± 0.71	1.31 ± 0.64
	Mann-Whitney test		**0.02455**	0.05651	0.1723	NA	0.1554	0.3103	0.2262	0.1906
	Sex									
SCZ	Women	91	1.51 ± 0.67	1.71 ± 0.78	1.62 ± 0.76	1.5 ± 0	1.67 ± 0.74	2.03 ± 0.78	1.31 ± 0.63	1.23 ± 0.79
	Men	112	1.67 ± 0.76	1.86 ± 0.89	1.63 ± 0.79	1.67 ± 0.58	1.75 ± 0.82	2.03 ± 0.78	1.87 ± 0.85	1.65 ± 0.89

	Mann-Whitney test		0.1134	0.4813	0.9874	1	0.697	0.8548	**0.02163**	**0.0264**
SSCZ	Women	55	1.13 ± 0.41	1.33 ± 1.04	1.28 ± 0.57	0 ± 0	1.23 ± 0.53	3 ± 1.73	1.29 ± 0.59	1.17 ± 0.68
	Men	147	1.3 ± 0.61	1.29 ± 0.57	1.4 ± 0.71	1 ± 0	1.47 ± 0.74	2.03 ± 0.74	1.61 ± 0.77	1.54 ± 0.75
	Mann-Whitney test		0.1074	0.4079	0.6057		0.2003	0.2207	0.135	0.123

CZ: climatic zones, SCZ: Sudanian climatic zone, SSCZ: Sudano-Sahelian climatic zone, M: Men, W: Women, bold values: *p*-value < 0.05, unbold values: *p* > 0.05

The fruits, roots and flowers use differ significantly across ethnolinguistic groups ($p < 0.05$). Thus, leaf use is highly varied in both climatic zones ($p < 0.05$). Leaves were more scored by Dioula (1.79 ± 0.85), followed by others (1.53 ± 1.06), Bobo (1.42 ± 0.68) and Bozo (1.31 ± 0.48) in the Sudanian climatic zone. Concerning the Sudano-Sahelian climatic zone, leaves were more scored by Dafing (1.43 ± 0.77) in the Sudano-Sahelian climatic zone. Men used more leaves than women in both climatic zones. Seeds were more recorded by women (1.67 ± 2.66) in the Sudano-Sahelian climatic zone (Table 19).

3.1.4. Traditional perception of occurrence habitats, management practices and the attitudes of informants to maintain and conserve *Celtis toka*

3.1.4.1. Local perception of occurrence habitats of *Celtis toka*

The species was reported to be present in both protected areas mainly gallery forests (rivers and streams (27%)) and communal areas (rocky areas/ rocky hills (11%), sacred forests (39%), farmlands (19%) and fallows (3%)). In the Sudanian climatic zone, *Celtis toka* could be found either at the top, slope, or bottom of rocky areas. *Celtis toka* was mentioned in almost all land use types in both climatic zones (Table 20 and Table 21). The species was scarce in fallows in the Sudanian climatic zone. Local knowledge of the habitat of the species varied significantly across ethnolinguistic groups ($p < 0.05$) in both climatic zones. However, there was no significant difference between sex and generation ($p > 0.05$) see Table 22. It was reported by some Bobo and Bwaba respondents in the Sudanian climatic zone that *Celtis toka* only appeared in old compounds (where ancestors lived before).

3.1.4.2. Traditional propagation and current management practices for *Celtis toka* conservation

No regeneration practice (Assisted tree regeneration, sapling transplantation and sowing) was recorded by interviewees during the survey. Management such as collective, individual, and state was recorded in both climatic zones. Moreover, *Celtis tota* individual trees were not protected from fire and animal grazing in both climatic zones (Table 20 and Table 21). Pruning was chiefly experienced by most traditional cattle breeders and farmers. Farmers for instance, often pruned branches to decrease the shade effect on yields.

Table 19: Effect of sociodemographic parameters on the mean frequencies (± SD) of *Celtis toka* plant parts used in Burkina Faso.

CZ	Variable	n	Leaves	Roots	Barks	Fruits	Stem	Seeds	Flowers
	Ethnolinguistic groups								
SCZ	Bobo	145	1.42 ± 0.68	1.13 ± 0.41	1.19 ± 0.41	2.4 ± 0.47	1.60 ± 0.87	2.4 ± 1.58	1 ± 0
	Bozo	17	1.31 ± 0.48	1 ± 0	1 ± 0	1 ± 0	1.63 ± 0.74	1.41 ± 0	0 ± 0
	Dioula	21	1.79 ± 0.85	1 ± 0	1 ± 0	1 ± 0	1.62 ± 0.50	1.03 ± 0	1 ± 0
	Others	20	1.53 ± 1.06	1.2 ± 1.5	1 ± 0	1.59 ± 1.5	1.69 ± 0.58	0 ± 0	0 ± 0
	Kruskal Wallis test		0.2122	0.586	0.4356	**0.00468**	0.9849	0.2369	NA
SSCZ	Bobo	28	1 ± 0	1 ±0	1 ± 0	0 ± 0	1 ± 0	0 ± 0	0 ± 0
	Bwaba	64	1.21 ± 0.45	1.17 ± 0	1 ± 0	0 ± 0	1.17 ± 0.43	1 ± 0	0 ± 0
	Dafing	47	1.43 ± 0.77	1.69 ± 0	1.38 ± 0.77	2 ± 0	1.94 ± 0.93	0 ± 0	0 ± 0
	Mossi	37	1.20 ± 0.62	1.33 ± 0	1.23 ± 0.48	1 ± 0	1.2 ± 0.61	0 ± 0	1.18 ± 0
	Others	26	1.33 ± 0.62	1.33 ± 0	1.33 ± 0.58	1 ± 0	1.43 ± 0.79	0 ± 0	1.05 ± 0
	Kruskal Wallis test		0.08659	**0.01664**	0.3927	0.1784	**0.00363**	0.2369	**0.01111**
	Generation								
SCZ	Old	108	1.37 ± 0.70	1.08 ± 0.28	1.10 ± 0.30	1.35 ± 0.89	1.6 ± 0.81		1 ± 0
	Adult	95	1.55 ± 0.74	1.13 ± 0.42	1.15 ± 0.46	1.17 ± 0.38	1.64 ± 0.72	0 ± 0	1 ± 0
	Mann-Whitney test		**0.03737**	0.8802	0.8445	0.9701	0.5701	NA	NA

	Old	83	1.17 ± 0.48	1.43 ± 0.74	1.06 ± 0.24	1 ± 0	1.45 ± 0.71	1.25 ± 0.71	-
SSCZ	Adult	109	1.38 ± 0.67	1.45 ± 0.82	1.56 ± 0.88	1 ± 0	1.29 ± 0.65	1.58 ± 2.54	1.23 ± 0
	Mann-Whitney test		**0.01556**	1	0.06483	NA	0.1982	0.6421	NA
	Sex								
SCZ	Women	91	1.37 ± 0.67	1.05 ± 0.23	1.06 ± 0.25	1.13 ± 0.5	1.62 ± 0.76	-	1 ± 0
	Men	112	1.52 ± 0.76	1.22 ± 0.55	1.25 ± 0.58	1.35 ± 0.83	1.62 ± 0.78	-	1 ± 0
	Mann-Whitney test		0.1067	0.161	0.1797	0.2126	0.9553	NA	NA
SSCZ	Women	55	1.12 ± 0.40	1.25 ± 0.5	1.33 ± 0.58	1 ± 0	1.29 ± 0.59	1.67 ± 2.66	1.27 ± 0
	Men	147	1.3 ± 0.62	1.46 ± 0.79	1.22 ± 0.60	1 ± 0	1.39 ± 0.71	1.02 ± 1.15	-
	Mann-Whitney test		0.07848	0.7729	0.4818	NA	0.7568	0.1988	NA

NA: Not available, bold values: $p < 0.05$, unbold values: $p > 0.05$

Table 20: Variation in local knowledge of *Celtis toka* in the Sudanian climatic zone

Criteria/ Patterns	**Variant**	**Bobo (n= 145)**		**Bozo (n=17)**		**Dioula (n=21)**		**Others (n=20)**	
		F	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**
Habitat	Rocky hills	15	10.34	0	0	5	**23.81**	2	10
	Sacred forests	63	**43.45**	0	0	5	14.29	2	10
	Protected areas	20	13.79	0	0	3	4.76	4	20
	Galleries / Part lands	46	**31.72**	17	100	1	**61.90**	21	100
	Fallows	0	0		0	13	0	0	0
	ΣF	129	-	17	-	22	-	27	-
Propagation and regeneration practices	Non-assisted tree regeneration	145	**100**	15	**88.24**	19	**90.48**	20	**100**
	Assisted tree regeneration	0	0	0	0	0	0	0	0
	Sowing	0	0	0	0	0	0	0	0
	Transplantation	0	0	0	0	0	0	0	0
	ΣF	145	-	15	-	19	-	20	-
Current management of the species	State	16	11.03	2	11.76		0	1	5
	Individual	35	**24.14**	2	11.76	4	19.05	0	0
	Collective	80	**55.17**	5	**29.41**	15	**71.43**	10	**50**
	Pruning	49	**33.79**	8	**47.06**	13	**61.90**	14	70
	Fire protection	0	0	0	0	0	0	0	0
	Grazing Protection	0	0	0	0	0	0	0	0
	ΣF	214	-	21	-	39	-	29	-

n: number of informants per ethnolinguistic group, F: frequency, ΣF: sum of frequency per ethnolinguistic group, FL: fidelity level. Bold values: FL>20%, unbold value: FL<20%

Table 21: Variation in local knowledge of *Celtis toka* in the Sudano-Sahelian climatic zone

Criteria/ Patterns	**Variant**	**Bobo (n=28)**		**Bwaba (n=64)**		**Dafing (n=47)**		**Mossi (n =37)**		**Others (n=26)**	
		F	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**	**F**	**FL (%)**
Habitat	Rocky hills	0	0	0	0	0	0	0	0	8	**30.77**
	Sacred forests	0	0	0	0	3	6.38	10	27.03	0	0.00
	Protected areas	1	3.57	0	0	20	42.55	11	29.73	3	11.54
	Galleries / Part lands	27	**96.43**	58	**90.63**	24	**51.06**	37	**100**	12	**46.15**
	Fallows		0	6	9.38		0	3	8.11	0	0.00
	ΣF	28	-	64	-	47	-	61	-	23	-
Propagation and regeneration practices	Non-assisted tree regeneration	28	**100**	61	**95.31**	47	**100**	37	**100**	26	**100**
	Assisted tree regeneration	0	0	0	0	0	0	0	0	0	0
	Sowing	0	0	0	0	0	0	0	0	0	0
	Transplantation	0	0	0	0	0	0	0	0	0	0
	ΣF	28	-	61	-	47	-		0	14	-
Current management of the species	State	0	0	2	3.125	1	2.13	0	0	0	0
	Individual	0	0	4	6.25		0	3	8.11	4	0
	Collective	28	**100**	44	**68.75**	46	**97.87**	18	**48.65**	15	**100**
	Pruning	4	14.29	62	**96.88**	32	**68.09**	19	**51.35**	11	**73.33**
	Fire protection	0	0	0	0	0	0	0	0	0	0
	Grazing Protection	0	0	0	0	0	0	0	0	0	0
	ΣF	32	-	124	-	91	-	49	-	**47**	-

n: number of informants per ethnolinguistic group, F: frequency, ΣF: sum of frequency per ethnolinguistic group, FL: fidelity level. Bold values: FL>20%, unbold value: FL<20

Table 22: Results of GLMs testing for differences in overall use value between climatic zones, sociocultural groups, sex, and age

Indigenous Knowledge	**Variables**	**Estimate**	**Std. Error**	**t value**	**Pr (>|t|)**
Biotopes	(Intercept)	-1.797124	0.315952	-5.688	< 0.0000
	Climate	-0.192799	0.130602	-1.476	0.1399
	Ethnolinguistic groups	0.090209	0.035119	2.569	**0.0102**
	Sex	-0.00524	0.111776	-0.047	0.9626
	Age	-0.001295	0.111108	-0.012	0.9907
Propagation and regeneration practices	(Intercept)	-1.38617	0.315677	-4.391	< 0.0000
	Climate	0.001506	0.157493	0.01	0.992
	ethnolinguistic groups	-0.00011	0.037343	-0.003	0.998
	Sex	0.000837	0.111999	0.007	0.994
	Age	-0.00161	0.11235	-0.014	0.989
Current Management	(Intercept)	-1.86E+00	2.53E-01	-7.338	< 0.0000
	Climate	-3.27E-02	1.35E-01	-0.242	0.8087
	Ethnolinguistic groups	6.20E-02	2.93E-02	2.112	**0.0347**
	Sex	8.49E-02	8.97E-02	0.946	0.3443
	Generations	6.74E-02	8.83E-02	0.764	0.445

Bold values: $p < 0.05$, unbold values: $p > 0.05$

In addition, to make more space, they sometimes cut down an entire *Celtis toka*. Cattle breeders pruned the species to feed their cattle, and this was more common in the Sudano-Sahelian climatic zone (14.29 < FL < 96.88) than the Sudanian climatic zone (33.79 < FL 70) as indicated in Table 20 and Table 21. The management of *Celtis toka* varied greatly between ethnolinguistic groups ($p < 0.05$) in the study sites. However, this management was similar across climatic zones, generation, and sex ($p > 0.05$) see Table 22. Traditional conservation strategies mentioned by the sociocultural groups were either mystic magic sacred fetish or taboo. However, some respondents have referred to *Celtis toka* as a mystic, magic, fetish, or taboo tree localized principally in sacred areas, some farmlands, and some rocky areas.

In the Sudanian climatic zone, Bozo culture perceived more *Celtis toka* as a sacred tree (FL: 52.94 %) and a magic tree (FL: 23.53%) while Bobo (FL: 40.81%) and Dioula (FL: 12.50%) sociolinguistic groups believed that the species is sacred. In the Sudano-Sahelian climatic zone, the species was perceived as magic by the Bwaba (FL= 21.88%), Dafing (FL = 17.02%) and Mossi (FL = 16.22%) cultures. The sacred aspect, on the other hand, was more perceived by Dafing culture (FL = 34.04%) and Mossi ethnolinguistic groups (FL = 27.03%).

3.1.5. Local perception of the status of *Celtis toka* in Burkina Faso

Overall, 68 % of informants (77.94 % in the Sudanian climatic zone and 58.28 % in the Sudano-Sahelian climatic zone) widely expressed that multiuse species *Celtis toka* was extremely decreasing (Sudanian climatic zone: 41 %< FL< 90 % and the Sudano-Sahelian climatic zone: 52 < FL< 96). Whereby 13 % (14 % in the Sudanian climatic zone and 09 % in the Sudano-Sahelian climatic zone) of people have expressed that the species is stable. In the Sudano-Sahelian climatic zone, around 19 % and 11 % of the interviewees have confirmed respectively that the taboo tree *Celtis toka* was either rare or extinct. However, 4 % of local people (5.88 % in the Sudanian climatic zone and 2.86 % in the Sudano-Sahelian climatic zone) highlighted that the population of the species was increasing (Figure 11, Table 23, and Table 24). As the most surveyed communities, Bobo, Bozo, Dioula, Bwaba, Dafing, Mossi, and Dioula represent the ethnolinguistic groups that perceive the most recent status of *Celtis toka* in the study area. Ethnobotanical knowledge of the state of *Celtis toka* varied greatly across ethnolinguistic groups. However, Dioula (FL: 90 %) and Bobo (FL:62 %) belonging to the Sudanian climatic zone perceived the decline of *Celtis toka*.

Whereas, in the Sudano-Sahelian climatic zone Mossi (FL: 96 %) and Dafing (FL:81 %) believed the decreasing of the species. Respondents in the Sudanian climatic zone with an age above 55 years, stated a more declining status of the species than others. Regarding sex, males (Sudanian climatic zone) and females (Sudano-Sahelian climatic zone) reported more threatened status based on their traditional knowledge when compared to others. The rarity of the species was perceived by Bwaba culture (FL: 42 %) and extinction features of *Celtis toka* were mostly perceived by Mossi (FL: 34 %) and other ethnolinguistic groups (FL: 35 %) in the Sudano-Sahelian climatic zone (Table 23 and Table 24).

GLM analysis reveals that local knowledge of *Celtis toka*'s status varied greatly across ethnolinguistic groups for extinction and stable status, sex for all status levels, and ages for all status levels except the decreasing (p–value < 0.05). Adult and elderly people in both climatic zones had dissimilar perceptions of the declining, scarcity, and extinction aspect of *Celtis toka* (p–value < 0.05) see Table 25.

3.1.6. Local perception of the threat factors of *Celtis toka* in Burkina Faso

According to the respondents, the sustainability of *Celtis toka* is threatened by some unfavourable factors such as anthropogenic and natural. However, 4 % of respondents have reacted that there are no threats to the sustainability of *Celtis toka*. Globally**,** the threat features to *Celtis toka* are pruning (25 %) for food and fodder, climate change (14 %), deforestation (10 %), ageing (10 %), debarking (9 %), agricultural expansion (7 %), bushfires (6 %), and others (6 %) (Figure 12). Others referred to the specific habitat of the species, infertility of soil, production of charcoal, diseases, attacks of parasites, fungi, epiphytes, gall, termites, invasion of *Azadirachta indica*, and *ficus*. In the Sudanian climatic zone, the main causes were pruning (21 %), deforestation (13 %) climate change (13 %), debarking (12 %), bushfire (9 %), ageing (8 %) and agriculture (8%). While in the Sudano-Sahelian climatic zone, pruning (28 %), and climate change (15 %) were the key drivers (Figure 12). Those disturbances affect the survival of the critically endangered species *Celtis toka*. Pruning (FL: 47 %), Climate Change (FL: 18 %), debarking (FL: 12 %), and ageing (FL: 12 %) were emphasized by Bozo; debarking (FL: 75 %) by others in the Sudanian climatic zone. Pruning (FL: 70 %), Climate Change (FL: 32 %), ageing (FL: 28 %) and debarking (FL: 26 %) were heightened by Dafing culture in the Sudano-Sahelian climatic zone (Table 23 and Table

24). Results globally suggested that pruning, climate change, deforestation, ageing, debarking, farming expansion and bushfires are the major factors that are threatening the survival of *Celtis toka* in the study area. Pruning, climate change, and deforestation ranked in the first, second and third places correspondingly, signifying that they are the most proximate threatening factors (Figure 12). In the Sudanian climatic zone, ageing was perceived by Bobo culture; climate change by Bozo culture; debarking, pruning, farming and failure of *Celtis toka* by Dioula culture and finally deforestation and settlement of infrastructures were mentioned by other ethnolinguistic groups as the main predictors of declining of the species. However, in the Sudano-Sahelian climatic zone, deforestation, farming, and pruning were the main causes of the extinction of *Celtis toka* quoted by Mossi. Dafing culture believed that *Celtis toka* is threatened due to climate change and humans (bushfires). According to Bwaba culture, overgrazing and debarking are the key reasons for the threat in the study area (Table 26 and Table 27). In both climatic zones, older people emphasized that the species have declined due to climate change, farming, ageing, deforestation, settlement of infrastructure, bushfires, failure of *Celtis toka*, pruning and, others (Table 26 and Table 27). The overall threat factors of *Celtis toka* varied only across ethnolinguistic groups for ageing, pruning**, c**limate change**,** farming**,** settlement of infrastructures**,** and lack of regeneration (*p*–value < 0.05). In addition, the threat drivers were statistically similar (*p–value* > 0.05) between sex and generations for deforestation, settlement of infrastructures, lack of regeneration, failure of *Celtis toka* and bushfire (Table 26 and Table 27).

Based on our observation in the field, the threat factor in both climatic zones could be natural (hollow, wind, drought, crown gall, fungi, and epiphyte) as well as anthropogenic effects. However, most of the old trees of *Celtis toka* contain a large hollow (Figure 13 A) which weakens the individuals during wind (Figure 14 I) or fire action (Figure 15 N).

In addition to the hollow, *Celtis toka* has a fibrous root (Figure 15 M) which accentuates the effect of wind. *Ficus thonningii* Blume (Figure 13 B), fungi (Figure 13 C) and crown gall (red round) and hollow (yellow round) (Figure 13 D) infest *Celtis toka* tree species. According to our field observation, the assessment of the threat by climatic zones showed that the Sudanian climatic zone was more exposed than the Sudano-Sahelian climatic zone (even though *Celtis toka* is less abundant in the Sudano-Sahelian climatic zone) due to anthropogenic activities such as artisanal (Figure 14 F), industrial (Figure 14 G) mining and bushfire (Figure 15 N). However, the exploitation of granite affects negatively seed germination and sometimes sapling growth. Some locale people cut (Figure 14 H) *Celtis toka* either for charcoal, firewood, or farming settlement purposes. Epiphyte (Figure 16 O), grazing by goats and cattle, and biological invasion by *Azadirachta indica* (Figure 16 O, 15 M, and 17 P) on *Celtis toka* plant parts or juveniles were noticed in some livelihoods of the study sites. Epiphytes were all over *Celtis toka* tree to the point that it lost its leaves and remains apparently dead.

3.1.7 Traditional potential solutions to the threat

The conservation strategies proposed by the locals included the conservation of *Celtis toka* and its habitat, the sustainable use of *Celtis toka*, and the promotion of education and awareness about *Celtis toka*. However, planting was the most important solution in all ethnolinguistic groups confirmed by the high FL (Sudanian climatic zone: 43%, the Sudano-Sahelian climatic zone: 73%) value in both climatic zones (Table 23 and Table 24). Planting (45 %), conservation of *Celtis toka* and its habitat (27%), sustainable use of *Celtis toka* (14%), promoting education and awareness about *Celtis toka* (10%), tree/ crop association (5%) were the future potential solutions to solve threat's problem of *Celtis toka* in the study area. Moreover, potential solutions in the Sudanian climatic zone were planting (34%), conservation of *Celtis toka* and its habitat (33 %) from human pressure such as cutting, fire, animal grazing and sustainable use of the species (16%) by avoiding overharvesting (pruning, debarking, and overusing the roots). Whereas in the Sudano-Sahelian climatic zone, planting (58%), conservation (19%), and sustainable use (10%) were the key solutions to the threat of the species (Figure 18). In the Sudanian climatic zone, conservation, sustainable use of the species, and planting were cited respectively Bobo, Bozo, and Dioula cultures as potential solutions to the threat of the species.

The chi-square test results of the different responses of informants who were involved in answering whether to plant or not *Celtis toka* shows that there is a significant relationship among the respondents in the study sites (Table 28).

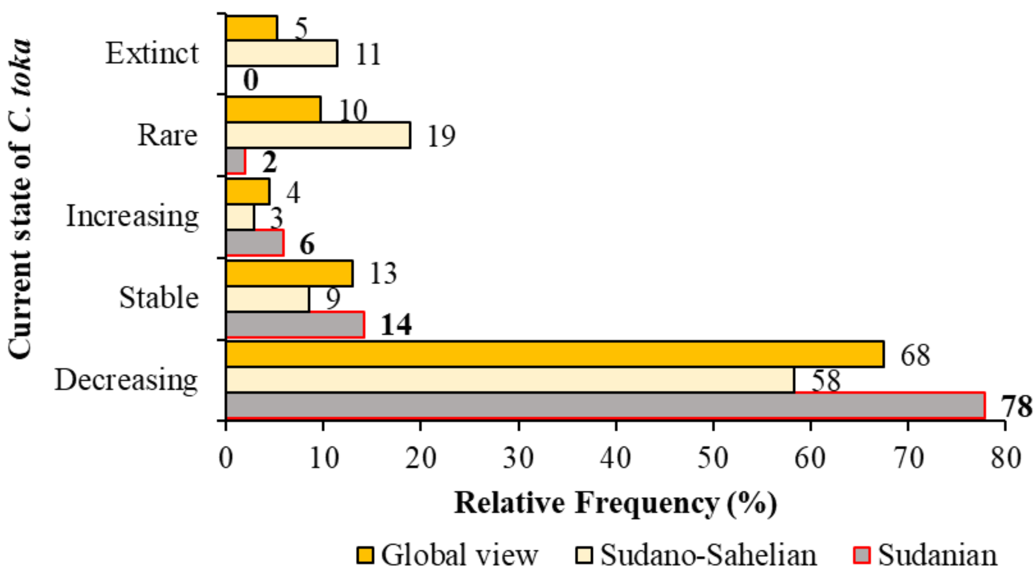

Figure 11**:** Local perception of the current state of sacred species *Celtis toka*

Table 23: Local knowledge of *Celtis toka* in the Sudanian climatic zones of Burkina Faso

Criteria /Patterns	**Variants**	Bobo (n=145)		Bozo (n=17)		Dioula (n=21)		Others (n=20)	
		F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)
Current state of *Celtis toka*	Extinct	0	0	0	0	0	0	0	0
	Rare	2	1	1	6	1	5	1	5
	Decreasing	90	62	7	41	19	90	21	70
	Stable	37	26	6	35	1	5	4	20
	Increasing	10	7	1	6	0	0	1	5
	ΣF	139	-	15	-	21	-	27	-
Threat factors	Pruning	56	39	8	47	13	62	13	65
	Bushfire	20	14	0	0	2	10	1	5
	Ageing	21	15	2	12	2	10	1	5
	Debarking	35	24	2	12	3	14	15	75
	Climate change	23	16	3	18	4	19	3	15
	Deforestation	19	13	1	6	3	14	3	15
	Farming	7	5	2	12	5	24	3	15
	Lack of regeneration	9	6	0	0	0	0	1	5
	Settle of infrastructures	8	6	0	0	1	5	3	15
	Overgrazing	6	4	1	6	0	0	0	0
	others	3	2	1	6	0	0	0	0
	Failure of *Celtis toka*	4	3	1	6	3	14	0	0
	ΣF	211	-	21	-	36	-	43	-
Potential Solutions to the threats	Tree/crop association	9	6	3	18	1	5	1	5
	Planting	38	26	4	24	9	43	4	20
	Conservation of *Celtis toka* and its habitat	47	32	3	18	1	5	0	0
	Sustainable use of *Celtis toka*	22	15	3	18	1	5	0	0
	Promoting education, and awareness about *Celtis toka*	13	9	1	6	0	0	1	5
	ΣF	129	-	14	-	12	-	6	-

Table 24: Local knowledge of *Celtis toka* in the Sudano-Sahelian climatic zones of Burkina Faso

Criteria /Patterns	**Variants**	Bobo (n=28)		Bwaba (n=64)		Dafing (n=47)		Mossi (n=26)		Others (n=26)	
		F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)	F	FL (%)
Current state of *Celtis toka*	Extinct	1	4	13	20	2	4	9	35	9	35
	Rare	2	7	27	42	2	4	8	31	6	23
	Decreasing	15	54	33	52	38	81	25	96	16	62
	Stable	8	29	5	8	5	11	0	0	1	4
	Increasing	3	11	0	0	2	4	0	0	0	0
	ΣF	29	-	78	-	49	-	42	-	32	-
Threat factors	Pruning	4	14	62	97	33	70	6	23	15	58
	Bushfire	1	4	2	3	7	15	0	0	0	0
	Ageing	0	0	13	27	13	28	8	31	7	26
	Debarking	6	21	4	6	12	26	4	15	3	12
	Climate change	2	7	20	31	15	32	5	19	2	8
	Deforestation	2	7	15	23	5	11	9	35	7	27
	Farming	1	4	17	27	4	9	10	38	7	27
	Lack of regeneration	2	7	7	11	4	9	0	0	0	0
	Settle of infrastructures	0	0	12	19	2	4	1	4	1	4
	Overgrazing	0	0	15	23	3	6	1	4	0	0
	others	3	11	5	8	2	4	0	0	0	0
	Failure of *Celtis toka*	0	0	1	2	0	0	0	0	0	0
	ΣF	21	-	173	-	100	-	44	-	42	-
Potential Solutions to the threats	Tree/crop association	0	0	2	3	2	0	2	8	0	0
	Planting	5	18	36	56	2	49	19	73	11	42
	Conservation of *Celtis toka* and its habitat	5	18	8	13	28	58	16	62	5	19
	Sustainable use of *Celtis toka*	3	11	7	11	4	9	2	8	1	4
	Promoting education, and awareness about *Celtis toka*	1	4	11	17	36	2	1	4	1	4
	ΣF	14	-	64	-	72	-	40	-	18	-

Table 25: Impact of socio-demographical factors and climatic zone on the current state of *Celtis toka* through GLMs analysis

CZ	Variables	n	Extinct	Rare	Increasing	Decreasing	Stable
	Ethnolinguistic groups						
	Bobo	145	0 ± 0	0.014 ± 0.12	0.23 ± 0.42	0.47 ± 0.5	0.26 ± 0.44
S	Bozo	17	0 ± 0	0.035 ± 0.22	0.47 ± 2.75	0.92 ± 5.63	0.48 ± 3.08
	Dioula	21	0 ± 0	0.048 ± 0.22	0.51 ± 0.51	1 ± 0.51	0.53 ± 0.22
	Others	20	0 ± 0	0 ± 0	0.3 ± 0.47	0.45 ± 0.51	0.25 ± 0.44
	Bobo	28	0.037 ± 0.19	0.074 ± 0.26	0.088 ± 0.27	0.56 ± 0.50	0.30 ± 0.47
	Bwaba	64	0.20 ± 0.41	0.42 ± 0.50	0.047 ± 0.21	0.47 ± 0.50	0.078 ± 0.27
SS	Dafing	47	0.043 ± 0.20	0.043 ± 0.20	0.064 ± 0.25	0.79 ± 0.41	0.11 ± 0.31
	Mossi	26	0.267 ± 0.46	0.133 ± 0.35	0.067 ± 0.26	0.67 ±0.49	1.333 ± 0.35
	Others	26	0.207 ± 0.46	0.103 ± 0.25	0.067 ± 0.26	0.57 ±0.39	1.303 ± 0.32
	X^2		7.83	2.1	1.15	2.98	6.08
	P- value		0.00468	0.138	0.295	0.0804	0.02
	Sex						
S	Female	91	0 ± 0	0.011 ± 0.11	0.269 ± 0.44	0.314 ± 0.47	0.337 ± 0.47
	Male	112	0 ± 0	0.027 ± 0.16	0.230 ± 0.42	0.566 ± 0.50	0.168 ± 0.38
SS	Female	55	0.15 ± 0.36	0.1 ± 0.30	0.025 ± 0.16	0.7 ± 0.46	0.175 ± 0.38
	Male	147	0.123 ± 0.33	0.254 ± 0.44	0.078 ± 0.27	0.561 ± 0.50	0.114 ± 0.32
	X^2		23.406	39.03	15.41	4.67	10.64
	P- value		0.00028	< 0.0000	0.00022 0.0309		0.00169
	Age						
S	Old	108	0 ± 0	0.020 ± 0.14	0.215 ± 041	0.479 ± 0.50	0.243 ± 0.43
	Adult	95	0 ± 0	0.017 ± 0.13	0.322 ± 0.47	0.406 ± 0.50	0.237 ± 0.43
SS	Old	83	0.086 ± 0.28	0.272 ± 0.45	0.074 ± 0.26	0.530 ± 0.50	0.123 ± 0.33
	Adult	119	0.178 ± 0.39	0.151 ± 0.36	0.055 ± 0.23	0.671 ± 0.47	0.137 ± 0.35
	X^2		14.49	34.65	18.26	2.04	4.66
	P -value		0.00055	< 0.00000	< 0.000 0.153		0.03407

CZ = Climate zones, S = Sudanian, SS = Sudano – Sahelian.

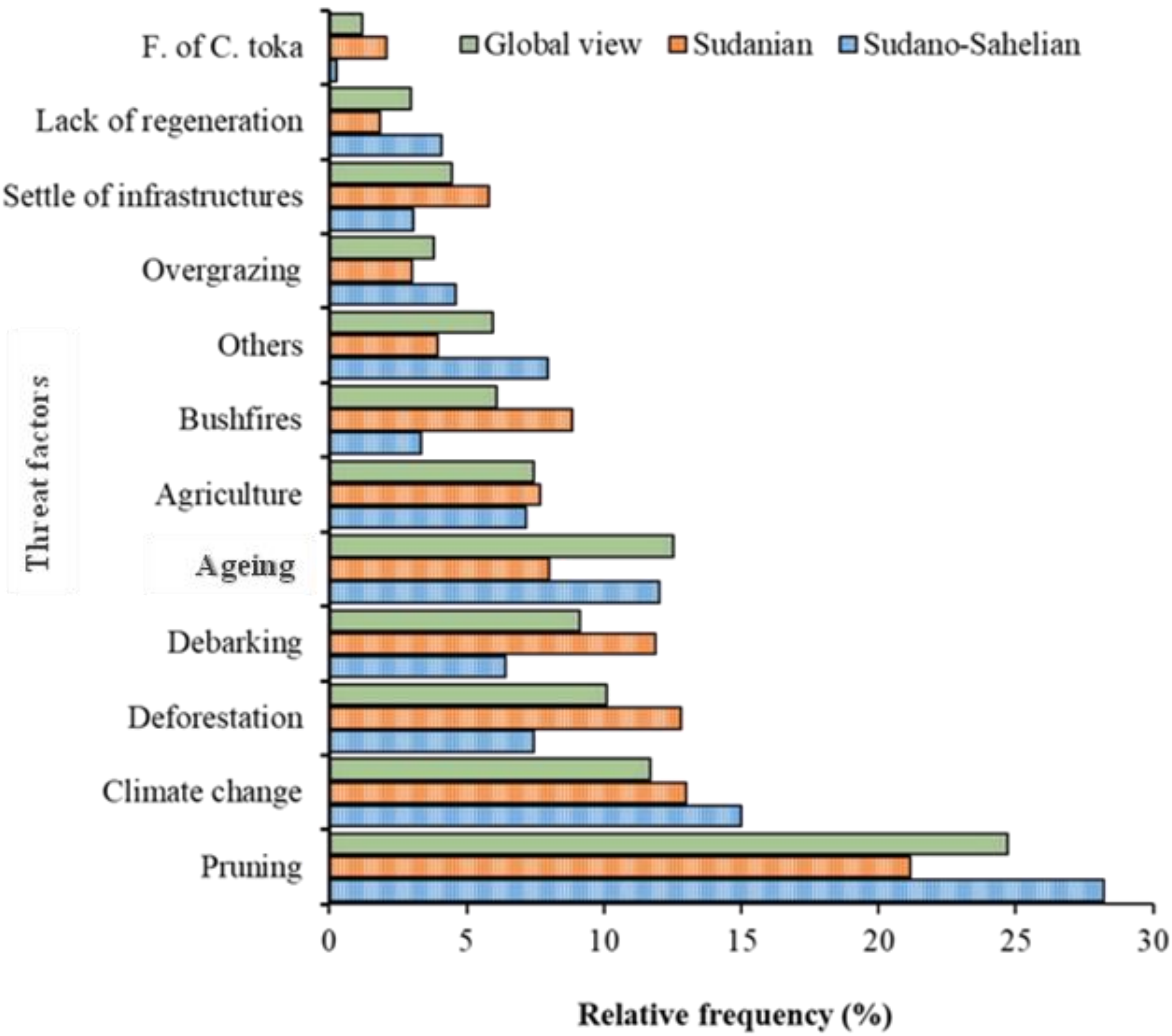

Figure 12: Threat factors by climatic zone in Burkina Faso.

F. of *Celtis toka*: failure of *Celtis toka*

Table 26**:** Mean values (± Std) and results of GLMs factors considered threats to *Celtis toka* in Burkina Faso

CZ	**Variables**	**n**	**Climate change**	**Farming**	**Deforestation**	**Settle of** infrastructures	**Ageing**	**Bushfire**
	Ethnolinguistic groups							
SCZ	Bobo	145	0.131 ± 0.34	0. 048 ± 0.22	0.131 ± 0.34	0.055 ± 0.23	0.172 ± 0.38	0.137 ± 0.35
	Bozo	17	0.222 ± 0.43	0.111 ± 0.32	0.056 ± 0.24	0 ± 0	0.111 ± 0.32	0 ± 0
	Dioula	21	0.190 ± 0.40	0.238 ± 0.44	0.143 ± 0.36	0.048 ± 0.22	0.095 ± 0.30	0.095 ± 0.3
	Others	20	0.142 ± 0.36	0.190 ± 0.40	0.190 ± 0.40	0.190 ± 0.40	0.048 ±0.22	0.095 ± 0.30
SSCZ	Bobo	28	0.071 ± 0.26	0.036 ± 0.19	0.071 ± 0.26	0 ± 0	0 ± 0	0.036 ± 0.19
	Bwaba	64	0.219 ± 0.42	0.265 ± 0.45	0.234 ± 0.43	0.188 ± 0.39	0.359 ± 0.48	0.031 ± 0.18
	Dafing	47	0.319 ± 0.47	0.085 ± 0.28	0.106 ± 0.31	0.043 ± 0.20	0.276 ± 0.45	0.148 ± 0.36
	Mossi	26	0.133 ± 0.35	0.267 ± 0.46	0.267 ± 0.45	0.067 ± 0.25	0.467 ± 0.52	0 ± 0
	Others	26	0.133 ± 0.35	0.267 ± 0.46	0.237 ± 0.41	0.056 ± 0.21	0.237 ± 0.24	0 ± 0
	X^2		6.41	17.7	2.39	3.7	7.03	2.14
	P value		0.00986	<0.000	0.117	0.0479	0.00699	0.152
	Sex							
SCZ	Female	91	0.144 ± 0.35	0.022 ± 0.15	0.067 ± 0.25	0.022 ± 0.15	0.167 ± 0.37	0.044 ± 0.21
	Male	112	0.147 ± 0.36	0.139 ± 0.35	0.183 ± 0.39	0.095 ± 0.30	0.130 ± 0.34	0.174 ± 0.38
SSCZ	Female	55	0.175 ± 0.38	0.125 ± 0.33	0.1 ± 0.30	0.025 ± 0.16	0.35 ± 0.48	0.025 ± 0.16
	Male	147	0.228 ± 0.42	0.184 ± 0.39	0.193 ± 0.40	0.123 ± 0.33	0.254 ± 0.44	0.079 ± 0.27
	X^2		1.64	5.27	2.12	2.53	2.9	0.05
	P value		0.195	0.0184	0.139	0.103	0.0844	0.832

	Age							
SCZ	Old	108	0.164 ± 0.37	0.103 ± 0.30	0.144 ± 0.35	0.068 ± 0.25	0.171 ± 0.37	0.089 ± 0.29
	Adult	95	0.101 ± 0.30	0.051 ± 0.22	0.102 ± 0.30	0.051 ± 0.22	0.085 ± 0.28	0.19 ± 0.39
SSCZ	Old	83	0.284 ± 0.45	0.148 ± 0.36	0.136 ± 0.34	0.086 ± 0.28	0.309 ± 0.46	0.062 ± 0.24
	Adult	119	0.137 ± 0.34	0.192 ± 0.40	0.205 ± 0.41	0.110 ± 0.31	0.247 ± 0.43	0.068 ± 0.25
	X^2		3.89	0.77	0	0.14	4.2	1.71
	P value		0.0445	0.373	0.938	0.699	0.0372	0.2

CZ **:** climate zones SCZ : Sudanian climatic zone, SSCZ : Sudano – Sahelian climatic zone

Table 27: Mean values (± Std) and results of GLMs factors considered threats to *Celtis toka* in Burkina Faso (Continued)

CZ	**Variables**	**n**	**Overgrazing**	**Lack of regeneration**	**Failure of *Celtis toka***	**Debarking**	**Pruning**	**Others**
	Ethnolinguistic groups							
SCZ	Bobo	145	0.041 ± 0.20	0.062 ± 0.24	0.028 ± 0.16	0.180 ± 0.74	0.329 ± 0.47	0.062 ± 0.24
	Bozo	17	0.056 ± 0.24	0 ± 0	0.056 ± 0.24	0.222 ± 0.43	0.222 ± 0.43	0 ± 0
	Dioula	21	0 ± 0	0 ± 0	0.143 ± 0.36	0.381 ± 1.53	0.381 ± 1.53	0 ± 0
	Others	20	0 ± 0	0.095 ± 0.30	0 ± 0	0.333 ± 0.97	0.367 ± 0.98	0.048 ± 0.22
SSCZ	Bobo	28	0 ± 0	0.071 ± 0.26	0 ± 0	0.038 ± 0.19	0.077 ± 0.29	0 ± 0
	Bwaba	64	0.234 ± 0.43	0.109 ± 0.31	0.016 ± 0.13	0.188 ± 1.11	0.234 ± 0.43	0 ± 0
	Dafing	47	0.063 ± 0.25	0.085 ± 0.28	0 ± 0	0.26 ± 1.29	0.106 ± 0.31	0.043 ± 0.20

	Mossi	26	0 ± 0	0 ± 0	0 ± 0	0.2 ± 0.56	0.267 ± 0.45	0 ± 0
	Others	26	0 ± 0	0 ± 0	0 ± 0	0.2 ± 0.56	0.241 ± 0.36	0 ± 0
	X^2		0.44	0.896	0.37	1.15	7.65	1.06
	P value		0.499	0.01	0.548	0.301	0.00412	0.304
	Sex							
SCZ	Female	91	0.022 ± 0.15	0.033 ± 0.18	0.044 ± 0.20	0.178 ±0.44	0.158 ± 0.37	0.040 ± 0.17
	Male	112	0.043 ± 0.20	0.070 ± 0.26	0.035 ± 0.18	0.252 ± 1.07	0.167 ± 0.39	0 ± 0
SSCZ	Female	55	0.025 ± 0.16	0.075 ± 0.27	0 ± 0	0.075 ± 0.35	0.185 ± 0.37	0 ± 0
	Male	147	0.149 ± 0.36	0.088 ± 0.28	0.009 ± 0.09	0.219 ± 1.17	0.221 ± 0.40	0.009 ± 0.09
	X^2		6.67	1.13	2.12	7.52	0.38	1.26
	P value		0.00707	0.279	0.169	0.0159	0.3056	0.1504
	Age							
SCZ	Old	108	0.006 ± 0.08	0.048 ± 0.21	0.034 ± 0.18	0.171 ± 0.68	0.164 ± 0.37	0.034 ± 0.18
	Adult	95	0.102 ± 0.30	0.068 ± 0.25	0.05 ± 0.22	0.340 ± 1.18	0.101 ± 0.30	0.05 ± 0.22
SSCZ	Old	83	0.136 ± 0.35	0.111 ± 0.32	0 ± 0	0.222 ± 1.25	0.284 ± 0.45	0.061 ± 0.20
	Adult	119	0.096 ± 0.30	0.055 ± 0.23	0.014 ± 0.117	0.137 ± 0.69	0.137 ± 0.34	0.014 ± 0.117
	X^2		1.4	0.95	1.71	0.17	4.51	2.65
	P value		0.227	0.321	0.215	0.681	0.0299	0.027

CZ **:** climate zones, SCZ : Sudanian climatic zone, SSCZ : Sudano – Sahelian climatic zone

Figure 13: Risk factors for *Celtis toka*
Pictures: Dabré, 2020 (A); 2021 (B, C) and 2022 (D).

Hollow (A) in most of *Celtis toka* natural stand, *Ficus thonningii* (B) fungi (C), and hollow (yellow round) ageing, crown gall (red round) attack coupled with debarking (D) in both climatic zones.

Figure 14: Risk factors for *Celtis toka*
Pictures: Dabré, 2020 (E, H) and 2021 (F, G, I)

Debarking (E) for traditional medicine purposes in BCZ. Artisanal (F) and industrial (G) mining in SCZ; cutting of *Celtis toka* juvenile in SCZ (H), wind (I) effects on *Celtis toka* in SCZ.

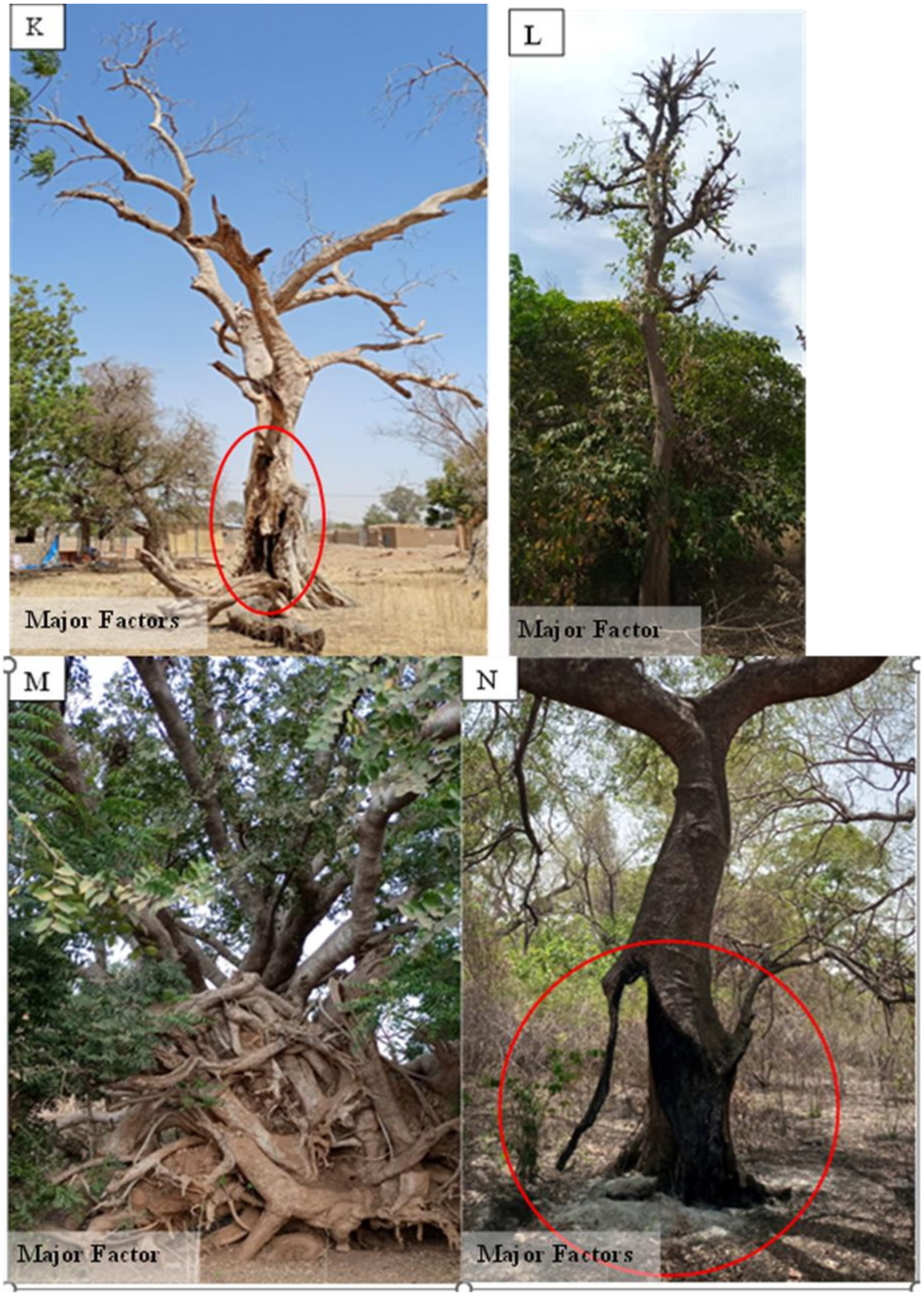

Figure 15: Risk factors for *Celtis toka*
Pictures: Dabré, 2021 (L, M, N) and 2022 (K)

Natural death due either to drought, diseases or ageing of the hollowed *Celtis toka* (K) in BCZ and heavy pruning (L), ageing, wind's action and *Azadirachta indica* invasion (M) ageing and fire effect (N) on hollowed-out *Celtis toka* in SCZ.

Figure 16: Risk factors for *Celtis toka* (continued)

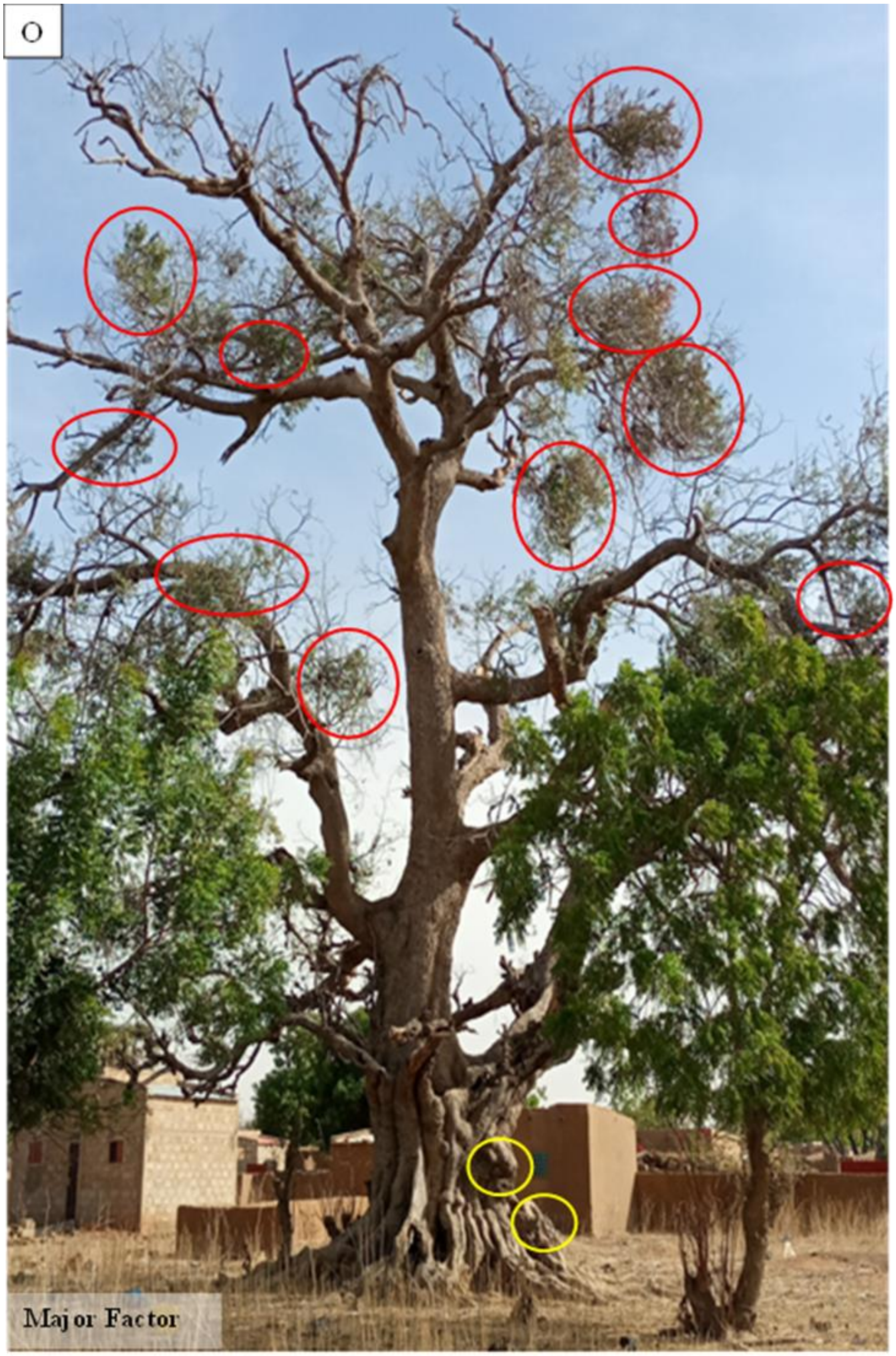

Figure 16: Risk factors for *Celtis toka*
Picture: Dabré, 2022 (O).

Ageing, epiphytes' attack (red circles), hollows, crown gall (yellow circles), and *Azadirachta indica* invasion (O).

Figure 17: Risk factors for *Celtis toka*
Picture: Dabré, 2022 (P).

Ageing, rotting, holes, *Azadirachta indica* invasion and animal grazing (P).

According to the Sudano-Sahelian climatic zone, the conservation of the species and its habitat was mostly perceived by Dafing and planting by Bwaba as key solutions to the threat. Most of the solutions were proposed by the males in both climatic zones. In the Sudanian climatic zone, adults proposed more solutions than older people. The contradiction has been found in the Sudano-Sahelian climatic zone (Table 29).

GLMs analysis of respondents' perceptions of potential solutions to the threat of *Celtis toka* reveals that local perception varied significantly according to ethnolinguistic groups, sex, and ages for planting, and ethnolinguistic groups for conservation of *Celtis toka* and its habitat, (p–value < 0.05, Table 29). However, no differences in promoting education and awareness about *Celtis toka*, associating *Celtis toka* with crops, and sustainable use of the species were found between all the sociodemographic parameters (p–*value* > 0.05, Table 29).

3.2. FLORISTIC COMPOSITION, DIVERSITY, REGENERATION AND POPULATION STRUCTURE OF *Celtis toka* IN BURKINA FASO.

3.2.1. Impacts of human pressures and environmental disturbances on the phenology and sanitary state of *Celtis toka* population along climate gradient and LUT

Flowering, leafing, an event of fruits (fruiting, unripe and ripe fruits) and old leaves (Table 30) were phenological phenomenon stages in the population of *Celtis toka*.

Climate and land use types had a significant ($P < 0.05$) effect on the flowering in the Sudanian climatic zone, and fruiting in both climatic zones (BCZ), unripe and ripe fruits in the Sudano-Sahelian climatic zone of Burkina Faso. In the protected areas of both climatic zones, all *Celtis toka* trees showed a dissimilar pattern of life events. *Celtis toka* populations were either flowering, leafing, or fruiting by having some basal old leaves. Between November and April, some fruits were only ripened in the unprotected areas of BCZ. Furthermore, from a given habitat of the same land use type and climatic zone, a great variety of patterns encountered in leafing, flowering, and fruiting were found among individuals of the species. Few individuals displayed at the same time leafing, flowering, and fruiting unripe and ripe fruits while retaining old leaves. Overall, individuals were mostly fruiting in the protected areas (Sudanian climatic zone: 0.68 ± 0.11, Sudano-Sahelian climatic zone: 0.64 ± 0.08) compared to unprotected areas (Sudanian climatic zone: 0.22 ± 0.05, Sudano-Sahelian climatic zone: 0.34 ± 0.05).

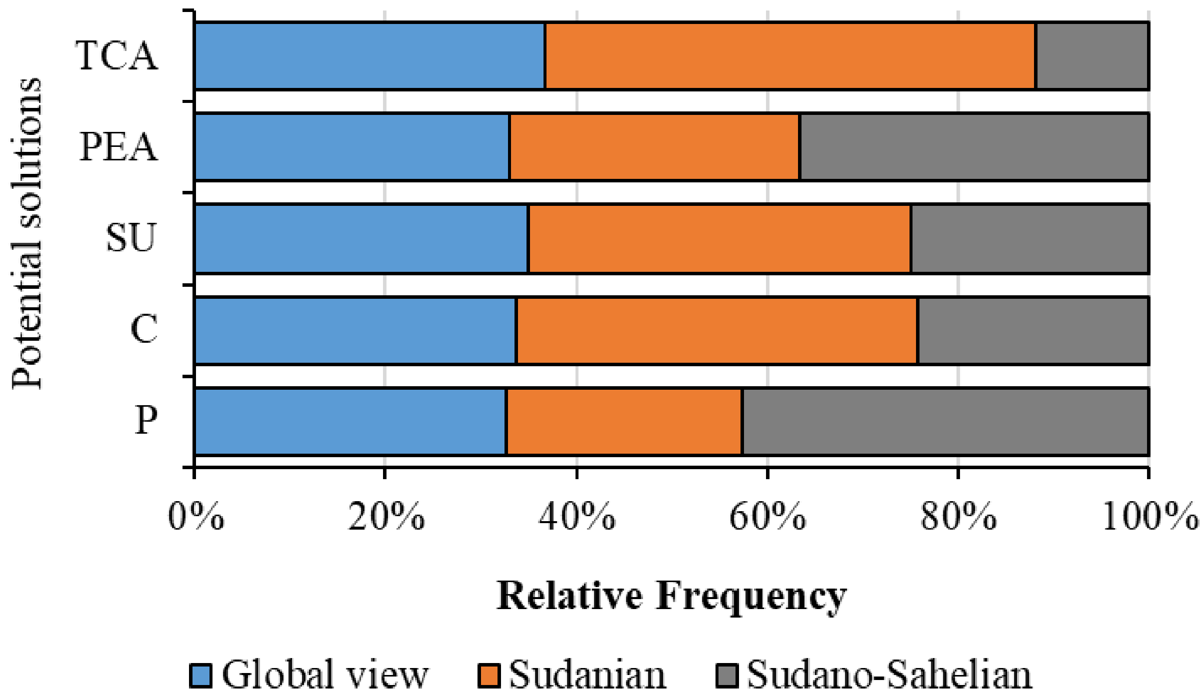

Figure 18: Traditional potential solutions to the threat according to climatic zones.

P: Planting, C: Conservation of *Celtis toka* and its habitat, PEA: Promoting Education and Awareness about *Celtis toka*, TCA: Tree/Crop Association, and SU: Sustainable Use of *Celtis toka*,

Table 28: Chi-square test showing whether to plant or not *Celtis toka*

Climatic zones	**% of respondents**		**Chi-square**		
	Yes	**No**	**DF**	**X^2**	**P value**
Sudanian	77.02	23.91	1	27.94	< 0.0001
Sudano-Sahelian	99.61	0.39	1	98.43	< 0.0001

P -value < 0.05, unbold: *P* -value > 0.05

Table 29: Mean values (± Std) and results of GLMs of the potential solution to the existence of *Celtis toka* in Burkina Faso

	Variables	**n**	**Planting**	**Conservation of *Celtis toka* and its habitat**	**Promoting education, and awareness about *Celtis toka***	**Tree / Crop association**	**Sustainable use of *Celtis toka***
	Ethnolinguistic groups						
S	Bobo	145	0.262 ± 0.44	0.152 ± 0.36	0.090 ± 0.29	0.062 ± 0.24	0.014 ± 0.11
	Bozo	17	0.235 ± 0.44	0.118 ± 0.33	0.059 ± 0.24	0.176 ± 0.39	0.059 ± 0.24
	Dioula	21	0.429 ± 0.51	0.048 ± 0.22	0 ± 0	0.048 ± 0.22	0 ± 0
	Others	20	0.2 ± 0.41	0 ± 0	0.05 ± 0.22	0.05 ± 0.22	0. 05 ± 0.22
SS	Bobo	28	0.179 ±0.39	0.107 ± 0.31	0.036 ± 0.19	0 ± 0	0 ± 0
	Bwaba	64	0.563 ± 0.5	0.094 ± 0.29	0.172 ± 0.38	0.031 ± 0.18	0.031 ± 0.18
	Dafing	47	0.489 ± 0.51	0.064 ± 0.25	0.021 ± 0.15	0 ± 0	0.021 ± 0.15
	Mossi	26	0.7 ± 0.51	0 ± 0	0.087 ± 0.26	0 ± 0	0 ± 0
	Others	26	0.6 ± 0.51	0 ± 0	0.067 ± 0.26	0 ± 0	0 ± 0
	X^2		19.55	15.56	1.41	4.21	0.48
	P value		< 0.000	< 0.00	0.244	0.051	0.477
	Sex						
S	Female	91	0.189 ± 0.39	0.111 ± 0.31	0.033 ± 0.18	0.044 ± 0.21	0.033 ± 0.18
	Male	112	0.336 ± 0.47	0.133 ± 0.34	0.106 ± 0.30	0.088 ± 0.29	0.009 ± 0.09
	Female	55	0.5 ± 0.51	0.1 ± 0.30	0.15 ± 0.36	0.025 ± 0.16	0 ± 0
SS	Male	147	0.464 ± 0.50	0.070 ± 0.26	0.070 ± 0.26	0.009 ± 0.09	0.026 ± 0.16

	X^2		6.09	0.29	0.29	0.27	0.05
	P value		0.013	0.596	0.587	0.613	0.831
	Age						
S	Old	108	0.285 ± 0.45	0.118 ± 0.32	0.056 ± 0.23	0.063 ± 0.24	0.021 ± 0.14
	Adult	95	0.24 ± 0.43	0.136 ± 0.35	0.119 ± 0.33	0.087 ± 0.28	0.017 ± 0.13
SS	Old	83	0.469 ± 0.50	0.49 ± 0.21	0.135 ± 0.34	0.025 ± 0.16	0.012 ± 0.11
	Adult	119	0.479 ± 0.50	0.109 ± 0.31	0.041 ± 0.20	0 ± 0	0.027 ± 0.16
	X^2		5.53	1.31	0.2	2.24	0.01
	P value		0.018	0.260	0.650	0.151	0.913

S = Sudanian, SS = Sudano – Sahelian

Among 339 adult individuals of *Celtis toka* studied, 94.99 % were unhealthy. Natural and anthropogenic factors were the two types of threats found in *Celtis toka* habitats.

In general, overgrazing (30.19%), hollows in the branches and or in the trunk (20.66%), insects' attacks (15.61%), others (10.35%), debarking (9.3208%), fire (7.71%), both debarking and pruning (4.03 %), and pruning only (2.13%) were factors that affect the growth of the species.

Others refer to the whole death or half death of *Celtis toka*, wind action (branches breaking, uprooting), flood, fungi, epiphyte, crown gall, invasive species, and *Ficus* attack (Figure 19).

Natural disturbances were drought, wind, hollow, crown gall, fungi, epiphyte, insect attacks, and others. Anthropogenic disturbances were overgrazing, the introduction of exotic species, fire, over-pruning of leaves, debarking, pruning, and debarking. Environmental disturbances and human pressures highly varied according to climate zones and land use types ($P < 0.05$) for gazing in the Sudano-Sahelian climatic zone, fire in the Sudanian climatic zone, hollows, termites, debarking, and pruning in both climatic zones (Table 31). The action of fire was greater in the protected areas of the Sudanian climatic zone (0.47 ± 0.12) than in the protected areas of the Sudano-Sahelian climatic zone (0.24 ± 0.07). In contrast, overgrazing was high in both protected areas. Individuals of *Celtis toka* in unprotected areas of the Sudanian climatic zone (0.97 ± 0.06) had more hollows, followed by unprotected areas of the Sudano-Sahelian climatic zone (0.94 ± 0.06), then protected areas of the Sudano-Sahelian climatic zone (0.63 ± 0.08) and finally protected areas of the Sudanian climatic zone (0.42 ± 0.12). Besides, some individuals were almost dead or dead in both climatic zones. Additionally, individuals of *Celtis toka* were pruned excessively to feed humans or animals, to the point where they no longer produced fruits. Also, after germination, young plants were burned by fire and trampled on by browsing animals.

3.2.2. Stand diversity and ecological importance of *Celtis toka* population across CZ and LUT

3.2.2.1. Taxonomic richness and alpha diversity indices of *Celtis toka* stands

Overall, 3642 individuals were identified, including 290 woody species divided into 113 genera ranging 105 families in *Celtis toka*'s natural stands. Species richness ($\chi^2 = 19.62$, $p < 0.000$), Shannon's diversity index ($\chi^2 = 15.60$; $p < 0.000$) and Simpson`s diversity index ($\chi^2 = 12.27$; $p < 0.00$) varied significantly across land use types in the Sudano-Sahelian climatic zone.

Table 30: Impact of climate and land use types on *Celtis toka* phenological phenomenon stages (mean (m), standard error (se))

CZ/LUT	**Dates**	**Leafing**	**Flowering**	**Events of fruits**			**Old leaves**
				Fruiting	Unripe fruits	Ripe fruits	
Sudanian		m ± se	m ± se	m ± se	m ± se	m ± se	m ± se
PA	December 2020-2021 to April 2021	0.79 ± 0.10	0.74 ± 0.10	0.68 ± 0.11	0 ± 0	0 ± 0	1 ± 0
UPA	November 2020 to April 2021	0.63 ± 0.06	0.26 ± 0.05	0.22 ± 0.05	0.11 ± 0.04	0.08 ± 0.03	0.88 ± 0.04
	Kruskal–Wallis ‘test	0.1951	**0.0001**	**0.0001**	0.1416	0.2081	0.1168
Sudano-Sahelian							
PA	February 2021 - 2022	0.78 ± 0.07	0.72 ± 0.07	0.64 ± 0.08	0 ± 0	0 ± 0	0.97 ± 0.03
UPA	November 2020 to February 2022	0.81 ± 0.04	0.55 ± 0.05	0.34 ± 0.05	0.17 ± 0.04	0.16 ± 0.04	0.92 ± 0.03
	Kruskal–Wallis’ test	0.6940	0.0772	**0.0020**	**0.0089**	**0.0119**	0.2946

CZ/LUT: Climatic zones/land use types, PA: Protected Areas, UPA: Unprotected Areas

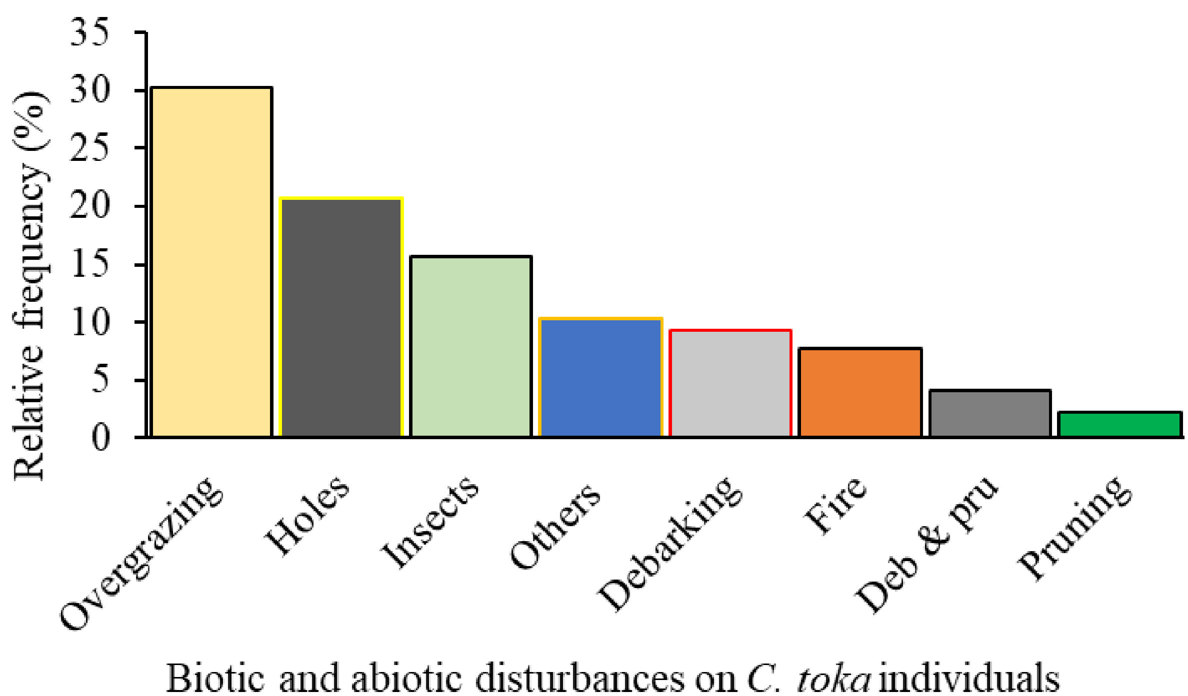

Figure 19: Factors affecting *Celtis toka* across two climatic zones in Burkina Faso.

Deb & pru: debarking and pruning.

In the Sudanian climatic zone, however, they do not differ across land use types. Unprotected areas of the Sudanian climatic zone have the greatest diversity (H = 3.759), with a total richness of 106 species. In contrast, protected areas of the Sudano-Sahelian climatic zone with a total of 48 species had the lowest diversity (H = 2.745) see Table 32.

3.2.2.2. Stand composition and ecological importance of *Celtis toka*

The floristic composition of *Celtis toka* differs according to climate zones and land use types with Sorenson's index of similarity < 0.50 (Table 33).

The most common species were *Diospyros mespiliformis* (IVI: 16.96%) and *Cordia myxa* (IVI : 15.24%) in the protected areas of the Sudanian climatic zone; *Anogeissus leiocarpa* (IVI: 25.82%) and *Diospyros mespiliformis* (IVI: 21.69%) in the unprotected areas of the Sudanian climatic zone; *Combretum micranthum* (IVI: 38.4 %) and *Balanites aegyptiaca* (IVI: 33.09%) in SSPA; and finally, *Tamarindus indica* (IVI: 61.38%) in the unprotected areas of the Sudano-Sahelian climatic zone (Table 34). However, *Faidherbia albida, Acacia nilotica* in protected areas of the Sudanian climatic zone; *Dialium guineense, Cola laurifolia* in unprotected areas of the Sudanian climatic zone; *Ximenia americana*, *Capparis sepiaria* in the protected areas of the Sudano-Sahelian climatic zone, and *Grewia bicolor Ficus sycomorus* in the unprotected areas of the Sudano-Sahelian climatic zone (Table 34) were specific wood species that grew in conjunction with *Celtis toka* natural stand.

3.2.3. Impacts of climate gradient and land use types on the dendrometry characteristics and *Celtis toka* natural stand.

3.2.3.1 Population density and dendrometry characteristics across CZ and LUT

The density of *Celtis toka* population significantly varied with climatic zones and land use types for adult trees ($p \leq 0.05$) but was similar for the young tree ($p > 0.05$) (Table 35). For adult trees, densities were highest in the protected areas of the Sudanian climatic zone, followed by unprotected areas of the Sudanian climatic zone, protected areas of the Sudano-Sahelian climatic zone and finally unprotected areas of the Sudano-Sahelian climatic zone. For juveniles' trees, densities were elevated in the unprotected areas of the Sudanian climatic zone, then protected areas of the Sudanian climatic zone, unprotected areas of the Sudano-Sahelian climatic zone and protected areas of the Sudano-Sahelian climatic zone (Table 35). In the protected areas, the density of young trees was lower compared to unprotected areas. The average density of *Celtis toka* in the protected areas of the Sudano-Sahelian climatic zone was sixty-three times lower for young trees compared to adults. The mean density of seedlings was higher in the unprotected areas than in protected areas at both sites (Table 35). The highest density was observed in the unprotected areas of the Sudanian climatic zone (160.31 ± 61.82 individuals ha-1), while the lowest was seen in the PA Sahelian climatic zone (0.31 ± 0.31 individuals ha-1). Total height varied significantly across climatic zones and land use types ($p < 0.05$) for adult trees whereas, for young trees, it was similar. DBH and the basal area did not fluctuate significantly among climatic zones and land use types ($p > 0.05$) either for young or adult trees (Table 35). The number of adults was greater than a sapling, or seedling in protected areas of the Sudanian climatic zone, while the number of juveniles was many than adults in the unprotected areas of the Sudanian climatic zone. Protected areas of the Sudano-Sahelian climatic zone had very few regenerations (Table 35).

Table 31: Generalized linear model test results of abiotic and biotic disturbances of *Celtis toka* (mean (m), standard error (se))

CZs/LUTs	Overgrazing	Hollows	Termites	Others	Debarking	Fire	Debarking and pruning	Pruning
Sudanian	m ± se	m ± se	m ± se	m ± se	m ± se	m ± se	m ± se	m ± se
PAs	1 ± 0	0.42 ± 0.12	0.74 ± 0.10	0.47 ± 0.12	0.11 ± 0.07	0.47 ± 0.12	0.63 ± 0.11	0 ± 0
UPAs	1.15 ± 0.05	0.94 ± 0.06	0.09 ± 0.04	0.31 ± 0.06	0.49 ± 0.06	0.09 ± 0.04	0.18 ± 0.05	0.22 ± 0.05
Sudano-Sahelian								
PAs	1 ± 0	0.63 ± 0.08	0.87 ± 0.06	0.42 ± 0.08	0.18 ± 0.06	0.24 ± 0.07	0 ± 0	0 ± 0
UPAs	1.16 ± 0.05	0.97 ± 0.06	0.43 ± 0.06	0.22 ± 0.05	0.54 ± 0.08	0.14 ± 0.04	0.43 ± 0.07	0.09 ± 0.03
P-value	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16

CZ/LUT: Climatic zones/land use types, PA: Protected Areas, UPA: Unprotected Areas, H: Kruskal–Wallis' test.

Table 32: Diversity indices of *Celtis toka* natural stands (mean ± standard deviation).

CZ/LUT	**Genera**	**Families**	**S**	**E**	**H**	**D`**
SPA	72	33	86	0.794	3.536	0.9425
			10.35 ± 4.04	0.91 ± 0.05	2.06 ± 0.37	0.84 ± 0.06
SUPA	63	30	106	0.806	3.759	0.9464
			10.19 ± 5.6	0.87 ± 0.15	1.91 ± 0.73	0.76 ± 0.20
Kruskal–Wallis' test	χ^2		2.038	0.026	1.552	1.1
	P-value		0.1533	0.8714	0.2128	0.2942
SSPA	33	23	48	0.709	2.745	0.904
			9.19 ± 3.37	0.89 ± 0.07	1.92 ± 0.42	0.81 ± 0.08
SSUPA	32	19	50	0.803	3.14	0.9242
			5.33 ± 3.67	0.85 ± 0.25	1.34 ± 0.63	0.66 ± 0.23
	χ^2		19.622	3.004	15.602	12.277
Kruskal–Wallis' test	P-value		**< 0.0000**	0.0830	**0.0000**	**0.0004**

CZ/LUT: Climatic zones/land use types, n: Plots' number, S: species richness, E: Pielou evenness, H: Shannon`s diversity index, D: Simpson`s diversity index, SPA: Protected Areas of the Sudanian climatic zone, SUPA: Unprotected Areas of the Sudanian climatic zone, SSPA: Protected Areas of Sudano-Sahelian climatic zone, SSUPA: Unprotected Areas of Sudano-Sahelian climatic zone, X^2: chi-squared.

Table 33: Sorenson's index of similarity of *Celtis toka* according to CZ and LUT

CZ/LUT	**SSUPA**	**SSPA**	**SUPA**	**SPA**
SSUPA	1			
SSPA	0.4538	1		
SUPA	0.4771	0.3459	1	
SPA	0.2703	0.2326	0.4332	1

CZ/LUT: Climatic zones/land use types, SPA: Protected Areas of Sudanian climatic zone, SUPA: Unprotected Areas of Sudanian climatic zone, SSPA: Protected Areas of Sudano-Sahelian climatic zone, SSUPA: Unprotected Areas of Sudano-Sahelian climatic zone.

Table 34: Most common and uncommon (*) woody species that occurred with *Celtis toka* natural stand throughout CZ and LUT

Family	**Species**	**IVI**				**Mean**
		SPA	**SUPA**	**SSPA**	**SSUPA**	**IVI**
Fabaceae	*Acacia ataxacantha* DC.	2.01	1.80	0.91	**4.55**	2.32
	Acacia dudgeonii Craib ex Holland	1.09	2.97	0.43	-	1.50
	Acacia erythrocalyx Brenan	-	-	**17.98**	**8.77**	13.38
	Acacia macrostachya Rchb. ex DC.	**4.22**	0.54	-	-	2.38
	Acacia nilotica (L.) Willd. ex Delile *****	2.56	-	-	-	2.56
	Acacia seyal Del.	**4.91**	-	**13.87**	**18.38**	12.39
	Acacia sieberiana DC.	1.92	**4.36**	-	1.68	2.65
Malvaceae	*Adansonia digitata* L.	1.68	-	**7.12**	**6.81**	5.20
Fabaceae	*Afzelia africana* Sm. ex Pers.	1.46	2.35	-	-	1.91
Combretaceae	*Anogeissus leiocarpa* (DC.) Guill. & Perr.	**9.53**	**25.82**	**9.88**	**10.01**	13.81
Zygophyllaceae	*Balanites aegyptiaca* (L.) Del.	0.51		**33.09**	**8.42**	14.01
Fabaceae	*Berlinia grandiflora* (Vahl) Hutch. & Dalziel	**3.7**	**3.42**	-	-	3.56
Meliaceae	*Carapa procera* DC. *****	**-**	**3.01**	-	-	3.01
Fabaceae	*Cassia siamea* Lam.	2.35	1.47	-	-	1.91
	Cassia sieberiana DC.	1.64	**4.05**	-	1.06	2.25

Malvaceae	*Ceiba pentandra* (L.) Gaertn.	0.88	**14.54**	-	-	7.71
Cannabaceae	*Celtis toka (Forssk.) Hepper et J.R.I.Wood*	**67.73**	**53.34**	**60.64**	**81.81**	**65.88**
Vitaceae	*Cissus populnea* Guill. et Perr. *****	1.08	-	-	-	1.08
Malvaceae	*Cola cordifolia* (Cav.) R.Br.	1.39	**3.01**	**-**		2.20
	Cola laurifolia Mast. *****	**-**	**8.14**	**-**		8.14
Combretaceae	*Combretum adenogonium* Steud. ex A.Rich.	0.47	2.26	-	-	1.37
	Combretum collinum Fresen.	1.97	1.99	0.47	-	1.48
	Combretum micranthum G. Don	-	-	**38.4**	**10.74**	24.57
	Combretum nioroense Aubrév. ex Keay *****	1.17	-	-	-	1.17
	Combretum paniculatum Vent. *****	**-**	1.83	-	-	1.83
Boraginaceae	*Cordia myxa* L.	**15.24**	0.43	-	2.16	5.94
	Cordia sinensis Lam.	2.35	-	-	1.68	2.02
Capparaceae	*Crateva adansonii* DC.	**-**	2.79	1.04	-	1.92
Fabaceae	*Cynometra vogelii* Hook.f. *****		2.76	-	-	2.76
Fabaceae	*Detarium senegalense* J.F.Gmel. *****	**-**	**6.38**	**-**	**-**	6.38
	Dialium guineense Willd. *****	**-**	**23.16**	**-**	**-**	23.16
Fabaceae	*Dichrostachys cinerea* (L.) Wight et Arn.	**4.57**	0.54	**3.46**	-	2.86
Ebenaceae	*Diospyros mespiliformis* Hochst. ex A. Rich.	**16.96**	**21.69**	**7.89**	**14.09**	15.16
Fabaceae	*Faidherbia albida* (Delile) A.Chev. *****	**4.40**	-	-	-	4.40
Rubiaceae	*Feretia apodanthera* Del.	**3.41**	0.69	**4.59**	2.34	2.76
Moraceae	*Ficus dicranostyla* Mildbr. *****	1.13	-	-	-	1.13
	Ficus glumosa Delile *****	1.69	-	-	-	1.69
	Ficus platyphylla Delile *****	**-**		-	1.05	1.05
	Ficus sur Forssk. *****	2.14	-	-	-	2.14
	Ficus sycomorus subsp. *****	**-**		-	2.60	2.60
	Ficus thonningii Blume *****	0.97	-	-	-	0.97
	Ficus trichopoda Baker *****	0.95	-	-	-	0.95
Salicaceae	*Flacourtia indica* (Burm.f.) Merr.	0.47	**8.74**	-	-	4.61
Rubiaceae	*Gardenia aqualla* Stapf et Hutch. *****	**-**		-	1.02	1.02
	Gardenia erubescens Srapf et Hutch. *****	0.93	-	-	-	0.93

Malvaceae	*Grewia bicolor* Juss. *	-		-	**12.94**	12.94
Apocynaceae	*Holarrhena floribunda* (G.Don) T.Durand & Schinz *	-	1.88	-	-	1.88
Meliaceae	*Khaya senegalensis* (Desr.) A.Juss.	2.69	1.56	2.12	-	2.12
Anacardiaceae	*Lannea microcarpa* Engl. et K.Krause	**5.91**	0.90	0.47	2.72	2.50
	Lannea velutina A.Rich. *	-	1.76	-	-	1.76
Celastraceae	*Lepisanthes senegalensis* (Juss.ex Poir.) Leenh	-	**7.43**	-	-	7.43
	Loeseneriella africana (Willd.) N.Hallé	-	0.42	**3.10**	1.02	1.51
Sapotaceae	*Manilkara multinervis* (Baker) Dubard *	-	**3.12**	-	-	3.12
Rubiaceae	*Mitragyna inermis* (Willd.) Kuntze	**4.62**	**21.05**	0.95	**3.89**	7.63
	Morelia senegalensis A.Rich. *	-	2.30	-	-	2.30
Rutaceae	*Oncoba spinosa* Forssk. *	-	**4.86**	-	-	4.86
Fabaceae	*Parkia biglobosa* (Jacq.) R.Br. ex G.Don	**5.01**	0.44	-	-	2.73
Fabaceae	*Philenoptera cyanescens* (Schumach. & Thonn.) Roberty *	-	**6.14**	-	-	6.14
	Philenoptera laxiflora (Guill. & Perr.) Roberty *	1.43	-	-	-	1.43
Fabaceae	*Piliostigma reticulatum* (DC.) Hochst.	**3.27**	0.44	0.83	**5.71**	2.56
Fabaceae	*Pterocarpus lucens* Lepr. ex Guill. & Perr.	-	-	2.52	-	2.52
	Pterocarpus santalinoides DC. *	-	**3.40**	-	-	3.40
Connaraceae	*Rourea minor* (Gaertn.) Alston *	-	**3.16**	-	-	3.16
Apocynaceae	*Saba senegalensis* (A.DC.) Pichon	**4.64**	0.86	**5.61**	1.32	3.11
Anacardiaceae	*Sclerocarya birrea* (A.Rich.) Hochst.	1.72	-	1.48	2.80	2.00
	Spondias mombin L. *	1.36	-	-	-	1.36
Apocynaceae	*Strophanthus sarmentosus* DC.	2.19	1.28	-	-	1.74
Fabaceae	*Tamarindus indica* L.	2.41	**3.24**	**17.29**	**61.38**	21.08
Combretaceae	*Terminalia macroptera* Guill. et Perr. *	-	-	-	1.02	1.02
Sapotaceae	*Vitellaria paradoxa* Gaertn. f.	**8.42**	-	0.54	**8.83**	5.93
Lamiaceae	*Vitex chrysocarpa* Planch. ex Benth.	0.48	1.13	2.39	-	1.33
Fabaceae	*Xeroderris stuhlmannii* (Taub.) Mendonça et E.C.Sousa *	-	2.85	-	-	2.85
Ximeniaceae	*Ximenia americana* L. *	-	-	**4.81**	-	4.81
Rutaceae	*Zanthoxylum zanthoxyloides* (Lam.) Zepern. & Timler *	1.4	-	-	-	1.40
Rhamnaceae	*Ziziphus mauritiana* Lam.	-	-	2.02	**6.73**	4.38

IVI: Importance value index, SPA: Protected Areas of Sudanian climatic zone, SUPA: Unprotected Areas of Sudanian climatic zone, SSPA: Protected Areas of Sudano-Sahelian climatic zone, SSUPA: Unprotected Areas of Sudano-Sahelian climatic zone. No stars: common faithful woody species to *Celtis toka*; stars (*): uncommon reliable species to *Celtis toka* natural stands by climatic zone and land use types

Table 35: Density and dendrometry characteristics (mean ± standard error) of *Celtis toka*.

Variables		**Climate zones and land use types**				**GLMs test**	
		SPA	**SUPA**	**SSPA**	**SSUPA**	**z-value**	**Pr(>|z|)**
Adults	Number of plots	32	32	32	33		
	Number of *Celtis toka*	156	71	73	39		
	Diameter at breast height (cm)	180.35 ± 30.38	156.95 ± 29.08	105.04 ± 14.34	106.17 ± 11.01	3.28	0.0595
	Height (m)	47.68 ± 10.47	20.84 ± 3.4	19.87 ± 3.67	11.63 ± 0.78	6.709	**0.0047**
	Density (ha)	102.33 ± 28.56	38.75 ± 7.64	34.06 ± 6.88	11.94 ± 0.77	6.275	**0.0057**
	Basal area (G, m2/ha)	930513.6 ± 340818.5	763296.5 ± 305333.3	214087.9 ± 54832.96	110940.5 ± 22994.55	3.684	0.0398
Juveniles	Number of subplots	8	20	1	8		
	Number of *Celtis toka*	32	279	1	52		
	Diamter.at the collar (mm)	14.23 ± 7.7	15.77 ± 4.14	2.64 ± NA	22.46 ± 6.54	0.332	0.569
	Height (cm)	294 ± 91.19	783.01 ± 259.14	35 ± NA	295.46 ± 106.20	0.147	0.697
	Density (ha)	20.67 ± 9.32	160.31 ± 61.82	0.31 ± 0.31	20.61 ± 10.80	0.601	0.419
	Basal area (G, m2/ha)	1566.11 ± 1427.18	4102.79 ± 1797.22	1.71 ± 1.71	2211.45 ± 1414.45	0.068	0.792

SPA: Protected Areas of the Sudanian climatic zone, SUPA: Unprotected Areas of the Sudanian climatic zone, SSPA: Protected Areas of the Sudano-Sahelian climatic zone, Unprotected Areas of the Sudano-Sahelian climatic zone.

3.2.3.2. Population structures

The distribution of diameter size classes (Figure 20) and height size classes of the juveniles (Figure 21) varied significantly ($P < 0.05$) throughout climatic zone and land use types for all land use types except in the unprotected areas of the Sudano-Sahelian climatic zone (adults, Table 36) and the protected areas of the Sudano-Sahelian climatic zone (Juveniles, Table 37).

Results of least-square linear regression for SCD curves revealed that there were negative slopes in all climatic zones and land use types except in the unprotected areas of the Sudano-Sahelian climatic zone (adults) and the protected areas of the Sudano-Sahelian climatic zone (juveniles) where the slopes were statistically positive. There was no statistically significant variation in density based on tree size class (Table 36, 37, Figure 20 d and Figure 21 c). In the protected areas of both climatic zones, the highest density was found between 5 and 15 cm while in the unprotected areas, the highest density was in the range of 45 and 55 cm. Furthermore, there were no individuals in the small (Figure 20 d) and sometimes large (Figure 20 a) size classes. There were negative slopes in the other land use types (Figure 20 a, b, c; and Figure 21 a, b, and d), often with the absence of individuals in certain classes of some zones. However, the low values of the slope - 0.369 and - 0.617 respectively in the unprotected areas of the Sudanian climatic zone and the protected areas of the Sudano-Sahelian climatic zone. Moreover, there was a positive value (0.075) of the slope with the absence of individuals in some classes (Figure 20 d). All permutation index (PI) values were greater than zero (Table 36). The computed quotients between consecutive size classes were not uniformly constant (Figure 22 A and B).

Additionally, there was an absence of individuals in some diameter classes ([105-115cm [, [115-125 cm [, [125-135 cm [and [135-145 cm [(Figure 20 a), [5-15 cm [, [15-25 cm [, [25-35 cm [, [95-105cm [, [155 – 165 cm [, and [165- 175cm [(Figure 20 d).

3.2.4. Impacts of climate gradient and LUT on the regeneration mechanisms of *Celtis toka*

The mean number of individuals of sexually and asexually regenerated seedlings varies significantly ($P < 0.05$) for the true seedlings in the Sudano-Sahelian climatic zone. Others' regeneration mechanisms, on the other hand, are identical ($P > 0.05$) across all land use types in both climatic zones (Table 38).

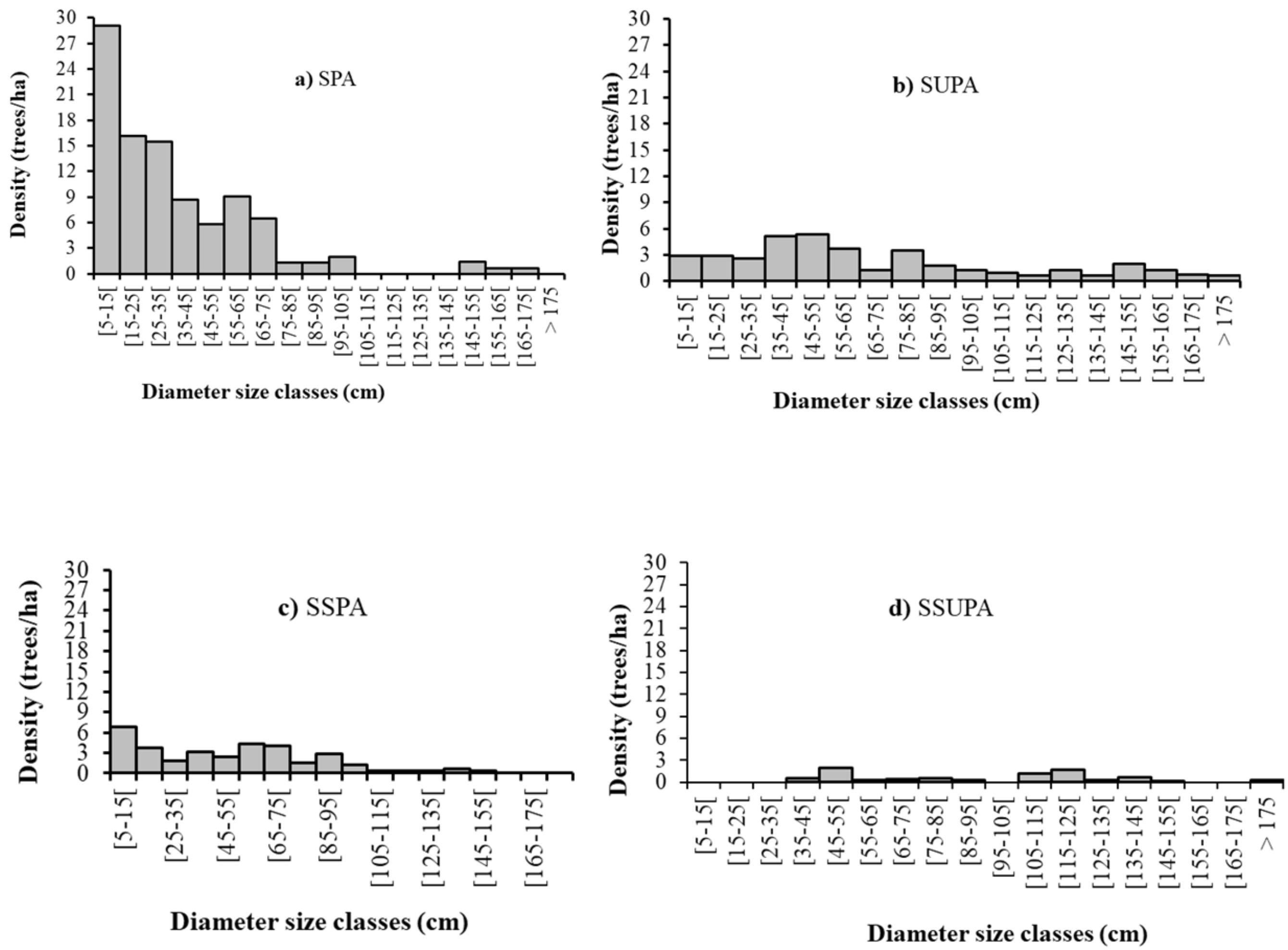

Figure 20: Diameter size class distribution of adults across CZ and LUT

SPA: Protected areas of the Sudanian climatic zone, SUPA: Unprotected areas of the Sudanian climatic zone. SSPA: Protected areas of the Sudano-Sahelian climatic zone, SSUPA: Unprotected areas of the Sudano-Sahelian climatic zone.

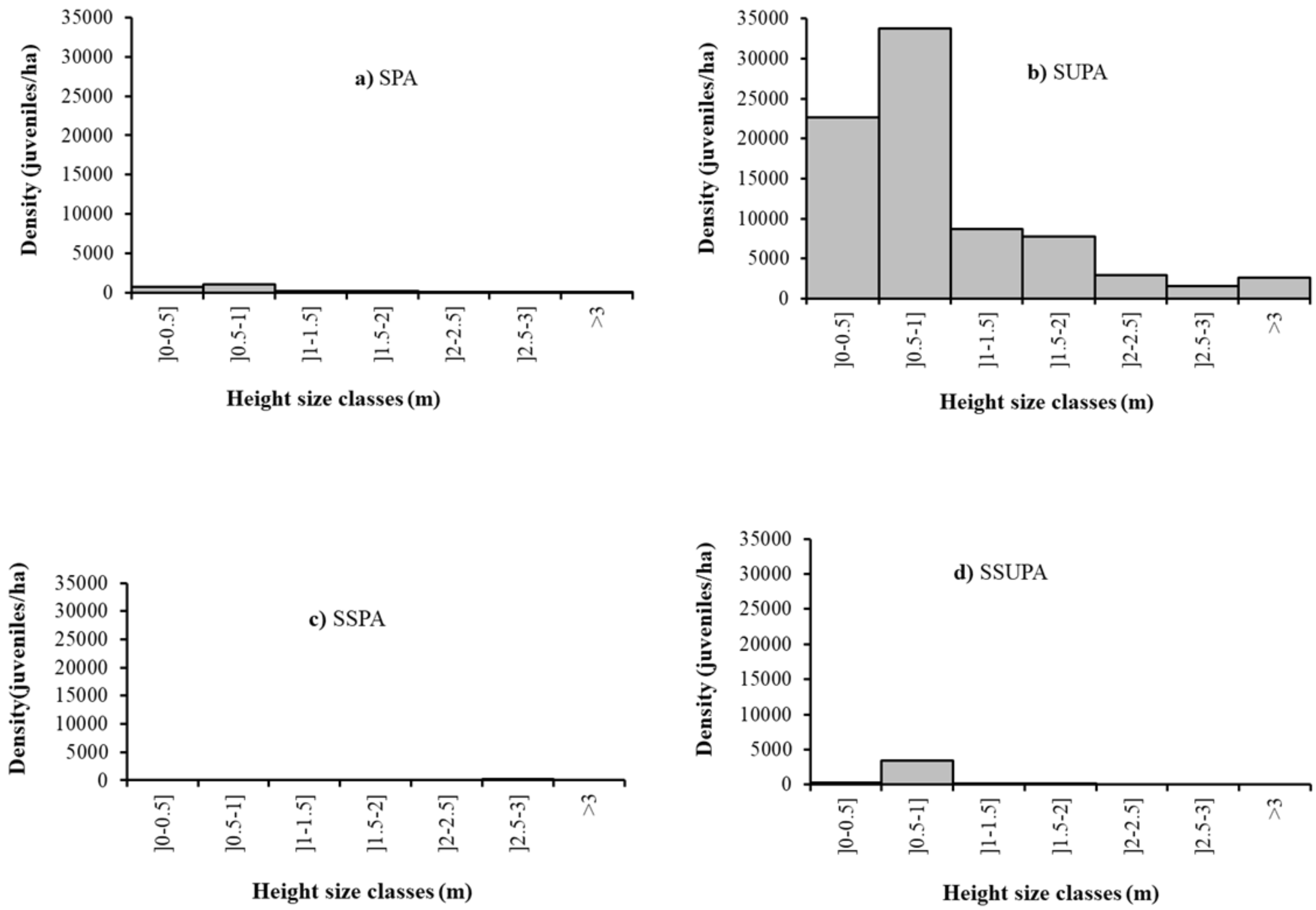

Figure 21: Height size class distribution of juveniles across CZ and LUT

SPA: Protected areas of the Sudanian climatic zone, SUPA: Unprotected areas of the Sudanian climatic zone. SSPA: Protected areas of the Sudano-Sahelian climatic zone, SSUPA: Unprotected areas of the Sudano-Sahelian climatic zone.

Table 36: Diameter size-class distribution slopes, mean-quotient and permutation index for *Celtis toka* adult populations.

CZ/LUT	**Stand stability measures**						
	R^2 (%)	**DF**	**F Value**	**SCD Slope**	***P* (Slope significance)**	**Mean-Quotient**	**Permutation Index (PI)**
Sudanian							
PA	82.83	15	72.36	-1.298	< 0.0001	1.5 ± 1.25	40
UPA	44.17	16	12.66	-0.3699	< 0.01	1.27 ± 0.66	56
Sudano-Sahelian							
PA	64.43	13	23.55	-0.6176	< 0.001	1.52 ± 0.99	38
UPA	03.19	16	0.5276	0.07594	0.4781	2.03 ± 2.80	94

CZ/LUT: Climatic zones/land use types, PA: Protected Areas, UPA: Unprotected Areas

Table 37: Total height size-class distribution slopes mean-quotient and permutation index for *Celtis toka* juveniles' populations.

CZ/LUT	**R^2 (%)**	**DF**	**F Value**	**SCD Slope**	***P* (Slope significance)**	**Mean-Quotient**	**Permutation Index (PI)**
Sudanian							
PA	73.82	5	14	-1.1073	0.01323	1.79 ± 1.28	7
UPA	73.78	5	14	-1.1129	0.01329	1.79 ± 1.28	7
Sudano-Sahelian							
PA	16.35	5	0.977	0.451	0.368	0	22
UPA	64.72	5	9.174	-2.9451	0.0291	15.69 ± 21.33	10

CZ/LUT: Climatic zones/land use types, PA: Protected Areas, UPA: Unprotected Areas

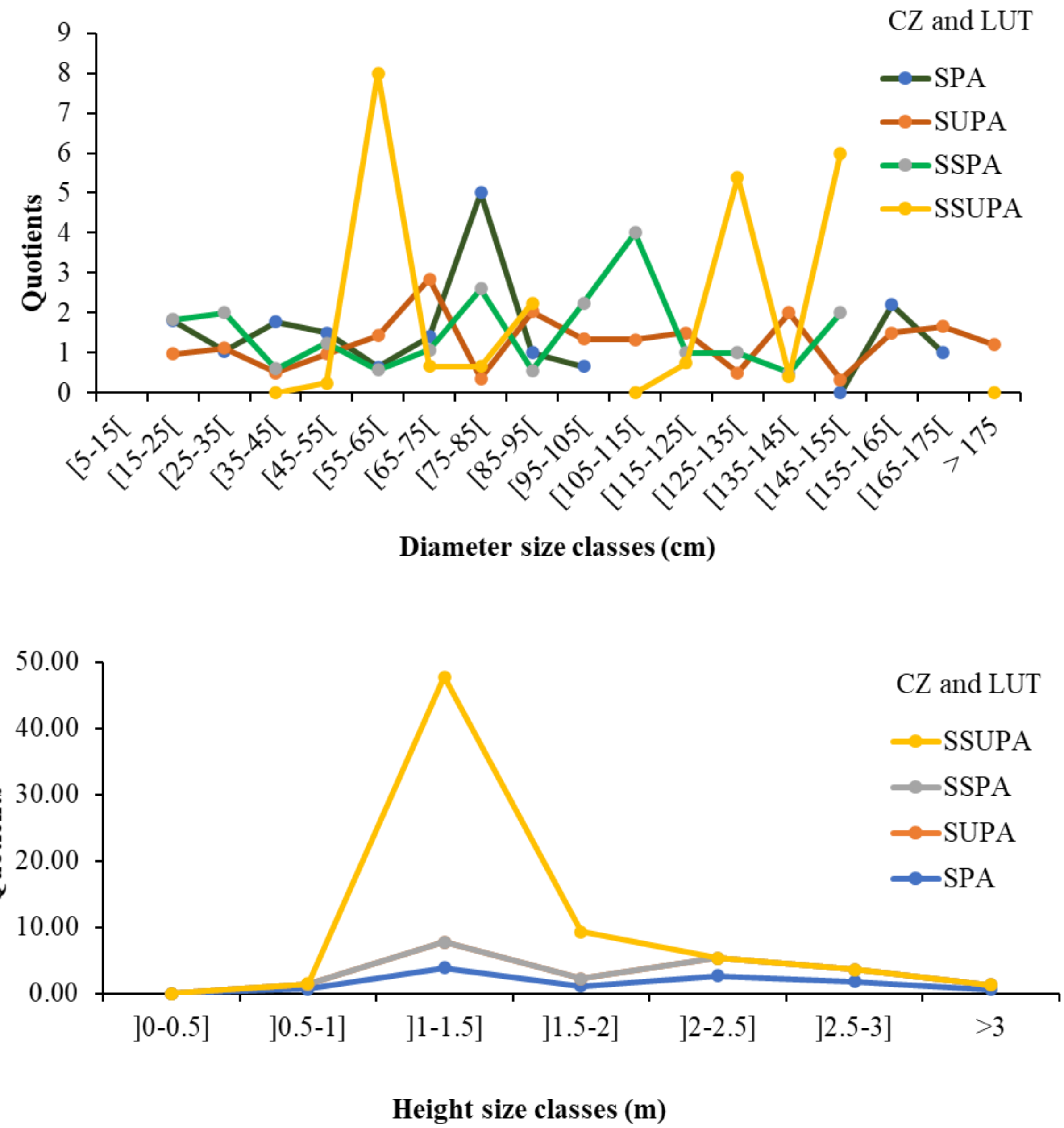

Figure 22. Population stability curves are shown by quotients between densities of *Celtis toka* in successive size classes based on diameter at breast height (A) and the height (B) for different climatic zones and land use types.

In general, 57.38 % of seedlings were regenerated asexually (coppice, root sucker, water sprout) while 42.62 % were sexual recruits (true seedlings and seedling sprouts). Asexual recruitment appeared to be the dominant mechanism in the unprotected areas of the Sudano-Sahelian climatic zone (84.91%) while sexual regeneration was the dominant mechanism in unprotected areas of the Sudanian climatic zone (61.72%) and the protected areas of the Sudanian climatic zone (6.27%). Sexual recruitment was the only mechanism of regeneration in the protected areas of the Sudano-Sahelian climatic zone (1.89%). Coppice (0.33%) was the very few mechanisms of recruitment. Protected areas of the Sudanian climatic zone had the highest number of regeneration mechanisms (5), followed by unprotected areas of the Sudanian climatic zone (4), then unprotected areas of the Sudano-Sahelian climatic zone (3), and lastly protected areas of the Sudano-Sahelian climatic zone (1) see Figure 23. The overall regeneration rate is 0.85 %. It varies greatly across climatic zones and land use types. It is highest in both unprotected areas (Sudanian climatic zone: 11.91% and the Sudano-Sahelian climatic zone: 4.30%) which have high anthropogenic activity (Figure 15). There are fewer in all protected areas (Figure 24) where overgrazing, fire and hollow pressures are active (Figure 19).

3.3. IMPACT OF CLIMATE CHANGE ON THE TREE RING GROWTH, WOOD ANATOMICAL PATTERNS, AND ABOVEGROUND CARBON STOCK OF *Celtis toka* IN BURKINA FASO

3.3.1. Characteristics of ring width and ring-width chronologies

The wood of *Celtis toka* showed distinct growth ring boundaries (Figure 25 A and B). The ring boundaries of *Celtis toka* were characterized by thick-walled latewood fibres and marginal parenchyma bands. The wood anatomy is diffuse-porous. Radial multiples of 2 to 4 are the most common vessel grouping, with a variable proportion of solitary vessels (Figure 25 B). The width of the ray is between one and six (Figure 25 C). Most of the perforations are simple and sometimes scalariform perforation plates with two bars (Figure 25 D).

The tree ring width of *Celtis toka* in the Sudanian climatic zone was weakly negatively correlated (r: -0.10; p-value = 0.749) with the tree ring width of *Celtis toka* in the Sudano-Sahelian climatic zone (Figure 26).

A slight negative correlation (Table 39, Figure 27 A and B) was noticed between tree growth for both climate variables (rainfall and temperature) of the Sudanian climatic zone. Whereas a slight positive correlation was noticed in the Sudano-Sahelian climatic zone (Table 39, Figure 27 C and D). The trend of the residual and standard chronologies of the tree ring width index of *Celtis toka* in the Sudanian climatic zone (Figure 28 A) and the Sudano-Sahelian climatic zone (Figure 28 B) has been decreasing in recent years.

3.3.2. Characteristics of the vessel of *Celtis toka* in Burkina Faso

The raw measurement of the tree-ring width series revealed mean sign GLK (%) and TV values of 0.88 % ± 0.48; 3.24 ± 3.18 and 0.67 % ± 0.27; 4.4 ± 2.34 in the Sudanian climatic zone and the Sudano-Sahelian climatic zone respectively. GLK (%) and TV values are statistically similar across climatic zones (Table 40). GLK (%) value was high in the Sudanian climatic zone (3.24 ± 3.18). The Sudanian climatic zone had greater wood density and ring width than the Sudano-Sahelian climatic zone. The Sudano-Sahelian climatic zone had a higher vessel density and number of vessels than the Sudanian climatic zone. These values vary greatly ($p < 0.05$) between climatic zones and land use types. MVA, MVRD, MVTD, TVA, TVAp values vary significantly ($p < 0.05$) between climatic zones and land use types. The age-radial growth relationships revealed that tree growth decreased with age (Table 41).

Variations in tree size-age relationships matched the weak correlation between stem DBH and tree age. Tree growth with age displayed a downward trend in age-radial growth relationships.

This was consistent with the tree-ring series, which presented a higher initial growth rate followed by a decrease as the tree aged (Figure 26). Pearson's correlation test revealed interrelationships between wood anatomical traits in both CZ across all individual trees (Figure 29). Five variables such as mean vessel area (MVA), mean vessel radial diameter (MVRD), mean vessel tangential diameter (MVTD), total vessel area percentage (TVAp), and vessel number (VN) were positively correlated with each other. While MVA revealed a significant correlation with MVTD, MVDR and TVAp. TVA also showed a significant correlation with VN. In contrast, wood traits such as MVA and MVTD out of the eight showed a negative correlation with vessel density (VD).

The first two axes of the principal component analysis (PC#1 and PC#2) explained 55.7 % and 18.3 % of the total variance of the dataset (Figure 30). PCA results showed that the first two principal components explained 73.96 % of the total variation in the data.

Wood anatomical traits such as MVA, MVTD, TVA, MVRD, TVAp, and RW were positively connected with PC#1 (Table 42). All these variables were found to be negatively related to vessel density (VD). PC#2 revealed that TVA and the number of vessels (NV) were positively related to each other and negatively related to the mean vessel tangential diameter (MVTD).

3.3.3. Historical record of environmental and human effects on *Celtis toka* along a climate gradient in Burkina Faso

Dendrochronology was used to date the event of disturbances but the effects on ring growth were not studied. Four types of disturbances were assessed: abiotic impacts such as climate (wind) and fungi; biotic aspects such as debarked and fire scars. Tree rings of the five cross-sections covered six decades. The oldest tree is stem disc C, which dates back to 1956. The youngest one is stem disc B, dating back to 2004.

Detection of debarking years

Sample A had debarking, which dates from 2016 to 2021 (Figure 31 A).

Detection of wind years

Sample B had wind action, which dates from 2005 to 2021 (Figure 31 B).

Detection of fungi years

Sample B had fungi, dated from 2014 to 2016 (Figure 31 B). Disc C had two periods of fungi action: from 1956 – 1970 and from 1973 to 2018 (Figure 31 C).

Detection of fire scar years

We identified seventeen fires during the last 50 years in the Sudano-Sahelian climatic zone. The seasonally determined fire scars generally occurred during the middle earlywood.

Table 38: Kruskal–Wallis' test of the regeneration mechanisms on the number of individuals per plot (mean (m), standard error (se))

CZ/LUT	**Coppice**	**Root sucker**	**Seedling sprout**	**True seedling**	**Water sprout**
Sudanian	m ± se	m ± se	m ± se	m ± se	m ± se
PA	0.067 ± 0.067	0.33 ± 0.16	0.33 ± 0.16	1.27 ± 0.53	0.13 ± 0.13
UPA	0 ± 0	2.15 ± 1.15	0.48 ± 0.44	6.93 ± 3.57	0.48 ± 0.37
H	0.1797	0.7341	0.1054	0.4448	0.4693
Sudano-Sahelian					
PA	0 ± NA	0 ± NA	0 ± NA	1 ± NA	-
UPA	0.38 ± 0.26	5.5 ± 2.43	0.63 ± 0.63	0 ± 0	-
H	0.5959	0.3097	0.7237	**0.0046**	-

CZ/LUT: Climatic zones/land use types, SPA: Protected Areas, UPA: Unprotected Areas, H: Kruskal–Wallis' test.

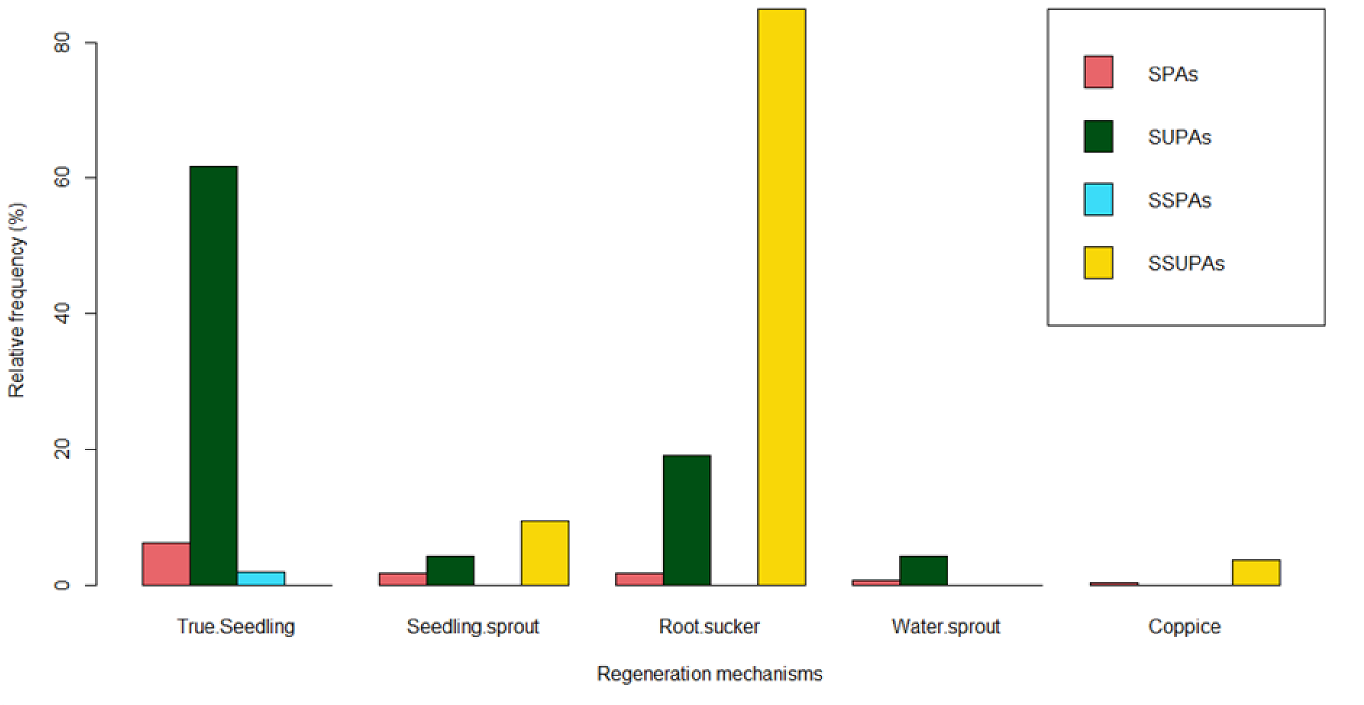

Figure 23: Regeneration mechanisms of *Celtis toka* according to CZ and LUT

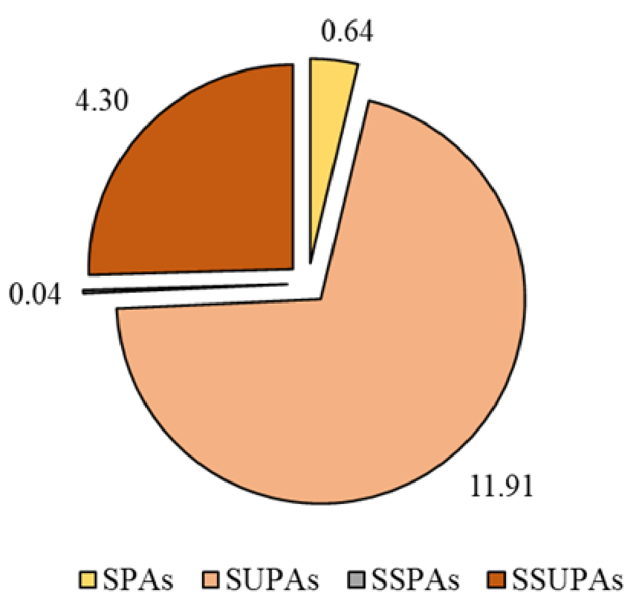

Figure 24: Regeneration rate of *Celtis toka* across CZ and LUT.

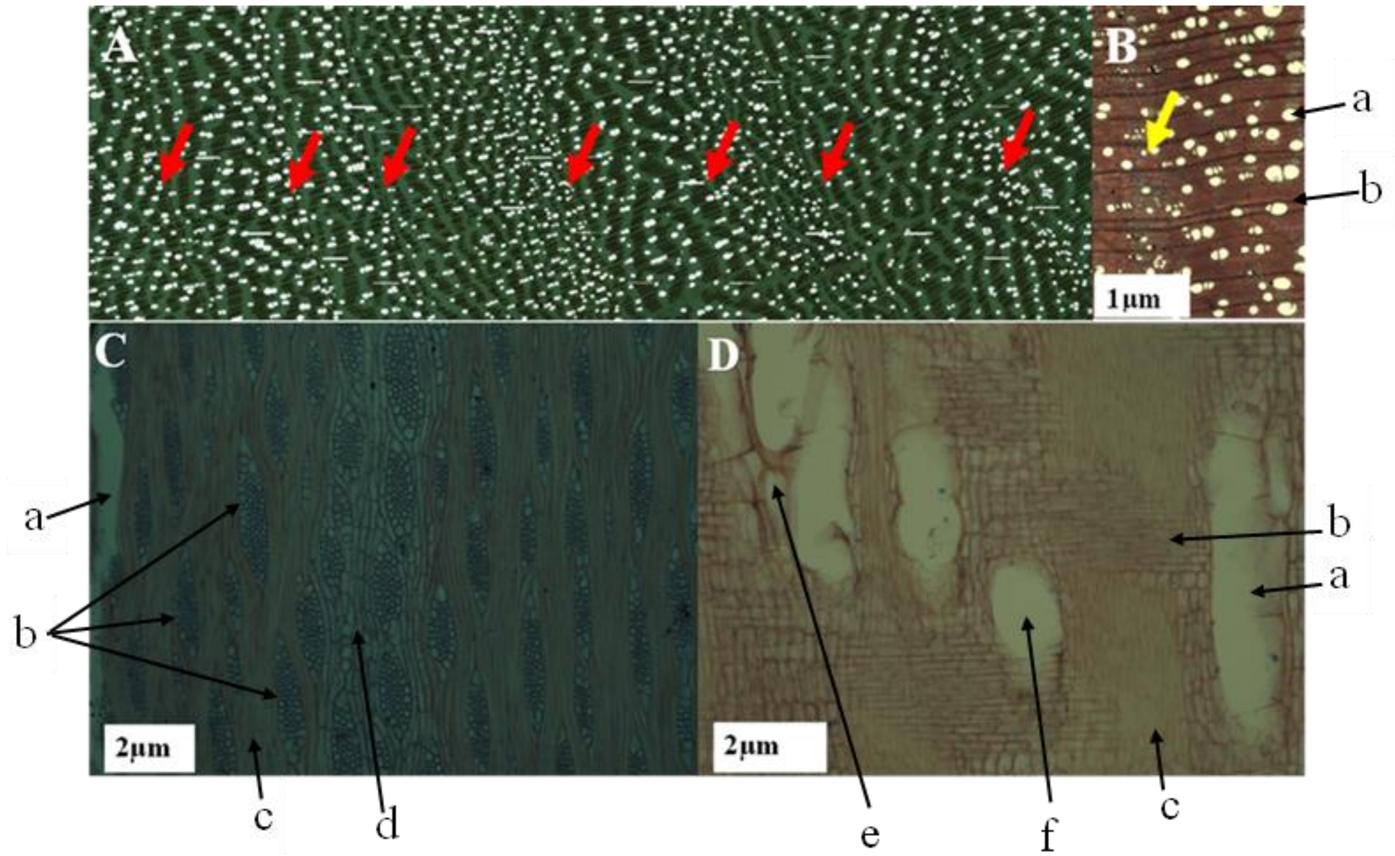

Figure 25: Characteristics of wood anatomical features of *Celtis toka*
Pictures: Dabré, 2022.

A: SmartZoom 5 image from the wood surface, B: cross-section image, C: tangential microsection and D: radial microsection, a: vessel, b: rays, c: fibres, d: parenchyma rays, e: Vessel–ray pits with distinct borders, f: simple perforation plate.

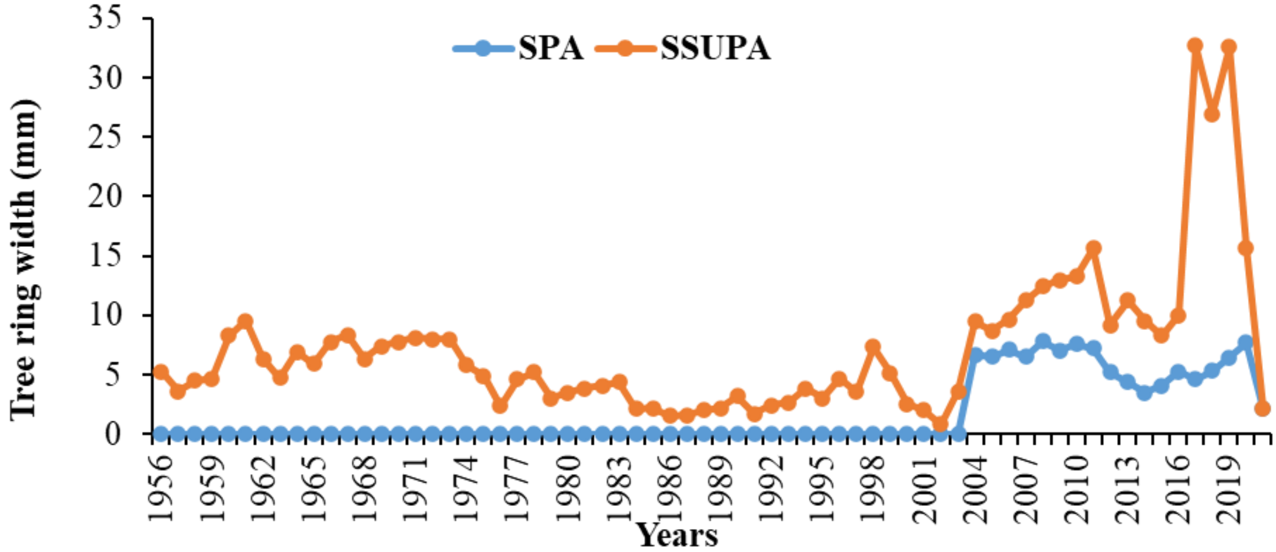

Figure 26: Tree ring growth series with raw ring width (mm) plotted across time.

Table 39: Results of Pearson correlation test

Variables	**Pearson correlation coefficient**	**t- value**	**p-value**
A	-0.33	-1.1136	0.2915
B	-0.22	-0.7249	0.4851
C	0.34	1.9698	0.0581
D	0.31	1.7902	0.0835

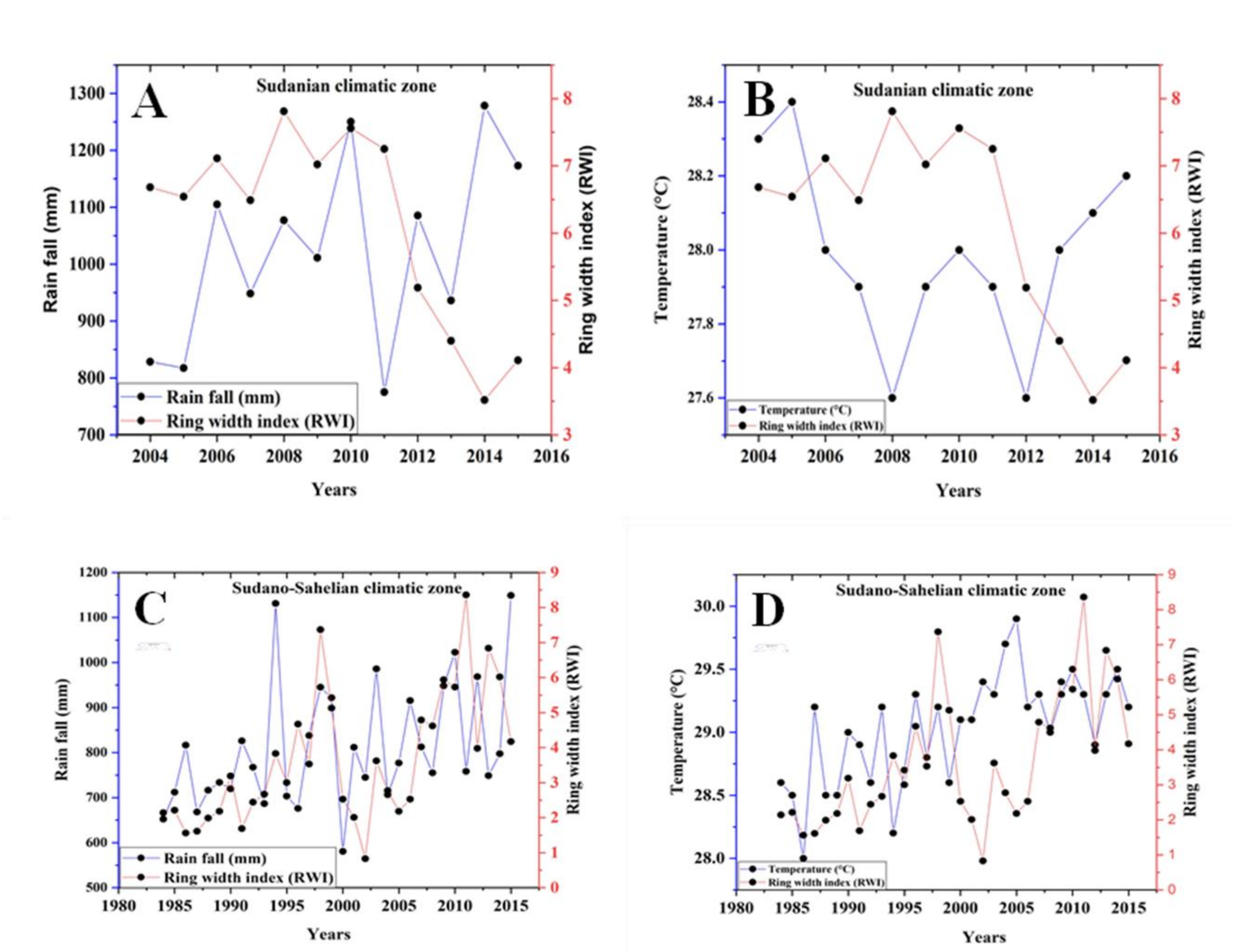

Figure 27: Correlation between annual precipitation and ring width index (RWI) of *Celtis toka*

Sudanian climatic zone (A) and Sudano-Sahelian climatic zone (C). Correlation between temperature and ring width index (RWI) in the Sudanian climatic zone (B) and the Sudano-Sahelian climatic zone (D).

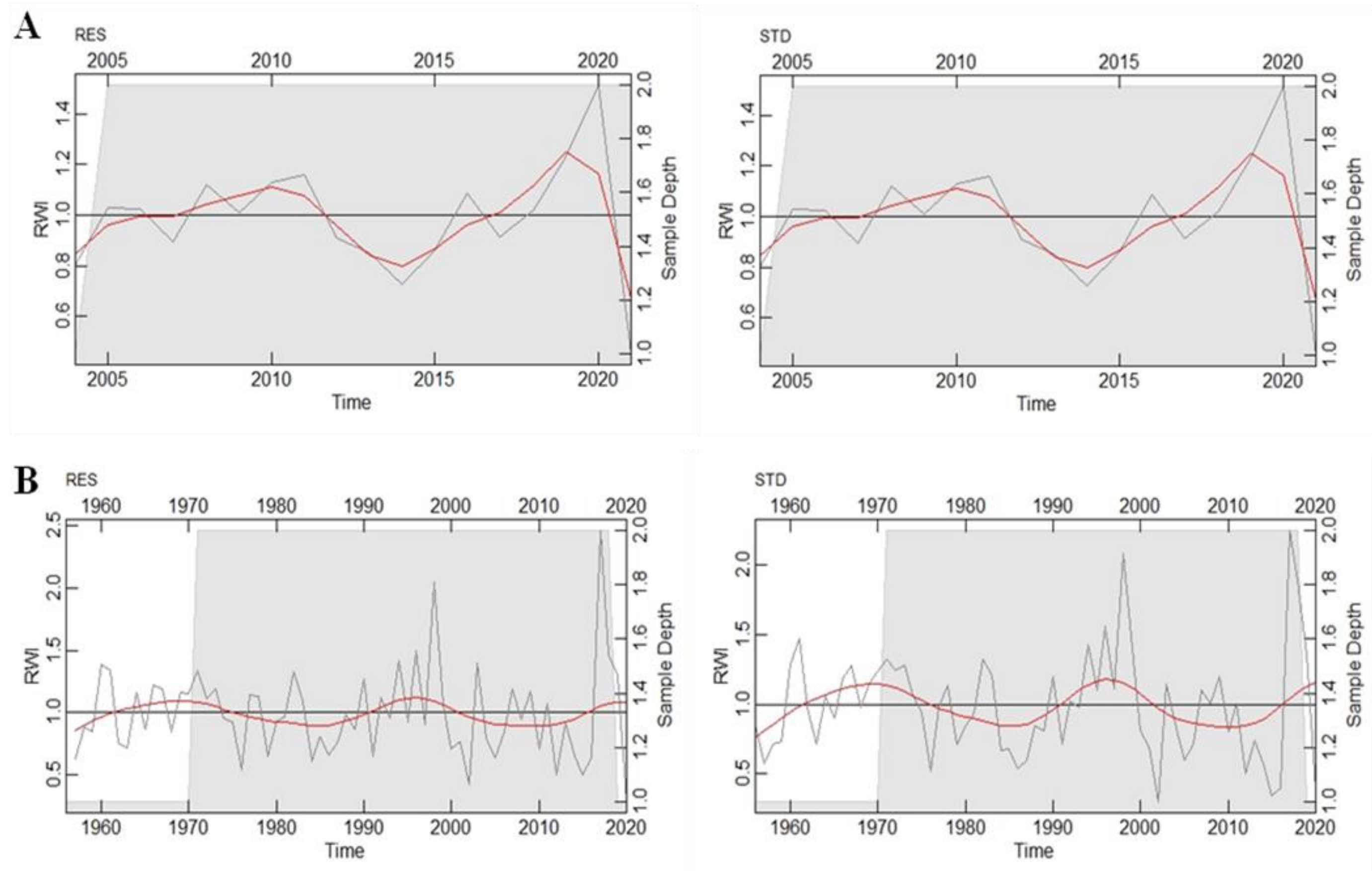

Figure 28: Residual and standard tree ring width chronologies and sample depth of *Celtis toka*.

A: Sudanian climatic zone for the years 2000-2022 and B: Sudano-Sahelian climatic zones for the years 1956 - 2020

Table 40: Statistical characteristics of tree-ring variables (ring-width and vessel) of *Celtis toka* according to climatic zones in Burkina Faso

CZ/ LUT	**Time span**	**Age range (years)**	**DBH (cm)**	**Height (m)**	**WD (g.cm^{-3})**	**GLK (%)**	**TV**	**RW**
			mean ± sd	mean ± sd	mean ± sd	mean ± sd	mean ± sd	mean ± sd
Sudanian climatic zone								
PA	17 - 18	17.5 ± 0.71	22.28 ± 1.45	8.25 ± 0.5	0.58 ± 0.08	0.88 ± 0.48	3.24 ± 3.18	5.85 ± 1.61
Sudano-Sahelian climatic zone								
UPA	50 - 63	56.5 ± 9.19	57.03 ± 6.76	8.73 – 0.4	0.56 ± 0.03	0.67 ± 0.26	4.4 ± 2.34	5.66 ± 4.88
Wilcoxon test						0.0579	0.0579	< 0.0001

CZ: climatic zones, LUT: land use types, DBH: diameter at breast height, WD: wood density, GLK: Gleichläufigkeit (sign test), TV: T-value, RW: ring width, PA: protected area, UPA: unprotected area, sd: standard deviation.

Table 41: Statistical characteristics of tree-ring variables (ring-width and vessel) of *Celtis toka* according to climatic zones in Burkina Faso (Continued)

CZ/LUT	**MVA**	**MVRD**	**MVTD**	**NV**	**TVA**	**TVAp**	**VD**
	mean ± sd	mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd
Sudanian climatic zone							
PA	0.010 ± 0.00	0.09 ± 0.02	0.11 ± 0.02	556.83 ± 360.84	5.53 ± 4.1	10.38 ± 3.51	10.78 ± 2.81
Sudano-Sahelian climatic zone							
UPA	0.010 ± 0.01	0.09 ± 0.01	0.12 ± 0.03	531.89 ± 206.70	5.43 ± 3.1	10.53 ± 2.15	11.61 ± 3.17
Wilcoxon test	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

MVA: mean vessel area, MVRD: mean vessel radial diameter, MVTD: mean vessel tangential diameter, NV: number of vessels, TVA: total vessel area, TVAp: total vessel area percentage, VD: vessel density, sd: standard deviation, PA: protected area, UPA: unprotected area.

Two site chronologies of *Celtis toka* were also used to find the effect and extent of the fires. One of the fire scars had long-term negative effects (up to 4 years) on tree growth in the years of 2003. Fires of 1978, 1979, 1985, 1991, 1993, 1994, 1997, 1999 and 2018 are seen in both sites, suggesting that these fires spread over large areas (Figure 32 D).

3.3.4. Above-ground biomass and carbon stocks of *Celtis toka* species in the Sudanian and the Sudano-Sahelian climatic zone of Burkina Faso

The total above-ground biomass (AGB) of *Celtis toka* in the Sudanian climatic zone was 51.44 ± 6.87 (Mg/ha). This equates to 34.39 ± 6.6 (Mg/ha) in protected areas and 87.68 ± 15.49 (Mg/ha) in unprotected areas. This biomass corresponded to a total aboveground carbon stock of 25.72 ± 3.43 (Mg/ha), for a mean total density of 70.54 ± 18.1 trees/ha. Regarding the Sudano-Sahelian climatic zone, the total aboveground biomass of *Celtis toka* was 69.21 ± 13.38 (Mg/ha). This corresponded to 43.78 ± 8.60 (Mg/ha) in protected areas and 107.06 ± 30.08 (Mg/ha) in unprotected areas. This AGB accounted for 43.78 ± 8.60 (Mg/ha) in protected areas and 107.06 ± 30.08 (Mg/ha) in unprotected areas. This biomass had a total aboveground carbon stock of 34.60 ± 6.69 (Mg/ha), corresponding to a mean total density of 23 ± 3.83 trees/ha (Table 43). The aboveground biomass as well as the aboveground carbon stock differ significantly ($P < 0.05$) between climatic zones and land use types in both climatic zones. Both were high in both the unprotected areas. The unprotected areas of the Sudano-Sahelian climatic zone had the highest aboveground biomass (107.06 ± 30.08) and carbon stock (53.53 ± 15.04) values, while the protected areas of the Sudanian climatic zone had the lowest aboveground biomass (34.39 ± 6.6) and aboveground carbon stock (17.20 ± 3.29) values.

3.4. ASSESSMENT OF THE POTENTIAL IMPACT OF CLIMATE CHANGE ON THE GEOGRAPHICAL DISTRIBUTION OF *Celtis toka* IN BURKINA FASO

3.4.1. Importance and contributions of bioclimatic variables, and validation of the model

Correlations analysis and the Jackknife AUC test identified eight bioclimatic variables as the most significant contributors to the model throughout the study area.

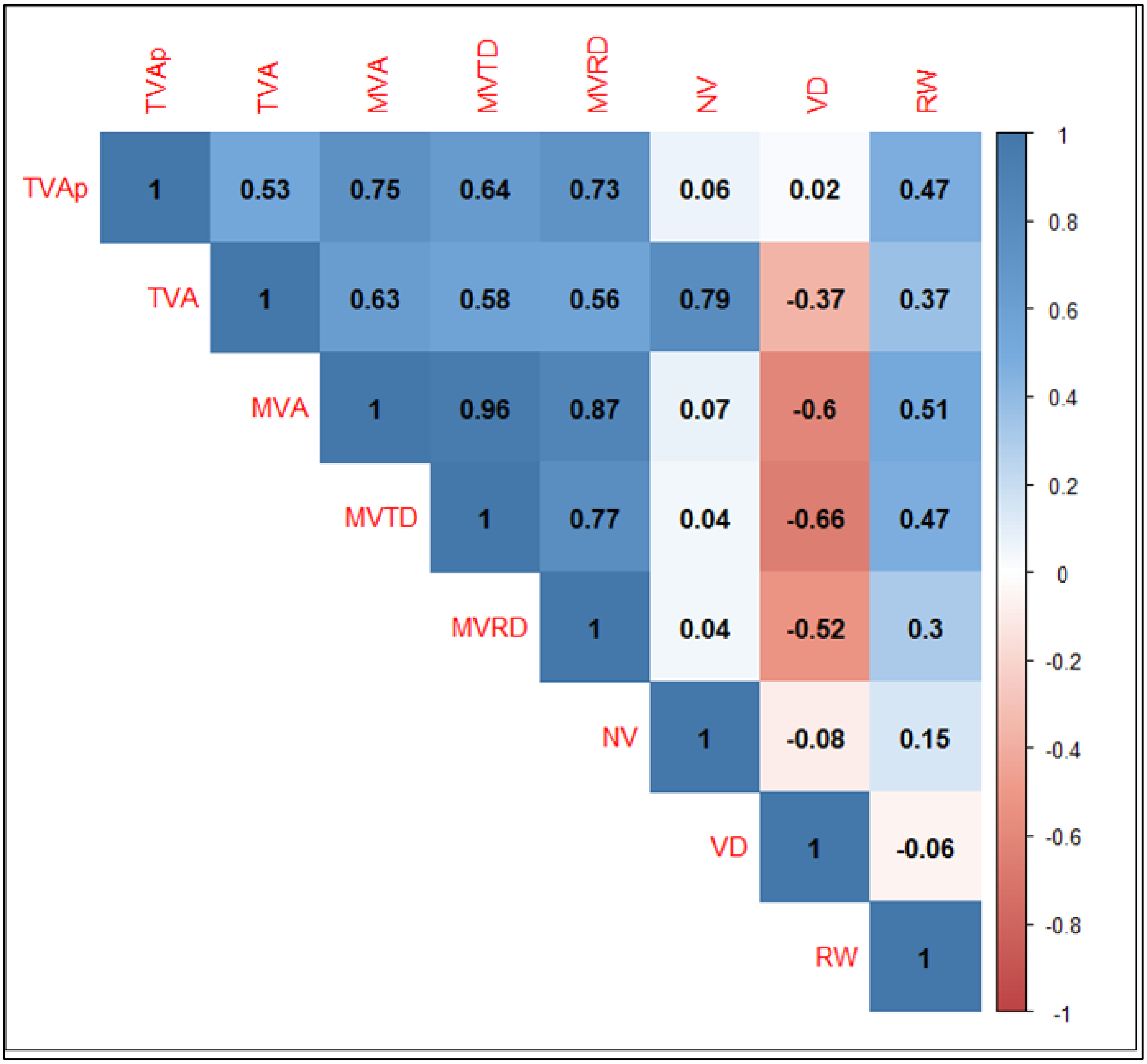

Figure 29: Pearson’s correlation matrix showing the correlation between wood anatomical traits.

MVA: mean vessel area; MVRD: mean vessel radial diameter; MVTD: mean vessel tangential diameter; RW: ring width; TVA: total vessel area; TVAp: total vessel area percentage; VD: vessel density; VN: vessel number.

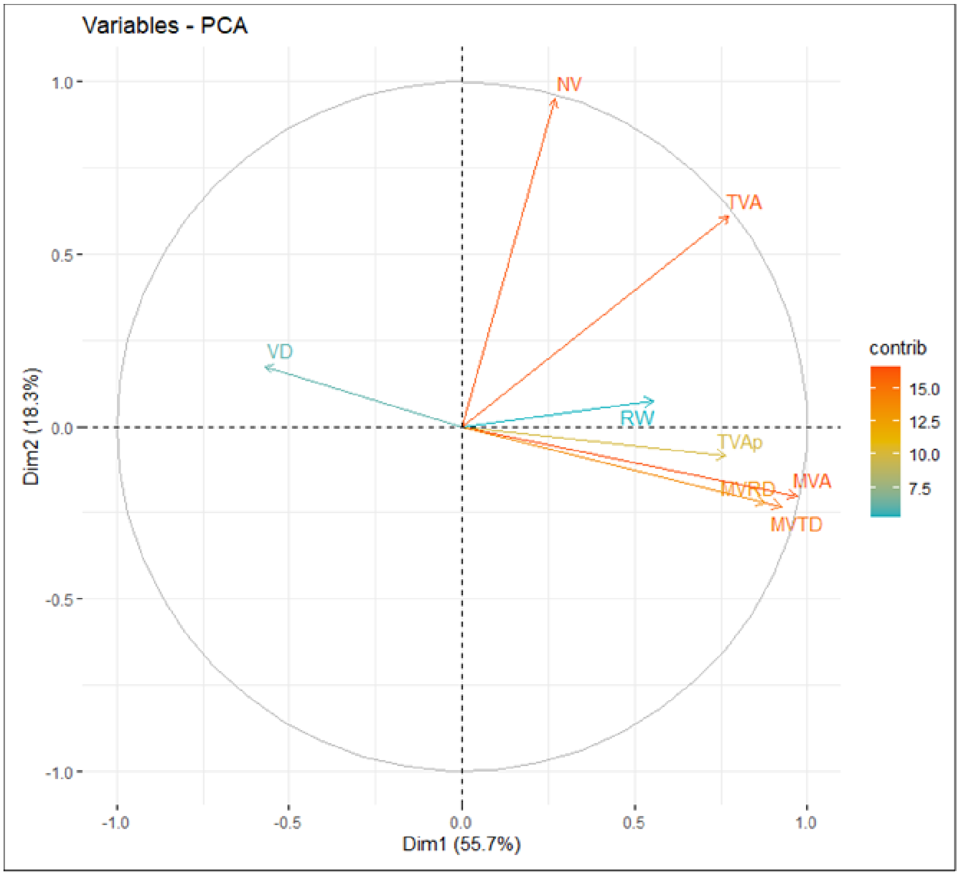

Figure 30: Projection of anatomical characteristics of wood the principal components.

MVA: mean vessel area; MVRD: mean vessel radial diameter; MVTD: mean vessel tangential diameter; RW: ring width; TVA: total vessel area; TVAp: total vessel area percentage; VD: vessel density; VN: vessel number.

Table 42: Correlation of wood anatomical traits to the principal components.

Variables	**PC1**	**PC2**
TVAp	0.76	-0.08
TVA	0.77	0.61
MVA	0.97	-0.20
MVTD	0.93	-0.23
MVRD	0.88	-0.22
NV	0.27	0.95
VD	-0.57	0.17
RW	0.55	0.07

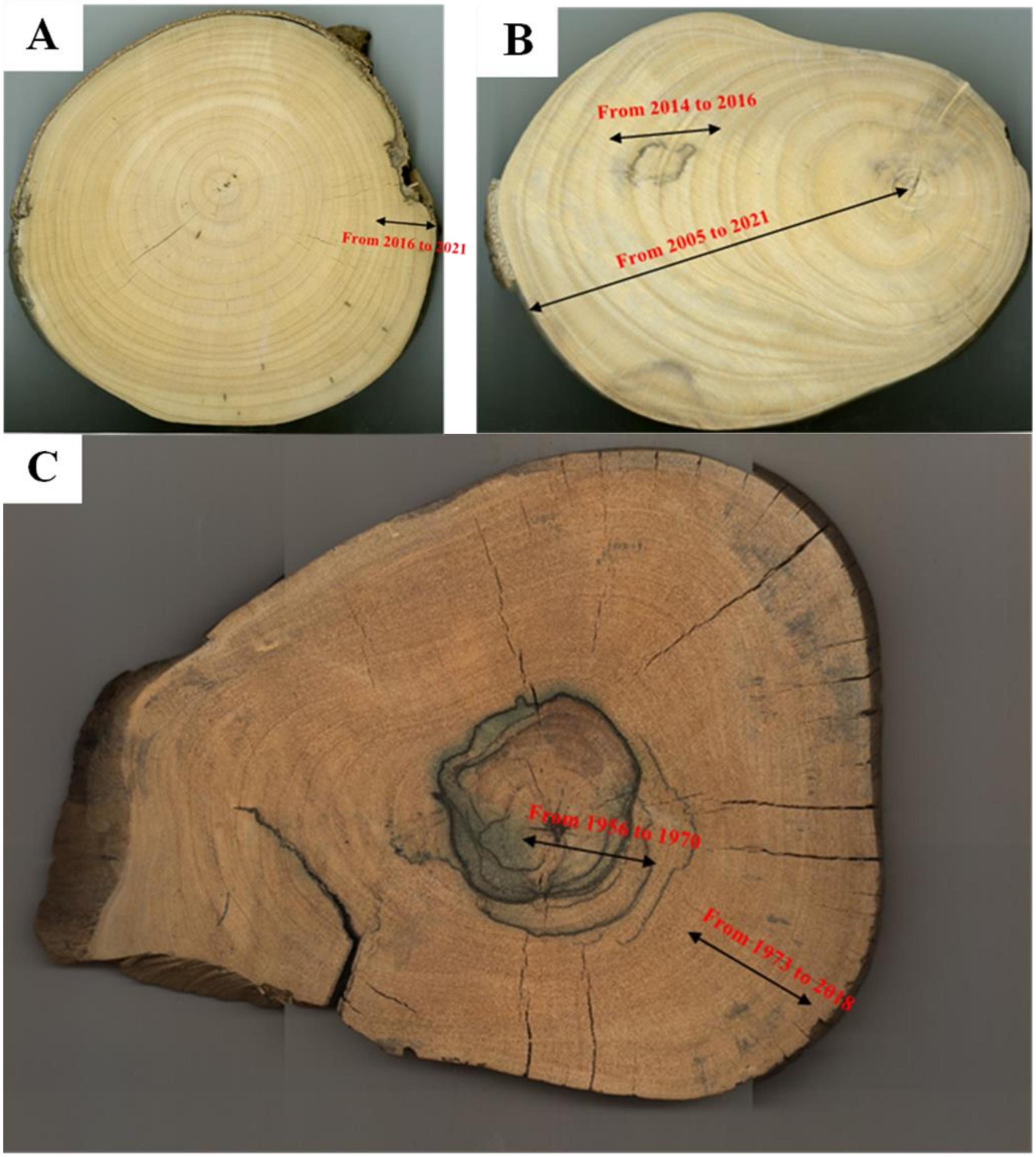

Figure 31: Demonstration images of a cross-dated disturbance.

Pictures: Dabré, 2022.

Reconstruction of debarking (A), climate and fungi (B) histories in the Sudanian climatic zone, fungi (C) in the Sudano-Sahelian climatic zone. Disc A was cut from a cutting tree, B was from a fallen tree and C was the snag tree.

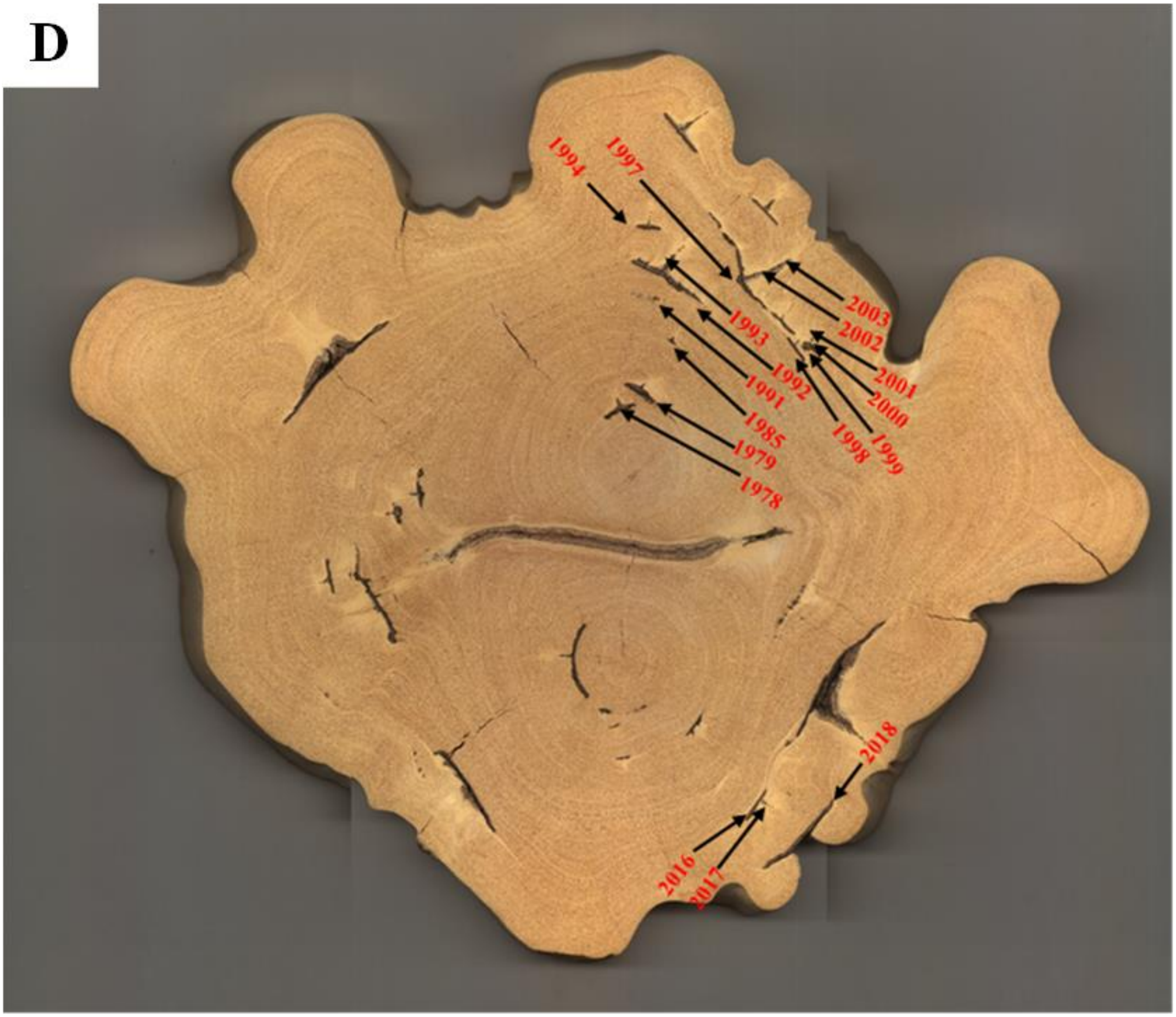

Figure 32: Demonstration images of a cross-dated disturbance.

Picture: Dabré, 2022.

Reconstruction of fire scars (D) histories in the Sudano-Sahelian climatic zone of Burkina Faso. Disc D was cut from a snag tree.

Table 43: AGB and carbon stock of *Celtis toka* across CZ and LUT in Burkina Faso

CZ/LUT	n	DBH (cm) Mean ± se (mean)	Height (m) Mean ± se (mean)	Density (tree/ha) Mean ± se (mean)	AGB (Mg/ha) Mean ± se (mean)	Carbon (Mg/ha) Mean ± se (mean)
Sudanian climatic zone						
PA	156	36.49 ± 2.59	9.34 ± 0.33	102.33 ± 28.56	34.39 ± 6.6	17.20 ± 3.29
UPA	71	67.61 ± 5.40	9.13 ± 0.45	38.75 ± 7.64	87.68 ± 15.49	43.84 ± 7.74
Sum	227	46.45 ± 2.64	9.27 ± 0.27	70.54 ± 18.1	51.44 ± 6.87	25.72 ± 3.43
Kruskal-Wallis	χ^2	19.16	1.22	6.275	18.65	18.65
	P-value	< 0.000	0.2703	0.0057	< 0.000	< 0.000
Sudano-Sahelian climatic zone						
PA	73	47.76 ± 4.52	8.72 ± 0.45	34.06 ± 6.88	43.78 ± 8.60	21.89 ± 4.30
UPA	39	84.45 ± 7.11	9.42 ± 0.43	11.94 ± 0.77	107.06 ± 30.08	53.53 ± 15.04
Sum	112	62.50 ±4.27	8.99 ± 0.32	23 ± 3.83	69.21 ± 13.38	34.60 ± 6.69
Kruskal-Wallis	χ^2	28.36	0.059	6.275	14.99	14.99
	P-value	< 0.000	0.8081	0.0057	< 0.000	< 0.000

CZ: climatic zones, LUT: land use types, n: number of individuals. DBH: diameter at the breast height, AGB: aboveground biomass, se: standard error of the mean, PA: protected areas, UPA: unprotected areas

Temperature range was the most contributing predictor (29. 5 %) driving the species distribution whereas min temperature of the coldest month (0.4%) was the least contributing variable (Table 44).

The Jackknife tests (Figure 33) revealed that bio7 (temperature annual range) is the environmental variable that reduces the gain the most when it is removed. When used alone, this variable is also the environmental variable with the highest gain. As a result, the temperature annual range appears to have the most useful information by itself as well as the most information that is not present in the other predictors.

The distribution model of *Celtis toka* is highly predictive, with a mean cross-validated AUC equal to 0.812 ± 0.081 (Figure 34). Similarly, the model demonstrated excellent predictive power (TSS: 0.891 ± 0.061) over random. This indicates that the predicted model is highly predictive.

3.4.2 Spatial distribution of *Celtis toka* under current and future climate change in Burkina Faso

The potential current suitable habitats for the species account for 54.77 % of Burkina Faso's land surface (Table 45). These habitats cover approximately 150300.3 km2 and are spread across the three climatic zones of the country (Figure 35). Under the current climatic conditions, approximately 45.23 % of the national territory is unsuitable for the conservation of *Celtis toka*.

Under the two emission scenarios, all climate models predicted a decrease in the extent of the suitable habitats of the species at the horizon 2041-2060 (Table 40, Figure 35). According to the ssp245, suitable habitats represented 26.96 % (73989.04 km^2) to 34.12 % (93634.79 km^2) of Burkina Faso's total land surface, corresponding to habitat loss of 20.65 % and 27.81 % by 2041-2060. Likewise, under the ssp585, approximately 5.94 % (16306.55km2) to 6.70 % (18390.37 km2) of the country surface was predicted to be suitable by 2041-2060, corresponding to 48.07 % - 48.83 % loss in the suitable habitats of the species. Under the ssp245, the projected suitable habitats range from 18996.31 km2 (6.92%) to 80989.04 km2 (29.51 %) at the horizon 2081-2100. By 2081-2100, the ssp585 predicted drastic changes in the species' spatial patterns, with suitable areas ranging from 1119.68 km2 (0.41 %) to 4119.68 km2 (1.50 %).

The range of habitat loss predicted for the species varies between climate models, emission scenarios, and horizons. Under the ssp245, and the horizon 2041-2060, the model MIROC6 predicts higher habitat loss (27.81 %) of the species than the model HadGEM3-GC31-LL (20.65 %). Similar results are obtained with scenario ssp245 and horizon 2041-2060. In contrast, MIROC 6 predicted low habitat loss (48.83 %) under the ssp585 for the horizon 2041-2080. For the horizon, 2081-2100, HadGEM3-GC31-LL predicts low habitat loss (53.27 %) under ssp585.

Table 44*:*Variables contribution in the prediction of *Celtis toka*'s geographic distribution

Code	**Description**	**Percent contribution**	**Permutation importance**
Bio7	Temperature Annual Range (BIO5-BIO6)	29.5	32.2
Bio10	Mean Temperature of Warmest Quarter	19.2	14.5
Bio4	Temperature Seasonality (standard deviation ×100)	18.4	16.7
Bio15	Precipitation Seasonality (Coefficient of Variation)	16.4	22.7
Bio9	Mean Temperature of Driest Quarter	7.7	2.5
Bio19	Precipitation of Coldest Quarter	6.8	4.2
Bio13	Precipitation of Wettest Month	1.7	5.7
Bio6	Min Temperature of Coldest Month	0.4	1.3

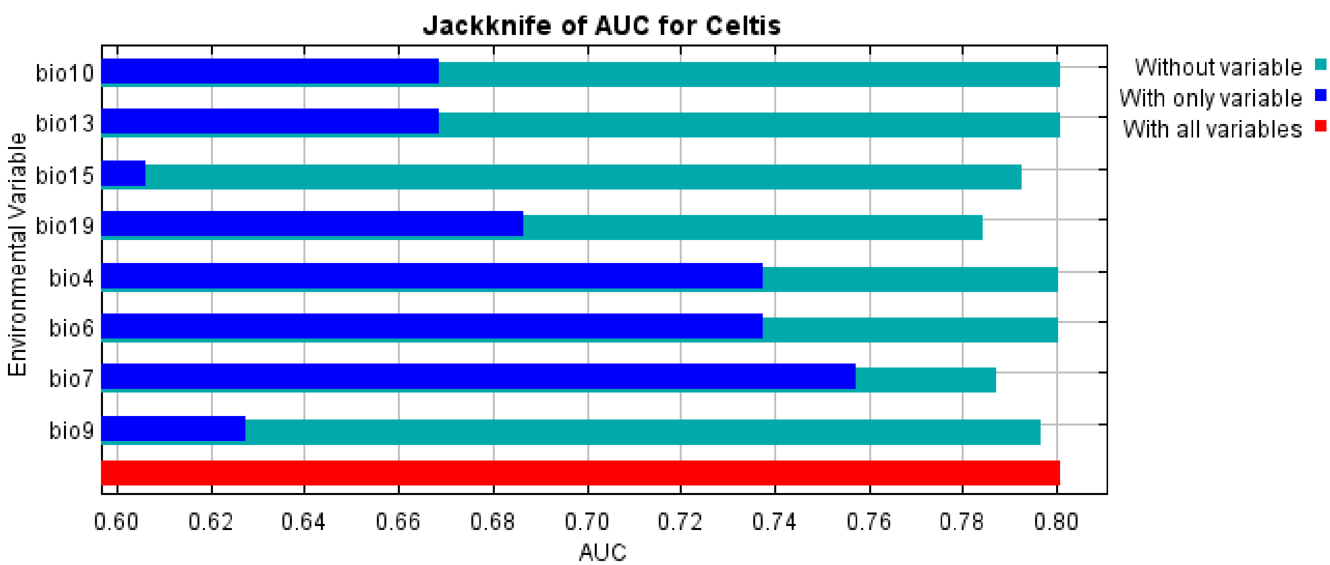

Figure 33: Results of a jack-knife test for regularized training gain for *Celtis toka*.

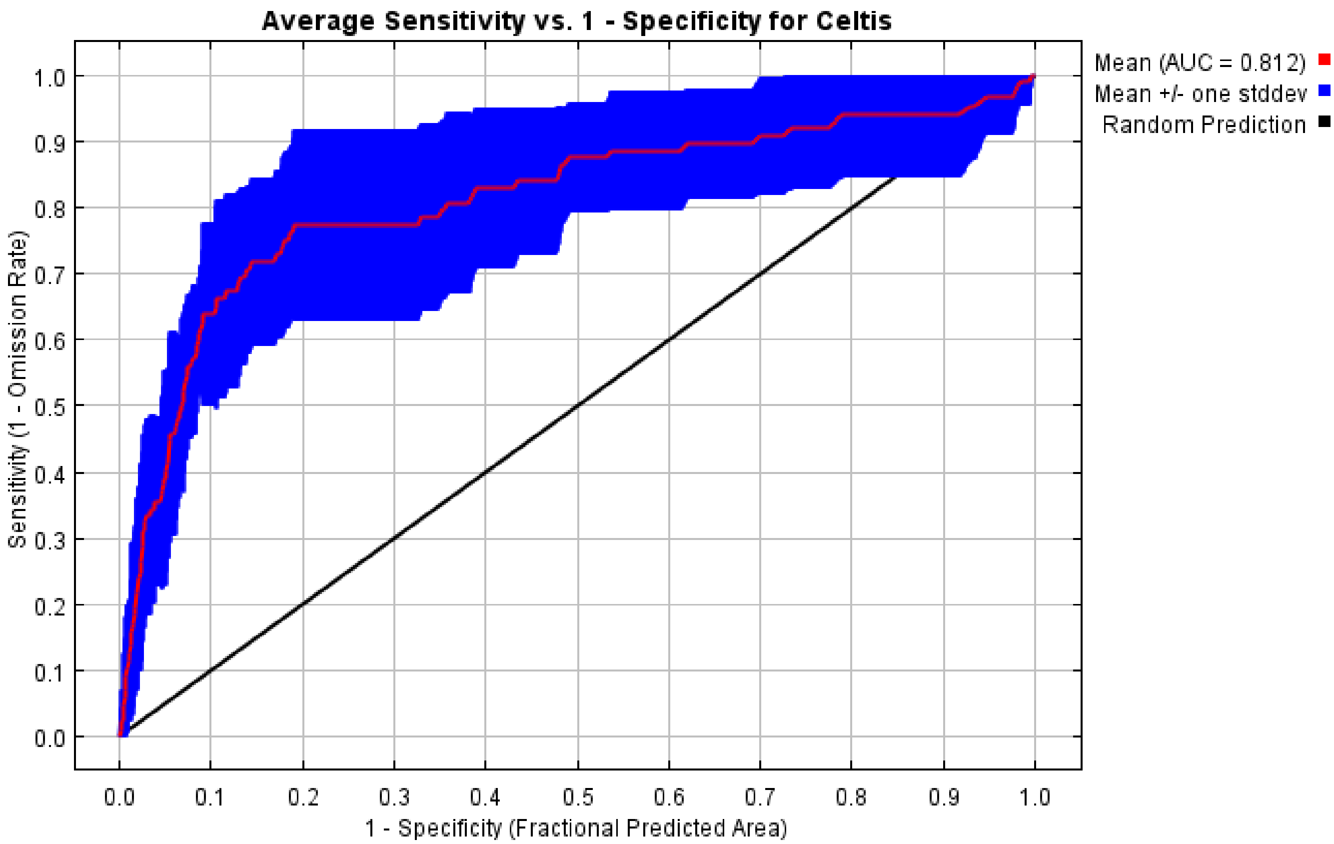

Figure 34: Results of the cross-validated areas under the receiver operating characteristic curve (AUC).

Table 45: Current and future geographic distribution of *Celtis toka* in Burkina Faso

Habitat suitability	Current		ssp245			ssp585		
	Areas (Km2)	(%)	Areas (Km2)	(%)	Trend (%)	Areas (Km2)	(%)	Trend (%)
			HadGEM3-GC31-LL (H)					
			2041-2060					
Suitable	150300.3	54.77	93634.79	34.12	-20.65	18390.37	6.70	-48.07
Unsuitable	124099.7	45.23	180765.21	65.88		256009.63	93.30	
			2081-2100					
Suitable	150300.3	54.77	80989.04	29.51	-25.26	4119.68	1.50	-53.27
Unsuitable	124099.7	45.23	193410.96	70.49		270280.32	98.50	
			MIROC6 (M)					
			2041-2060					
Suitable	150300.3	54.77	73989.04	26.96	-27.81	16306.55	5.94	-48.83
Unsuitable	124099.7	45.23	203410.96	74.13		258093.45	94.06	
			2081-2100					
Suitable	150300.3	54.77	18996.31	6.92	-47.85	1119.68	0.41	-54.37
Unsuitable	124099.7	45.23	255403.69	93.08		273280.32	99.59	

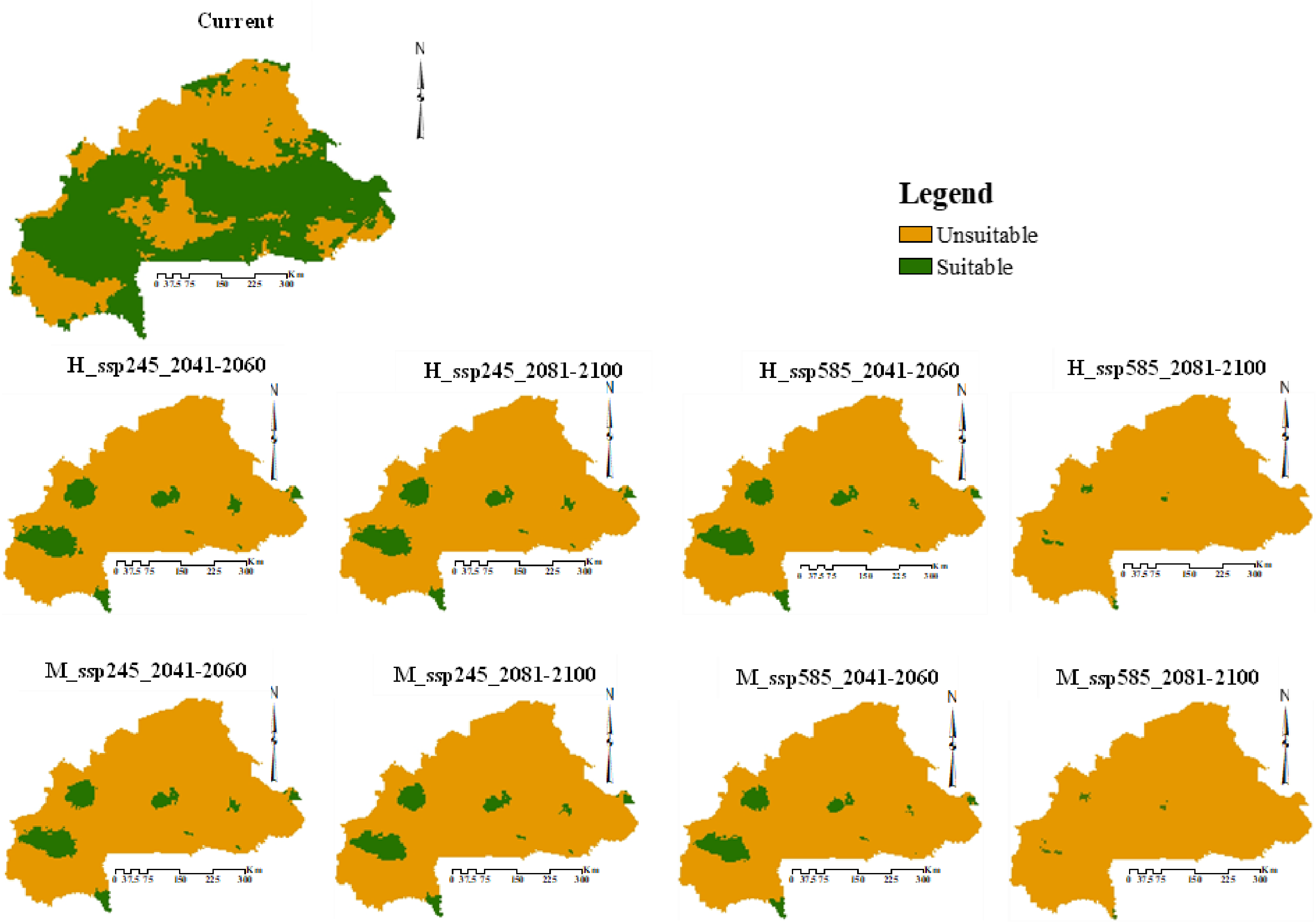

Figure 35: Geographic distribution of *Celtis toka* under the models H and M.

CHAPTER IV: DISCUSSION

Globally, 49 specific local names were given to *Celtis toka* although some informants were not able to give the exact meaning of the name of the species in their respective mother tongues. Some vernacular names perceived by local people could be a pointer to how vital the species is in their culture. Based on the value and the use of the plant parts, local names of *Celtis toka* differ from one ethnolinguistic group to another. "Nongon Na baa", "kamignan", "Sondeyni or Seideni" respectively in Dioula, and Bobo and which mean delicious stew made from fresh dried and pounded leaves. "Ganki" denotes the use of the species as fodder by Fulani culture. The local name Ganki has been stressed by Fulani in Cameroon (Seignobos, 2014). *Celtis toka* is a wild food tree, some of them were considered either a "taboo" "sacred" "magic" or even a ''fetish'' where their areas any person (mostly children, women, and strangers) should not point the finger or worse go under it. It is for instance the case of local names "Djo", "Djo la la", "Yobo", and some vernacular names "Kamignan", ''Mabri'', ''Mambri'', "Sondeyni or Seideni", ''Yibiligou'' and ''Yibourougou''. Most custom or cultural ritual activities and decisions of elders are taken under *Celtis toka* as stressed by Belemsobgo *et al*. (2010) and Gilbert *et al*. (2019).

The food use stated throughout this study concerned mostly leaves followed by fruits and seeds. They were eaten by both humans and animals (cows (leaves), sheep (leaves), birds (fruits), some small ruminants (fruits, leaves), some mammals (leaves, fruits), termites (leaves, fruits) etc.,). Plant parts are mainly eaten by children (fruits and seeds) and adults (fruits) during times of shortage. Fruits and seeds were taken raw by local people. Local communities (Bobo and Bwaba) mostly used dried fresh leaves to cook delicious stew. However, 28.06 % of respondents believed that the stew of *Celtis toka* is as sweet as *Adansonia digitata* L. stew. Edible plant parts reported in this study are also consumed raw in Burkina Faso (Hahn-hadjali and Thiombiano, 2000; Lykke *et al*., 2004) and other parts of Africa during plenty and food scarcity (Seignobos, 2019; Teklehaymanot and Giday, 2010; Arbonnier, 2019). Hence, the high value (61.23 %) of leaves in food might be attributed to the fact that leaves are not toxic (Geidam and Adole, 2014; Mahre *et al*., 2017; Abah *et al*., 2018). In the study sites, fruits were often difficult to find because of the competition between birds, mankind (severe pruning) and the probability of the low productivity of the species. Some local people thought that *Celtis toka* does not produce any fruits. This could be the reason for the overharvesting of either leaves or fruits. According to informants, fruits and seeds were as sweet as *Ziziphus mauritiana* Lam. fruits and *Sclerocarya birrea* (A. Rich.) Hochst.

seeds. In Ethiopia for instance, food insecurity was combated by combining fruits of *Celtis toka* with some wild edible plants (Lulekal *et al*., 2011). Moreover, in Senegal, *Celtis toka*'s fruits were consumed by Malinke culture (Gueye *et al*., 2014). Besides, the nutrient contents, amino acids, and proteins of *Celtis toka* leaves could explain why they are valued by locals. In Nigeria for instance, many studies have shown that leaves were rich in mineral elements such as Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Copper (Cu), Zinc (Zn), Lead (Pb), Iron (Fe), Manganese (Mn) and Cadmium (Cd) (Kubmarawa *et al*., 2011; Abah *et al*., 2018; Tadzabia and Dimas, 2020). Furthermore, leaves content of 8.20 % as proteins and Lysine, Threonine, Cysteine, Valine, Methionine, Isoleucine, Leucine, Tyrosine, and Phenylalanine as amino acids (Kubmarawa *et al*., 2011). However, plant protein provides health and physical function to mankind (Hertzler *et al*., 2020). Besides, coumarins, flavonoids, mucilage, triterpenoids and steroids are phytochemical constituents of *Celtis toka* leaves' (Fall *et al*., 2017). Locals also used the species as energy (firewood and charcoal), but due to the scarcity of *Celtis toka*, they replaced it with other species. Moreover, informants sometimes used either the wood from fallen trees, or the branches cut during the agricultural installation to generate their energy. In addition, this species is seldom used as charcoal.

This ecologically, socio-economically (Diémé *et al*., 2018), cultural and sociocultural species were furthermore highly valued as fodder for the animals in the Sudano-Sahelian climatic zone (23.70%) than in the Sudanian climatic zone (14.23%). This could probably be the reason for the installation of Bella people who pruned leaves to feed their cattle. The use of the species as livestock is in agreement with the findings of several authors (Blench, 2000; Lykke *et al*., 2004; Piqué *et al*., 2016; Arbonnier, 2019). This survey puts in evidence a weak building of *Celtis toka* in shed and house constructions due to the lightness of the wood and the high attacks of ants. Few (0.84 %) informants from the Sudanian climatic zone only used it for cooking (wooden spoon) and farming tools (daba). In the study area, 10.16 % of local people acknowledged that *Celtis toka* is used to heal 29 diseases. However, several diseases testified in this study had been mentioned by many studies in Africa. The healing action of *Celtis toka* in cases of sore, malaria, mycosis, headache, and mental disease was in agreement with previous studies (Hahn-hadjali and Thiombiano, 2000; Betti *et al*., 2011; Arbonnier, 2019; Diatta *et al*., 2019). Leaves, roots, bark, seeds, and flowers were used in preparing traditional human and animal medicines. Roots were the greatest used plant parts and were used against ringworm, diarrhoea, backache, toothache, ulcer, measles, and chickenpox. Moreover, they were also used in the treatment of rheumatism, paralysis, epilepsy, sterility and mental diseases (Abah *et al*., 2018; Arbonnier, 2019). However, Betti *et al*. (2011) have reported that barks were sold in Cameroon and they were used in curing hernia, and intestinal helminthiasis. In Burkina Faso, no toxicological tests have approved the effectiveness of the formulation in disease treatments like in Nigeria (Geidam and Adole, 2014; Mahre *et al*., 2017; Abah *et al*., 2018). Therefore, this medicine use should be taken with attention. Even though *Celtis toka* is a mystic or sacred tree, it is pruned and/or debarked by some locals. Promoting *Celtis toka* will help with food security, provide income for women, provide good health and well-being; and treat a variety of diseases as four of the 17 internationally supported United Nations Sustainable Development Goals (SDGs) declared by the United Nations.

In the research areas, sacred (37.99%), taboo (25.04%), mystic (11.62%), magic (10.28%), fetish (8.96%) and medico-magic (6.12%) were six specific uses of *Celtis toka*. Sacred, taboo and fetish characters are places of cults where custom and ritual sacrifices are attached to *Celtis toka. Celtis toka* plays a medico-magic role in the local community. For instance, it heals diseases mystically transmitted by humans and evil spirits. The mystical aspect refers to the nature of supernatural forces (demons and evil spirits) involved in *Celtis toka*. The term sacred tree has been highlighted by (Seignobos and Tourneux, 2002). Indigenous biodiversity conservation strategy (Fournier, 2011; Savadogo and Adjima, 2010) underpins all of this. The mystical aspect of the species could be related to its habitat of the species. The species mostly occurs in galleries forests and rocky zones.

Additionally, most of the species are giant evergreen trees where demons and/or spirits could shelter. Diversity and distribution of knowledge on the use patterns of *Celtis toka* were heterogeneous among various socio-professional groups. However, farmers (UD:0.51; UE: 1) have a perfect distribution knowledge of the use of *Celtis toka* than other socio-professional groups. This could be explained by the fact that farmers made up most of the interviewees. Moreover, farmers are more familiar with the species than other socio-professional groups. Thus, this knowledge varies among farmers as itemized by (Poncet *et al*., 2021).

Furthermore, the study emphasizes differences in some form of uses across the ethnolinguistic groups, ages and sex as stated by Gouwakinnou *et al*. (2011) on *Sclerocarya birrea* (A. Rich.)

Hochst., Balima *et al*. (2018) on *Afzelia africana* Sm, Goudégnon *et al*. (2018) on *Lannea macrocarpa* Engl. & K.Krause, Avakoudjo *et al*. (2019) on *Strychnos spinosa* Lam., and Ouédraogo *et al*. (2019) on *Gardenia erubescens* Stapf & Hutch. Local people have very rich ethnobotanical knowledge due to the diversity of ethnolinguistic groups. Yet, the knowledge differs from one ethnolinguistic group to another for food, energy, and pharmacopoeia use in the Sudano-Sahelian climatic zone. These differences within ethnolinguistic groups were due to respondents having different backgrounds. However, food, fodder, pharmacopoeia, culture, and customs use are basic needs for locals living in both climatic zones. They are crucial for farmers, traditional healers, and breeders of Bobo, Bwaba, Dioula and Dafing cultures.

All use patterns were treasured by men compared to women. The difference could be explained by the fact that female informants comprised fewer groups than male informants. Additionally, men were either farm owners, farmers and breeders or farmers and traditional healers. Also, custom and cultural activities were made by men. Women were mostly housemaids and sometimes traders. In the Sudanian climatic zone, elderly people placed a higher value on *Celtis toka* in *the* pharmacopoeia, sacred and magic use than the adults. In contrast, adult informants from the Sudano-Sahelian climatic zone cherished less *C toka* in most use categories (food, fodder, sacred, magic, energy, and building). This could be the reason for the cultural erosion due to the rise of imported religions (Islam and Christianity) or the lack of knowledge of young people on *Celtis toka* use. In addition, young people may not inherit knowledge from their parents. Besides, because the species is uncommon in most communal areas, young people may be unfamiliar with the species.

Differences in plant parts used were also highlighted across ethnolinguistic groups, ages, and sexes. Leaves, roots, barks, and fruits were more valued by Bobo and Dafing cultures. In the Sudano-Sahelian climatic zone, women tended to place more importance on seed use, whereas men placed more importance on leaves and roots. Because women spent more time with children, they were more aware of the species' seed uses. Children in the study area primarily removed seeds from fruits and chewed them like *Sclerocarya birrea* (A. Rich) Hochst seeds.

Deciduous, semi-deciduous or evergreen semi-deciduous tree *Celtis toka* (Diémé *et al*., 2018; Alfaifi *et al*., 2021) was abundant and spread in the Sudanian climatic zone compared to the Sudano-Sahelian climatic zone. Results showed that the wild species were further found in sacred forests, rocky areas, farmlands, and protected areas of the Sudanian climatic zone. This could be justified by the fact that the Sudanian climatic zone is better-wetted than the Sudano-Sahelian climatic zone. Hence, some interviewees of the Sudanian climatic zone believed that *Celtis toka* only appeared in old compounds (where ancestors lived before). However, this is hard to prove without a stronger investigation. In Saudi Arabia, Alfaifi *et al*. (2021) stressed that the magic tree habit was rocky, slope or valley bottom. Moreover, this was confirmed by several studies across Africa. In the Sahel, the species biotope is a valley (Lykke *et al*., 2004). Thus, *Celtis toka* is either settled in riparian areas, gallery forests, berg of water bodies, dense dry forests or savanna frameworks (Sambare *et al*., 2010; Sambaré *et al*., 2011; Höhn and Neumann, 2016; Arbonnier, 2019). In the study sites, management such as sowing, seedling transplantation and assisted natural regeneration were all lacking. No individuals were found planted next to houses. This could be explained by the huge size and mystic aspect of the species. In most cases, the species were pruned either by breeders or farmers.

Mystic, fetish, sacred, taboo, magic, or medico-magic species are the traditional strategies for the conservation of *Celtis toka*. However, the more a species was known as taboo, the more it was a luxury to the local population. Hence, (Gaoue *et al*., 2017) highlighted taboo as a conservation strategy used by native people to preserve heavily threatened species. Sacred areas are where earth sacrifices are made and where the earth chiefs are buried (Seignobos and Tourneux, 2002). Most people across the study sites have reported that the species was sacred. However, according to residents, activities such as custom, culture, or ritual were taken under the species. For instance, under the majority of *Celtis toka* trees were tools such as hen feathers, canaries or pieces of canaries, cowries, coins, and eggs which witnesses the ritual activities. Moreover, according to Bobo elders, any problems were solved when rituals are done under *Celtis toka* tree. This could be due to the good spirit that shelters *Celtis toka*. Sociolinguistic groups such as Bobo, Bozo, Bwaba, Dafing and Mossi thought that some of the species were mystics because they believed that they were haunted, and represent the presence of evil spirits, genies, and demons. Therefore, the mystical *Celtis toka* possessed power beyond human conception. In addition, some people across the study sites have emphasized that the species was magic like it protects villages and their contents, gives worth, power, water, birth, reconciliation of couple, genuine love, and promotion in work. Additionally, according to the magical aspect, any plant parts hung in a house could sack evil spirits, witchcraft, and witches. In the Sudanian climatic zone for instance, some fishermen (Bozo) thought that the presence of the plant parts (bark or roots) of *Celtis toka* in their pirogue protects them against ferocious water animals' attacks, particularly hippopotami in rivers. Also, certain Bobo traditional healers believed that the decoction of the epiphyte found on *Celtis toka* provided worth and promotion to them. In the Sudano-Sahelian climatic zone, local people from Kaminiankoro (a village named after the local name of *Celtis toka* (Kaminian)) believe that the species provides them with long life, protection, joy, and peace. Besides, according to some Mossi cultures, the death of an individual of *Celtis toka* raises the death of the chief of the village. As a result, local people (Bobo, Bozo, Mossi, traditional healers, hunters, elders etc.,) highly hold the species as a fetish, mystic, sacred, magic, or taboo tree which were their approaches to sustainability and conservation.

The spatial dynamic of *Celtis toka* was declining in the study area. This could be explained by the fact that the species was once rare. Moreover, human action could be the reason for the decrease. Most youth were unaware of the value of species, therefore, they cut juveniles as well as adults. In addition, to install farms, some locals cut *Celtis toka* individuals. In addition, habitat loss could be the factor responsible for the changes in the species' population dynamic. However, the transformation of the species' habitat (gallery forests) by market gardening or exotic plants could explain its decline. For instance, in Sudanian climatic zone, the habitat of *Celtis toka* was converted into vegetable crops (such as tomatoes, cucumbers, strawberries, eggplants, sorrels, carrots, papaya and others) and exotic tree plantations (*Mangifera indica*, *Tectona grandis, Anacardium occidentale, Eucalyptus camaldulensis, Annona muricata, Annona squamosa, Delonix regia, citrus lemon).* In the Sudano-Sahelian zone, *Celtis toka* was reported to be rare and even extinct. This extinction could be a result of a lack of regeneration to replace the ageing population of the species. Hence, *Celtis toka* has extremely small population sizes and therefore is in extreme danger of extinction. For instance, *it* was so difficult to get two or three individuals in the same area, most of them were old and isolated in their communities. Moreover, the use of the species in traditional medicine could likewise be the reason for the extinction. Climate has a greater impact on the species abundance and distribution in the Sudano-Sahelian climatic zone than in the Sudanian climatic zone because *Celtis toka* is denser in the Sudanian compared to the Sudano-Sahelian. Deforestation caused by agricultural development, infrastructure installation, as well as climatic variability, have an impact on the spatial dynamic of *Celtis toka.* Similar findings were reported by Hahn-hadjali and Thiombiano (2000); Garzuglia (2006); Thiombiano *et al*. (2010); Bayala *et al*. (2010); Savadogo *et al*. (2017) in Burkina Faso. Hence, ethnolinguistic groups, sexes and generations have diverse views on the status of *Celtis toka* due to cultural differences. Traditional knowledge of the dynamics of *Celtis toka* is influenced by ethnolinguistic groups over time. All sociocultural groups perceived the scarcity and decline character of *Celtis toka*. Bobo, Bozo, Dioula Dafing and Mossi cultures perceived the declining factor of *Celtis toka*. This is because those cultures are autochthonous and know the status of the species over time. Traditional healers (Bobo, Bwaba, Dioula, and Mossi), hunters (Bwaba) and fishermen/women (Bozo) who interact with the environment of *Celtis toka,* have a better knowledge of the species status. According to Mossi and other cultures from the Sudano-Sahelian climatic zone, the species was extinct. This could be due to overexploitation, the change in the environment and the failure of *Celtis toka* in that area. Knowledge of the declining characteristic of *Celtis toka* within a hamlet is similar from one generation to another. This could be explained by the fact that both adults and the elderly were aware of the species' status and thus noticed the decline and or extinction of *Celtis toka*.

Even though *Celtis toka* is a mystical tree, it faces diverse threats to its continued existence from various anthropogenic activities and natural factors. Extinction and decline of *Celtis toka* are due to a range of factors including overharvesting (pruning, debarking, and rooting), climate change, deforestation, ageing of the population, and farming expansion. According to rural people, overharvesting is the major threat because coupled with *Celtis toka*'s failure, plant parts of *Celtis toka* were harvested in an anarchic way. Respondents were confident that roots, leaves, and barks are a critical part of *Celtis toka* therefore its overharvesting affects the reproduction of *Celtis toka*. It has been reported that the overharvesting of bark and leaves decreased fruit production in Burkina Faso (Nacoulma *et al*., 2017). Moreover, tree development and photosynthesis are impacted by heavy pruning (Suchocka *et al*., 2021). Three percent (3%) of the rural community believed that the species is threatened due to the lack of regeneration. It may be impacted either by seed availability or seed quality. The lack of seeds may be the primary cause of the lack of regeneration as *Celtis toka* has been over-pruned to the point where it no longer produces fruits in some areas. Moreover, the lack of regeneration may also be caused by overgrazing. Four percent (4%) of locals trusted that the scarcity of the species is caused by the overgrazing of seedlings and saplings. In addition, harvesting of roots, barks and even leaves may expose *Celtis toka* to diseases such as fungi, gall, epiphytes, termites, and others. These pathogens could be the cause of the species extinction because they may affect the reproduction of *Celtis toka* on the one hand while increasing competition for nutrients and, most likely, mortality on the other hand. Yet, Boussim *et al*. (2004**)** indicated that *Celtis toka* is parasitized by a pest called *Tapinanthus globiferus*. However, Ostry and Laflamme (2009) confirmed that various fungi are pathogens of specific tree species that cause tree mortality in vulnerable trees. About 12 % of the respondents have stressed that climate change is one of the reasons for the extinction of the taboo species. They noticed that during the past 30 years, there have been drastic changes in the frequency and volume of precipitation patterns, rising of temperature and wind. However, strong winds in the savannah and rocky zones cause the aging population of the species to uproot because it lacks a taproot, while drought causes the species to dry out. Furthermore, because the ideal temperature for *Celtis toka* is between 26 and 30°C, an increase in temperature could inhibit regeneration (Watrin *et al*., 2007). According to the floods affect the habitat of *Celtis toka* by destroying the habitat and uprooting any *Celtis toka* found on the riverbanks because some of them had their roots hanging in the rivers in some way. In addition, ageing (13 %) lead to the death of *Celtis toka*. Thus, drought and pathogens can hasten this death. Franklin *et al*. (1987) demonstrated that tree death is a natural ecological process involving one or more pathogens and other microbes. Even though, the proportion of farming expansion (7 %) and urbanization (4 %) were less in the contribution of the extinction of the sacred tree *Celtis toka*. They are still a major challenge today because the population is growing, and forests are being destroyed to make way for infrastructure and farmlands. According to locals, previously, *Celtis toka* tree was not widespread (1 %) in different villages of Burkina Faso and it was not accessible even for local food, fodder, firewood, and medicine purposes. Most of the fishermen, hunters, and traditional healer were traveling to another villages in search of *Celtis toka* plant parts. Fire (6 %) impact the seeds, seedlings, sapling and even the age population of the species. Bushfires significantly reduced the abundance of seedlings by killing seedlings and reducing the seed bank of *Celtis toka* in the soil. Moreover, Furthermore, they have an impact on the trunk and hollow of adult individuals, which can lead to the species' death. Local knowledge on threat factors of *Celtis toka* was dissimilar among the ethnolinguistic groups, generation, and sex due to the diversity of cultures.

Conservation of the species and its habitat, sustainable use and promoting education and awareness were three of the five themes of the Global Strategy for Plant Conservation developed and implemented through the framework of the Convention on Biological Diversity (CBD 2002).

Planting remains the foremost solution to the threat in both climatic zones. Even though the mystic tree *Celtis toka* was scarce in study sites and extinct in some areas, no individuals were found planted near the houses. Most rural residents were willing to plant *Celtis toka* on their farms and in public places (markets, administrations, and schools) because they believed it was the best way to keep the species from extinction. Some rural residents have decided not to plant it in their yards because they trust that *Celtis toka* is a huge plant. Furthermore, the mystic nature of *Celtis toka* may have discouraged locals from domesticating the species. The second possible solution was the in-situ conservation of *Celtis toka* and its habitat (13%) against all human activities, including animal grazing, bushfires, and juvenile and adult cutting. Conserving the natural habitat requires no activity on the part of the farmers, as any agricultural exploitation carried out without respecting the 100 meters of the banks of the rivers would cause the siltation of water bodies. However, habitat conservation may be the best solution to the threat because seeds could be obtained from the remains of individuals and used to produce seedlings in nurseries. Seedlings could help with reforestation and soil restoration. For instance, *Celtis toka* could be used as a keystone plant to restore deeply destroyed ecosystems. Moreover, the reintroduction of the wild species *Celtis toka* into a restoration framework that includes the economic and ecological rehabilitation of traditional agroforestry systems may aid in the prevention of extinction. The conservation (in-situ, and ex-situ) of species is the primary solution to extinction (Oldfield 2003). Furthermore, invasive species should be eradicated in the habitat to reduce competition. According to Barney *et al*. (2013), alien invasive species change the nutrient pool and alter fire regimes. However, rural people indicated that *Celtis toka* is scarcer and threatened than *vitellaria paradoxa*, *Lannea microcarpa*, *Parkia biglobosa*, *Bombax costatum*, *Adansonia digitata*, and yet it is not protected. To reduce the rate of decline of *Celtis toka*, local people suggested associating crops with *Celtis toka*. We recommend in-situ, ex-situ, and circa-situ conservation of *Celtis toka*. Circa-situ conservation is a successful conservation strategy in traditional agroforestry systems and backyard gardens (Sanchez *et al*., 2010; Lokonon *et al*., 2021). As such, we recommend that local communities increase their capacity to cultivate the species and replant in traditional agricultural landscapes and home gardens. Promoting youth education about good practices and harvesting techniques for plant parts used in food, fodder, medicine, or for other specific uses.

From the Greek phainein, which means "to show or appear", phenology is a study of the timing of the life history events of plant species (Fenner, 1998). Flowering, leaf development, fruit production (fruiting, unripe and ripe fruits) and old leaves were phenological patterns of *Celtis toka* in the study area. However, after leaves fall, leafing, flowering, and fruiting events occur concurrently either at the same individuals or different individuals at the same period. Only a few individuals displayed leaf flushing, flowering, fruiting, unripe and ripe fruits, and old leaves all at the same time (from November to April). The majority of *Celtis toka* trees (semi-deciduous) only lost the top of their leaves while keeping the bottom leaves (old leaves). Few individuals (deciduous) have lost all leaves. While some were developing leaves, flowers, and /or fruits, others retained their old leaves (evergreen) in the same environmental condition. At times, leafing is made simultaneously with flowers, fruiting, unripe and ripe fruits. However, from the same climatic zone and land use type, *Celtis toka* population lifestyle differs among individuals. This could be due to the inter or intraspecific competition among them and other species, the invasive species, the availability of pollinator agents and/or nutrient content in the soil. In addition, this difference in the biological events could be reflected in various biotic and abiotic pressures on *Celtis toka* individuals in the community as many of them were unhealthy (parasites, termites, ants, hollows in the trunk and/or in some branches, fungi, crown gall, epiphyte, and insects' attacks) and were pruned and/ or debarked. In addition, some reasons could be the overharvesting of the plant parts of *Celtis toka* (pruning and/or debarking) as highlighted by (Nacoulma *et al*., 2017) on *Afzelia Africana* and fire action on *Celtis toka* as described by Alvarado *et al*. (2014) on Tapia woodlands. Flowering and fruiting events with few differences were highlighted in Saudi Arabia on *Celtis toka* (Alfaifi *et al*., 2021). Similar results were observed by Arbonnier (2019) where the flowering is done in the first part of the dry season. Additionally, fruits were only ripened in some unprotected areas. This could be explained by the management of *Celtis toka* (pruning) by locals and or the fertilizers used by farmers. Anderson *et al*., 2005 stressed that the variations in rainfall, temperature and solar radiation are factors that influence tree phenology in tropical savannahs. Moreover, from a given habitat of the same land use type and climatic zone, a great variety of patterns encountered in leafing, flowering, and fruiting were found among individuals of the species. However, the disturbances cited above could affect the phenology, production, function, and the structure dynamic of *Celtis toka* (Dale *et al*., 2001; Hanberry, 2021) and may be the primary drivers of the decline of the species (Pereira *et al*., 2010). Disturbances may also cause the reduction of leaf function, tree death, and shift regeneration patterns. Fire for instance could reduce hardwood ingrowth and kill seedlings (Dale *et al*., 2000). Moreover, invasive species could have an impact on *Celtis toka* via habitat destruction, competition, disease, and mortality (Dale *et al*., 2000; Seidl *et al*., 2017; Hanberry, 2021).

The floristic inventory identified a total of 290 woody species in the natural stand of *Celtis toka* which represents 54.61 % (Thiombiano *et al*., 2012) of the woody flora of Burkina Faso. Thiombiano *et al*. (2012) reported that the woody flora of the country comprises 531 species. This number of species is greater than that stated by Sambaré *et al*. (2011) in the three climatic zones of the country (196 species). This disparity could be explained by the various sampling methods used, plot sizes, and investigated habitats and landscapes. Results, also, revealed that the Sudanian climatic zone supported more richness in terms of numbers of species, genera, and families as well as the diversity of woody species than the Sudano-Sahelian climatic zone. The protected areas of the Sudano-Sahelian climatic zone recorded the lowest number of woody species. This could be explained by the degradation of the protected areas probably caused by human pressure. This could be attributed to the ongoing anthropogenic disturbances, such as the cutting of trees for firewood/charcoal, and construction as well as annual human-induced fires, in addition to climate change and heavy overgrazing, primarily, by domestic animals, but also wild animals. The resulting Sorensen similarity index was less than 0.5 (maximum1.0), indicating that there is little similarity between the two unprotected areas and that each unprotected area has its characteristic species. The woody species found in *Celtis toka* natural stand are in agreement with the work of Awas, 1997; Mahamane, 2005; Mahamane *et al*., 2008 who observed that *Diospyros mespilifomris, Tamarindus indica,* and *Anogeissus leiocarpa* were associated with *Celtis toka.*

This study compared tree density, and dendrometry characteristics among two land use types within two climatic zones: protected forests and unprotected areas (farmlands, fallow, and rocky zones). A study showed that there was a low density of *Celtis toka* in the Sudano-Sahelian climatic zone. This observation could be explained by the climatic conditions, which are 600 and 900 mm of precipitation over 4 to 5 months and temperatures ranging between 20 and 30°C (Kagambega *et al*., 2010). Additionally, *Celtis toka* grows in hot areas with arid/semi-arid to sub-humid climates; the annual temperature and precipitation limits for *Celtis toka* are given as 26-30°C and 110 - 1400 mm (Watrin *et al*., 2007; Julier, 2018), which may limit the distribution of *Celtis toka*. Precisely, there was a lower adult and young tree density respectively in the unprotected areas of the Sudano-Sahelian climatic zone and the protected areas of the Sudano-Sahelian climatic zone. In Northern Cameroon, unprotected areas had a tree density of only 0.1 *Celtis toka* individuals ha-1 (Moksia *et al*., 2019). The highest densities were recorded in protected areas (adults) and unprotected areas (young) of the Sudanian climatic zone. However, this study showed that climate and land use types have an impact on the density of *Celtis toka*. On the first hand, the lowest density observed in unprotected areas of the Sudano-Sahelian climatic zone can be partly attributed to several factors including the pressure exerted by the humans on *Celtis toka* leaves, barks, and roots, overgrazing and trampling, soil type, forest fires, flood, wind, and high variability of rainfall caused by climate change (Conway and Schipper, 2011). *Celtis toka*, on the other hand, is easily uprooted by the wind and flood actions due to its fibrous roots and the fact that it is mostly found in rivers or on riverbanks. Leaves were overharvested in the feeding of mankind and animal. Furthermore, there is a fruit harvesting competition among animals (birds and buts) and mankind. Additionally, this study compared diameter, and height size class distributions of *Celtis toka* among two land use types: protected areas and unprotected areas and two types of climatic zone: Sudanian and Sudano-Sahelian climatic zones. This is most likely due to certain recurring tree perturbations such as pruning, overgrazing, fires, debarking, and illicit cutting. The species' leaves and fruits are heavily consumed which may limit *Celtis toka* growth. Similar findings were reported for *Parkia biglobosa* in Cameroon (Moksia, *et al*., 2019), and baobab in Benin (Assogba *et al*., 2020). The SCD of diameter revealed that *Celtis toka* population structure was unstable in all land use types within the climatic zone. The instability is expressed by the scarcity and or absence of the individuals in the small or some large diameter classes. This is, however, relatively better in the protected areas of both climatic zones implying that the population of *Celtis toka* is slightly healthier in the protected areas than in the unprotected areas. This instability is exacerbated in unprotected areas of the Sudano-Sahelian climatic zone, where there are no individuals in [5-15[, [15 -25[, [25 -35[, [95 -105[, [155 – 165 [and [165 -175 [diameter classes. This could be due to juvenile cutting, overgrazing, forest fires, death of large trees, or the large tree being uprooted by flood or wind. In general, a higher proportion of juveniles compared to adult trees results in an inverse J-shaped SCD curve, indicating a healthy and potentially growing population (Condit *et al*., 1998). However, protected areas of both climatic zones are slightly inverse J-shaped compared to unprotected areas showing a bell-shaped or bimodal curve (Figure 20b and 20d). Unprotected areas of the Sudanian climatic zone had few individuals in small classes compared to medium classes. Unprotected areas of the Sudano-Sahelian climatic zone had no individuals in small-size classes. The observed differences in SCD are most likely the result of the previously mentioned factors influencing species' natural regeneration and adult tree density in the study area. Moreover, pathogens, diseases and overharvesting may be the reason for the instability of the population structure. The management of *Celtis toka* (pruning) by humans, especially in farmlands could contribute to higher *Celtis toka* tree juveniles in unprotected areas. We found that the species had low frequencies of seedlings and generally low densities, which is consistent with results obtained in a study made in the North of Cameroon (Moksia *et al*., 2019). The relatively high seedling density observed in unprotected areas is similar to those recorded by Moksia *et al*. (2019), who also discovered regeneration conditions are more favourable outside of protected areas (0.02 %) than within them (0%). This could be explained by the fact that protected areas are less sensitive to external disturbances such as human pressures, thereby favouring natural processes of sexual regeneration while favouring non-sexual regeneration. Anthropogenic and environmental disturbances could explain the species' poor regeneration. However, tree species richness, soil pH, annual rainfall, tree density, elevation, canopy openness, lightning, winds, illicit cutting, agricultural activities, and overgrazing are unfavourable factors affecting the natural regeneration of plants (Ibrahim and Hassan, 2015; Khaine *et al*., 2018; Limon *et al*., 2021) and forest fires. Environmental conditions, pathogens, and anthropocentric actions such as fires, overgrazing, hollows, invasive species, juvenile cutting, and anarchic harvesting, may be factors limiting the regeneration of *Celtis toka*. Hence, to prevent. *toka* from extinction, quick conservation and management action are required. Planting, protection of *Celtis toka* from livestock trampling and grazing, and growth of *Celtis toka* outside of protected forests while also promoting agroforestry.

The study presents pioneer tree-ring, quantitative wood anatomical, and wood density research in Burkina Faso**.** *Celtis toka* presented distinct growth ring boundaries. Previous research on *Celtis philippensis* and *Celtis timorensis* discovered this distinctiveness of growth rings

(Sattarian, 2006). Vessels solitary and in groups of 2–4 found in this study corroborated with the study of Neumann *et al*. (1998). However, the presence of anatomically distinct annual growth rings is required for the development of accurate ring-width chronologies (Gebrekirstos *et al*., 2014). Previous studies on tropical tree species reported anatomical features that characterized ring boundaries such as fibres and marginal parenchyma (Balima *et al*., 2020; Avakoudjo *et al*., 2022). There was a slight positive and negative correlation between tree-ring growth, tree-ring growth and climate variable (temperature and precipitation) in the Sudanian climatic zone and the Sudano-Sahelian climatic zone. This slight negative correlation could be explained by the disturbances. *Celtis toka* faces disturbances such as fire, debarking, pruning, and debarking.

Wood densities were **(**0.58 ± 0.08 g.cm^{-3}) and (0.56 ± 0.03 g.cm^{-3}) respectively in the Sudanian climatic zone and the Sudano-Sahelian climatic zone. These slightly similar values increased slightly from the Sudano-Sahelian climatic zone to the Sudanian climatic zone. This could be explained by the fact that *Celtis toka* is slightly harder and denser in the Sudanian climatic zone than in the Sudano-Sahelian climatic zone. These values are high to the average values found by Mukuralinda *et al*. (2021) which were 0.48 ±0.03 g.cm^{-3} and 0.50 ±0. g.cm^{-3} respectively for *Cupressus lusitanica* and *Cedrela serrulate.* Tree growth with age showed a downward trend in age-radial growth relationships. This was consistent with the tree-ring series, which showed a higher initial growth rate followed by a decrease as the tree aged. However, the stem diameter of tropical trees is a poor predictor of tree age (Brienen *et al*., 2016; Rahman *et al*., 2017). Ring widths can be reduced similarly to releases after gap formation when trees become overgrown or face increased competition (Bleicher, 2020). Moreover, the driest site (Sudano-Sahelian climatic zone) had higher vessel density than the wettest site (Sudanian climatic zone). These anatomical changes can be attributed to stem length elongation, which has been reported to be the principal driver of the overall variation in vessel diameter (Lechthaler *et al*., 2019). Variations in vessel size and density between drier and wetter environments may also indicate xylem hydraulic responses to precipitation and temperature variability (Islam *et al*., 2019).

Forest fires are one of the most significant events that cause a sudden decrease in tree ring width. Although humans are the primary cause of forest fires, extreme weather conditions or climate change may increase the frequency and severity of fires (Mazarzhanova *et al*., 2017). All seasonally determined fires occurred during the earlywood formation.(Mazarzhanova *et al*., 2017).

The results show that the scars are all on the side of the tree; once scarred, the tree is vulnerable to subsequent fires and is easily scarred in the same location (Lafon, 2015). The most common natural and anthropogenic driving effect is an abrupt decrease in ring width. Their severity and duration vary greatly depending on the species and the extent, and timing of the damage, as well as the stand structure (Bleicher, 2020). However, pruning could suddenly and deeply impact the growth reduction of a species (Joos, 1984 unpubl., cited in Schweingruber 1996; Guibal and Bernard 2002). When limited to the most shaded branches, pruning could even result in wider rings. Hence, Bleicher (2020) stressed that the more pruning reached the productive parts of the crown, the more growth was reduced. Due to reserves, the reduction may be small in the first year, but significant in the second and third years. However, browsing which is not identifiable in single ring-width series can also affect ring width by changing the soils around it (Bleicher, 2020). Since bark and cambium do not produce carbohydrates, the effects on ring growth are generally moderate and primarily local. There was no evidence that partial debarking killed any trees (Niklasson *et al*., 1994).

This study demonstrates that *Celtis toka* has a carbon stock potential. In both climatic zones, unprotected areas had a high value of carbon stock compared to the protected areas. This could be explained by the huge diameter (DBH) of *Celtis toka* in unprotected areas, which varies greatly between climatic zones and land use types. However, the majority of *Celtis toka* found outside of protected areas were agroforest trees growing along the gallery forests in Burkina Faso. Unprotected areas of the Sudano-Sahelian climatic zone had the highest value of aboveground biomass, so the highest values of carbon content, and thus the greatest carbon sequestration. Dimobe *et al*. (2019) established the high contribution of large individuals to total biomass stocks. The low quantity of carbon stock in protected areas compared to unprotected areas could be explained by the abundance of small-diameter individuals. Density is one of the key parameters on which carbon stocks depend according to (Dimobe *et al*., 2019). However, in our study, the protected areas have the highest number of individuals per hectare but the fewest biomasses carbon stock. Ganamé *et al*. (2020) emphasized that the aboveground biomass increased proportionally with tree DBH. The quantities of biomass and carbon stored, are superior to those of Balima *et al*. (2019) in the Sudanian and Sudano-Sahelian climatic zones of Burkina Faso. The quantities of aboveground biomass in the unprotected areas of the Sudano-Sahelian climatic zone are also superior to those of Bayen *et al*. (2020) in the Sudano-Sahelian climatic zones of Burkina Faso. Additionally, the quantity of aboveground carbon found in the different land use types was also superior to those of Gebrewahid *et al*. (2018) in Northern Ethiopia. In contrast, these amounts are far from those obtained by Mukuralinda *et al*. (2021) in the arboretum of Ruhande in Rwanda.

The geographic distribution of the species was predicted using eight less correlated predictors. Temperature annual range and mean temperature of the warmest quarter are the most important factors influencing the habitat suitability of *Celtis toka*. Our findings are consistent with those of Ndayishimiye *et al*. (2012) who identified the temperature annual range and mean temperature of the warmest quarter as significant climatic variables influencing the distribution of seven endemic *Caesalpinioideae* species in Central Africa (Democratic Republic of the Congo, Burundi and Rwanda). The findings underscore the ecology of *Celtis toka* which occurs in environments with 600 and 900 mm of precipitation and temperatures ranging between 20 and 30°C (Kagambega *et al*., 2010). Additionally, *Celtis toka* could grow in hot areas with arid/semi-arid to sub-humid climates; the annual temperature and precipitation limits for *Celtis toka* were given as 26-30°C and 110 - 1400 mm (Watrin *et al*., 2007; Julier, 2018), which may limit the distribution of *Celtis toka*.

The predicted currently suitable habitats for *Celtis toka* conservation in Burkina Faso cover 54.77 % of the country's total area. Habitats predicted suitable for species conservation are located within the Sudanian and Sudano-Sahelian zones of the country, covering some districts. These results are consistent with the distribution range of the studied species in West Africa. The natural distribution range of *Celtis toka* extends from Senegal to Sudan (Arbonnier, 2019). The Cascade region lacks suitable areas in current and future maps due to a lack of occurrence records. However, we discovered that future climate change will harm the spatial patterns of *Celtis toka* in Burkina Faso. At both horizons, all climate models predicted a decline in environmental suitability. The species lose space initially right across Burkina Faso. *Celtis toka* loses more climate space over time, implying that the understorey and ground floor composition of its habitat could alter (Harrison *et al*., 2006). *Celtis toka* loses a large proportion of suitable climate space, particularly under the MIROC and scenarios ssp585 due probably to a decrease in the quantity and fragmentation of habitat, and rainfall, as well as a loss of quality (through the intensification of agriculture). The high potential distribution was detected in regions of the upper basin and Mouhoun loop which have rivers (Kou and Mouhoun rivers), and high rainfall (upper basin) in Burkina Faso. Thus, it generally grows on river banks, some rock areas and deep, well-drained soils (Arbonnier, 2019) which may limit its natural geographical distribution. The study results, which were consistent with the literature, revealed that rainfall was one of the variables highly associated with the current distribution of *Celtis toka*. Indeed, the lower value of the future suitable habitats predicted for *Celtis toka* emphasises the conservation status of this species in Burkina Faso. Additionally, *Celtis toka* is subjected to severe anthropogenic pressures in most West African countries where it is found as an critically endangered (Garzuglia, 2006), endangered (Hahn-hadjali and Thiombiano 2000; Dansi *et al*. 2013) or threatened species (Moksia *et al*., 2019). These pressures may reduce the occurrence of habitat and the geographic range of *Celtis toka*. To be completely effective, *Celtis toka* recovery planning should be undertaken by non-governmental organizations and the government. Additionally, it is best practice to involve, all interested and knowledgeable parties in the preparation of conservation and recovery strategies and action plans, particularly the local population.

CONCLUSION

CONCLUSION

This study investigates the biology, ecology, and dynamics of African Hackberry (*Celtis toka* (Forssk.) Hepper & J.R.I. Wood) in the context of global change in Burkina Faso, West Africa. The study focused on the wild species *Celtis toka* with the overall goal of documenting its use values and biological and ecological responses to climate and land use change in the Sahel region of Africa. Findings from ethnobotanical surveys revealed that *Celtis toka* is a mystic tree species widely used by the rural community for a wide variety of purposes. The mystic species *Celtis toka* is a multipurpose tree primarily used for food, fodder, traditional medicine, sacred, magic and medico-magic. The use in traditional medicine, food and sacred has remained widespread. The agroforest species is involved in the treatment of twenty-nine ailments and the furthermost extensively used plant parts were leaves, roots, and bark. Local knowledge of the use patterns is highly diverse and influenced by ethnolinguistic groups, age, and sex levels. Overall sociolinguistic groups investigated, Bobo and Dafing apprehended high knowledge of the species. Additionally, the vegetable species colonized gallery forests (mostly), sacred forests, protected areas and rocky areas. Pruning was the management practice. Traditional sustainable use and conservation strategies were either mystic or taboo or sacred or fetich or medico-magic and magic characters of the species. Despite its usefulness and mystical nature, *Celtis toka* has been subjected to significant anthropogenic pressure in villages and agroforestry systems, resulting in a decline in its abundance and population, and even extinction in some communal areas. Species are also being harmed by global environmental change. The main threat drivers were pruning, climate change, deforestation, and debarking. However, most of the local future potential solutions included planting; conservation of the species, its seeds, regeneration, and its habitat; avoidance of the overuse of *Celtis toka*; fire protection; association of *Celtis toka* in farmland; and promoting education and awareness of the youth about *Celtis toka*. The incorporation of local people's perceptions into policy making is of critical importance in *Celtis toka* management and for its sustainable conservation strategies. These findings from the residents were similar to the results of forest inventories, which revealed regeneration issues and declining adult populations of the species in both land use types, with communal areas being the most affected. Population structures of *Celtis toka* in protected forests and communal areas were unstable. Consequently, enhancing the conservation of protected forests is critical to preserving the current populations of the species. Climate and land use types impact the phenology, dendrometry parameters, natural stand structure, and regeneration pool. The regeneration patterns were sexual (true seedling and seedling sprouts) and asexual (coppice, root sucker, water sprout) with a very low regeneration rate (0.85 %). The variation in density and regeneration of *Celtis toka* was due to natural and anthropogenic threats combined with hollows, pathogens, fire, overgrazing, and overharvesting.

Findings from tree ring analysis revealed that *Celtis toka* tree has distinct annual boundaries in its growth rings characterized by thick-walled latewood fibres and marginal parenchyma band. Cross-dating between Sudanese and Sudano-Sahelian tree-ring series was corrected for all tree-ring series due to disturbance factors. The annual increment growth rate was similar within the wettest and driest sites. Quantitative wood anatomy revealed differences in vessel size and frequency between the Sudanian zone and the Sudano-Sahelian zones. This suggests that the species adjusts vessel size and frequency in response to temperature and precipitation variability. The assessment of *Celtis toka* biomass in different land use types shows that these systems help to mitigate climate change by storing carbon. Communal areas store more carbon than protected forests. As a result, *Celtis toka* can contribute adequately to the REDD+ program currently underway in Burkina Faso. However, actions to fully protect *Celtis toka* and its habitat could help increase its carbon sequestration capacity and even mitigate the effects of climate change.

The spatiotemporal distribution modelling results revealed that climate change will have a significant impact on the habitat suitability of *Celtis toka* in Burkina Faso. Approximately 54.77 % of the country's area was climatically suitable for species conservation under current climatic conditions. Across all selected climate models under the ssp245 and ssp585, the suitable areas were predicted to decrease from 20.65 % to 27.81 % at the horizon 2041-2060, and from 53.27 % to 54.37 % at the horizon 2081-2100. Climate change induced range shifts and habitat loss. These findings support the research hypothesis that future climate change will affect the spatial distribution of *Celtis toka* in Burkina Faso

PERSPECTIVES AND RECOMMENDATIONS

PERSPECTIVES

Although the mystical aspect of *Celtis toka* contributes to its conservation, the species was under strong anthropogenic pressure in its natural habitat, resulting in a decline in population abundance, decline and extinction in the communal areas. Therefore, to prevent the extinction of *Celtis toka*, special attention must be paid to it. Moreover, this reveals the need for conservation measures to ensure its long-term sustainability. Conservation efforts should perhaps focus on *Celtis toka* and its habitat from fire, trampling and overgrazing by livestock. Moreover, efforts should perchance be concentrated on the domestication of *Celtis toka* to enhance regeneration and increase production. Growing *Celtis toka* outside of protected forests while promoting agroforestry should be encouraged. The promotion and enhancement of *Celtis toka* could provide significant socio-economic benefits to the local community. Stakeholders, forest managers, local people, and traditional and administrative authorities additionally, should eradicate the alien species which threaten *Celtis toka* and its habitats.

Additionally, efforts should be made by government agencies to initiate a program to educate the rural people on the propagation possibilities of *Celtis toka* species. Also, this requires preservation action, such as collecting seeds and propagating them in similar environments throughout Burkina Faso. *Celtis toka* needs to be evaluated and monitored regularly. This research raises new concerns about toxicity, reproduction, production, and stable carbon isotopes. Further research on the current study is required. The following are the axes that we intend to pursue:

- the assessment of toxicity through laboratory tests to confirm its traditional uses in Burkina Faso.
- the assessment of the production and reproduction of *Celtis toka;*
- the assessment of stable carbon isotope of *Celtis toka*;
- the assessment of the genetic diversity of *Celtis toka* in Burkina Faso and in its geographical range;
- extend the study to West Africa, Asia and South America;
- extend the study of biomass, carbon stock, modelling, and ring growth assessment on other multiuse species.

RECOMMENDATIONS

Given the findings, recommendations should be developed and implemented to improve the species' long-term management in Burkina Faso.

In terms of research structures, it is crucial to:

- Promote research that incorporates the monitoring of *Celtis toka* in the study area and its surroundings.

To policy makers, it is essential to:

- Recommend in situ, ex-situ, and circa-situ conservation of *Celtis toka.*
- Strengthen the conservation of *Celtis toka* isolated individuals in communal and protected areas. Building a fence around protected areas where *Celtis toka* can be found will help to strengthen their protection. Establish new protected areas in communal areas with a population of *Celtis toka*
- Reclassify *Celtis toka* in the International Union for Conservation of Nature's red list of threatened species.
- Use available information to advocate total protection of the species at local and international levels by informing future environmental and biodiversity conservation efforts.
- Use *Celtis toka* to rehabilitate and restore degraded ecosystems to promote the recovery of this species.
- Concentrate the effort on the domestication of *Celtis toka* to enhance regeneration and increase production.
- Promote and valorise *Celtis toka* because this could provide significant socio-economic benefits to local communities Promoting *Celtis toka* could provide significant socio-economic benefits to local communities by selling plant parts in markets.
- Include the species in the list of fully protected species in Burkina Faso, given that the species is already scarce, and that climate change is having adverse effects on habitats.
- Incorporate *Celtis toka* into reforestation efforts because of its failure, scarcity, and great capacity to store carbon.

- Sensitize young people through workshops on good practices and techniques for harvesting plant parts used for food, fodder, medicine, or other specific uses.

To local people, it is vital to:

- Change the method of leaf harvesting. For example, locals should not harvest leaves from all branches, but rather remove half of them and leave the rest so that the leaves on the remaining branches produce fruit.

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APPENDICES

Appendix 1: Scientific publications

Published paper.

Dabré Z., Zerbo I., M. B. I. Nacoulma, Soro D., & Thiombiano, A. (2023). Local perception of the current state and threat factors of a critically endangered species, *Celtis toka* (Forssk .) Hepper & J . R . I . Wood, in Burkina Faso : implications for species conservation. *Nature Conservation*, *51*, 189–225. https://doi.org/10.3897/natureconservation.51.96255

Under review papers

Dabré Z., Zerbo I., Nacoulma B. M. I., Soro D., & Thiombiano A. Ethnobotany and conservation of the mystic species *Celtis toka* (Forssk.) Hepper & J.R.I.Wood: a way forward for sustainable use in Burkina Faso. *Heliyon*

Dabré Z., Zerbo I., Bayen P., Nacoulma B. M. I., Kargbo A., Soro D., & Thiombiano, A. Do climate and land use types impact the population structure and the regeneration of *Celtis toka* (Forssk.) Hepper & J.R.I. Wood in Burkina Faso, West Africa? *Environmental Challenges*

Appendix 2: Training, Seminars and Workshops

Seminars/Workshops

Dabré Z., Nacoulma B. M. I., Zerbo I., Soro D., & Thiombiano A. Conservation of *Celtis toka* (Forssk.) Hepper & J.R.I. Wood, a mystic critically endangered species of Burkina Faso. Symposium International sur la Science et la Technologie (SIST) 2021. From 15 to 19 September 2021 in Ouagadougou, Burkina Faso

Dabré Z., Zerbo I., Nacoulma B. M. I., Soro D., & Thiombiano A. Ethnobotany and Ecology of a critically endangered species *Celtis toka* (Forssk.) Hepper & J.R.I.Wood: implication for conservation and sustainable use in Burkina Faso. Conference of UZKZ from 16 to 18 February 2022 in Ouagadougou, Burkina Faso

Dabré Z., Zerbo I., Nacoulma B. M. I., Soro D., & Thiombiano A. Impact of climate and land use on the stand structure of *Celtis toka* (Forssk.) Hepper & J.R.I., a critically endangered species in Burkina Faso, West Africa. World PhD climate change students summit 9th March 2022, HAW Humburg, Germany

Dabré Z., Potential of dendrochronology in assessing climate and human impact on *Celtis toka* in Burkina Faso, West Africa. Institut für Geographie. 16th November 2022, Erlangen, Germany

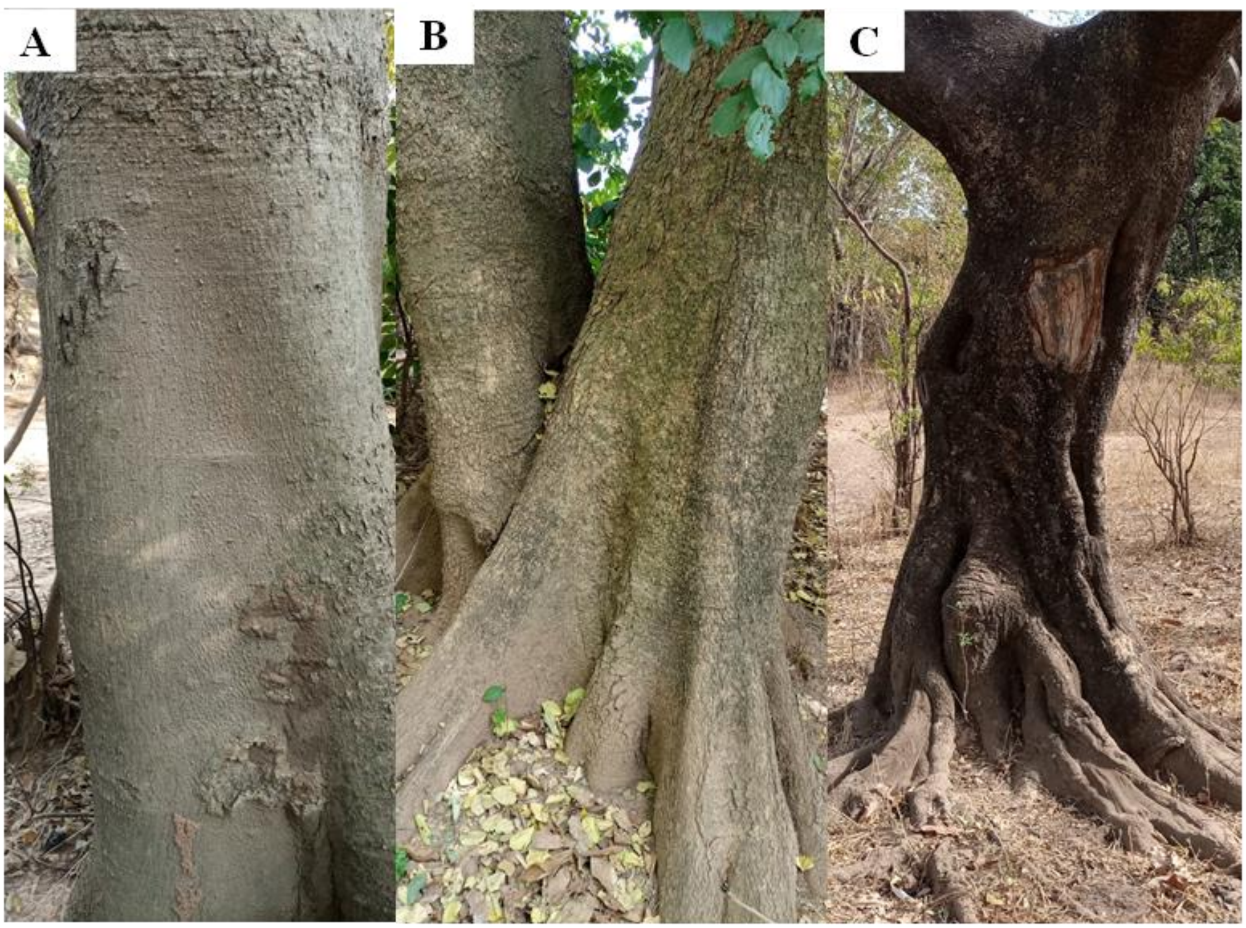
Training

Training workshop on Satellite-based open data collection and processing on Google Earth Engine, climate data analysis, and data management. From 3 to 5 May 2021, Competence Centre, in Ouagadougou, Burkina Faso

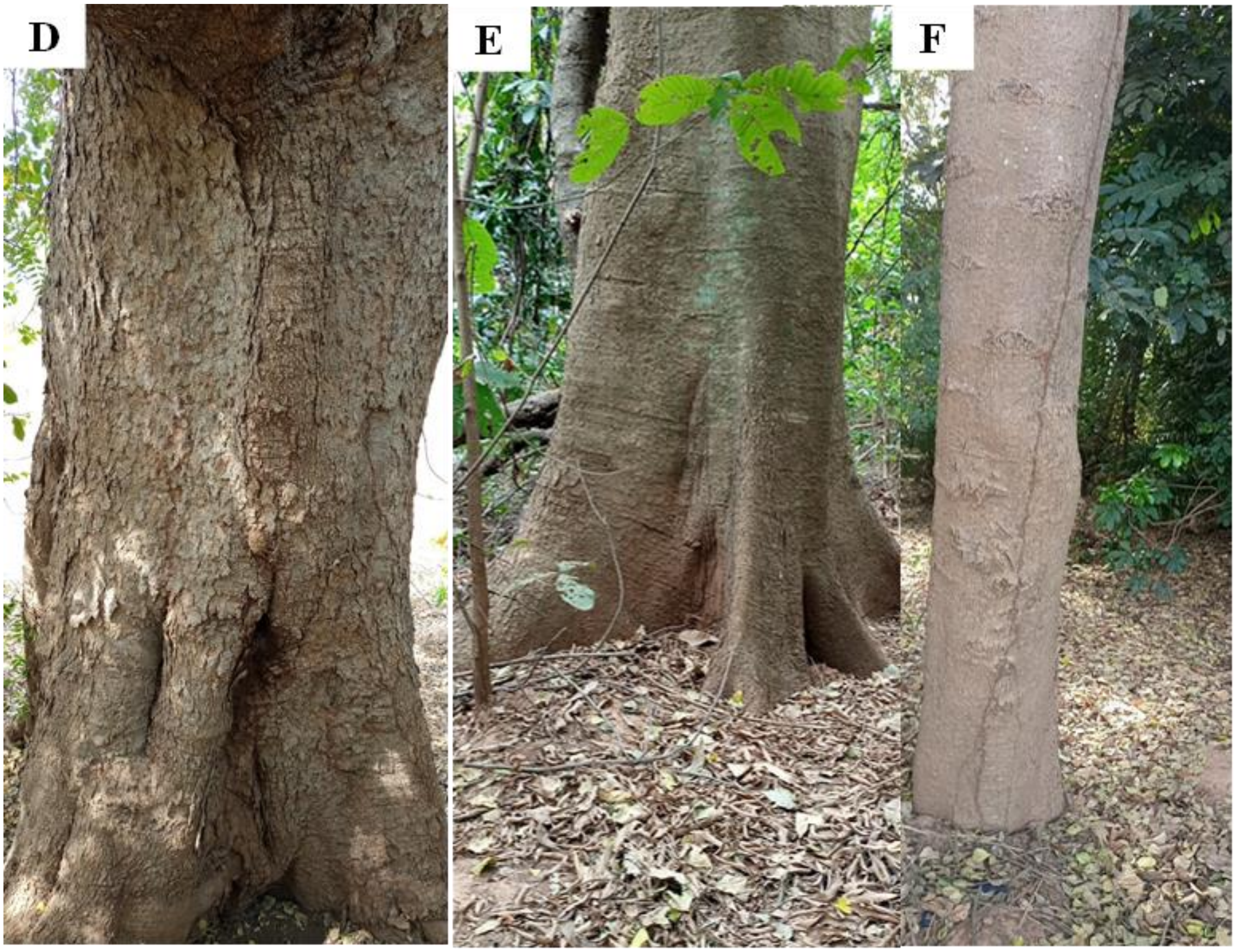
Training workshop on AgRAIN Python and Commercial Microwave links Processing organized by the University of Augsburg, Joseph Ki-Zerbo and WASCAL from 12th to 13th January 2022, at Competence Centre of WASCAL, Burkina Faso

Training workshop on scientific communication, 15th March 2022 in the university Joseph Ki-Zerbo, Burkina Faso

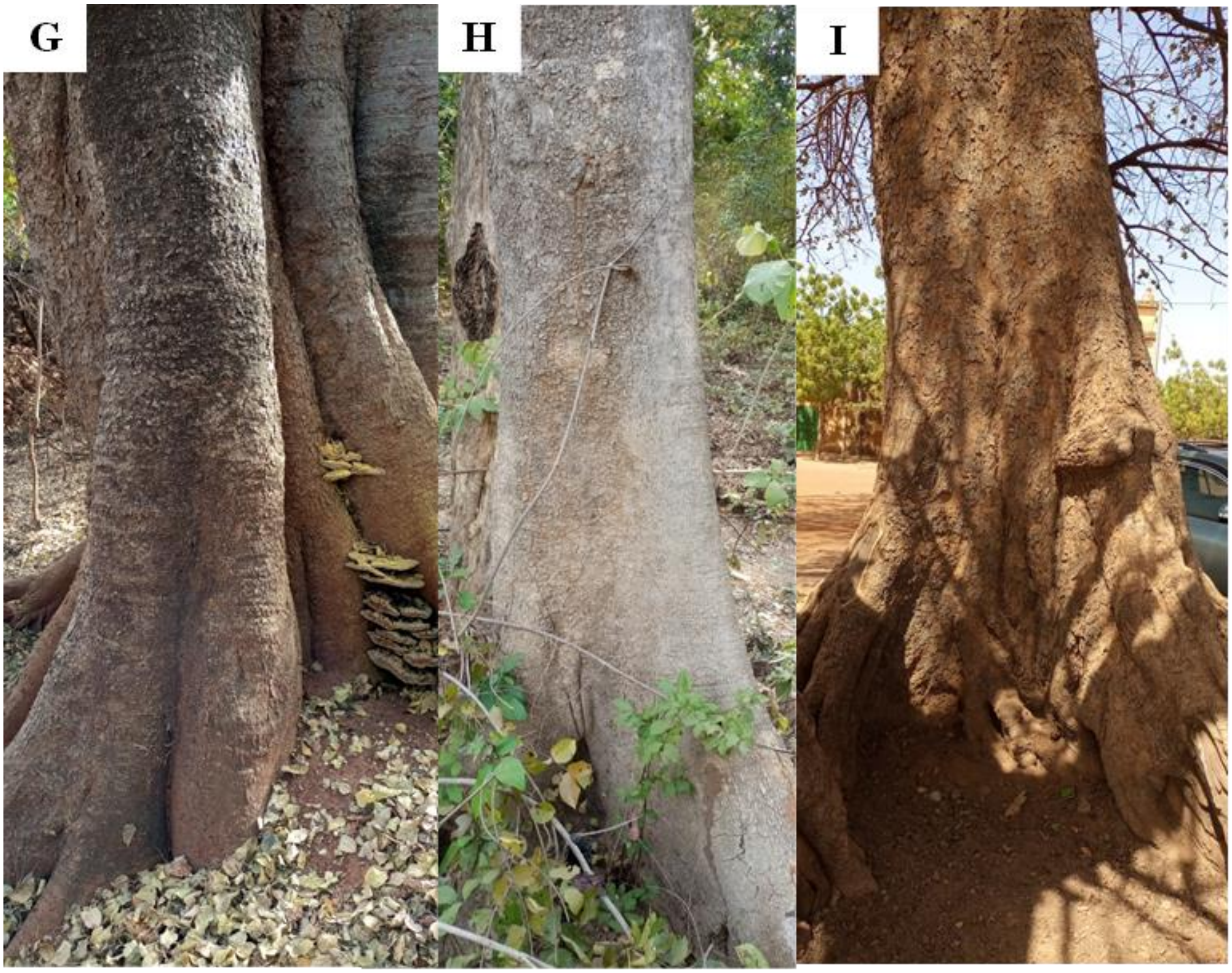
Appendix 3: Variations in bark colour and texture of *Celtis toka* in Burkina Faso



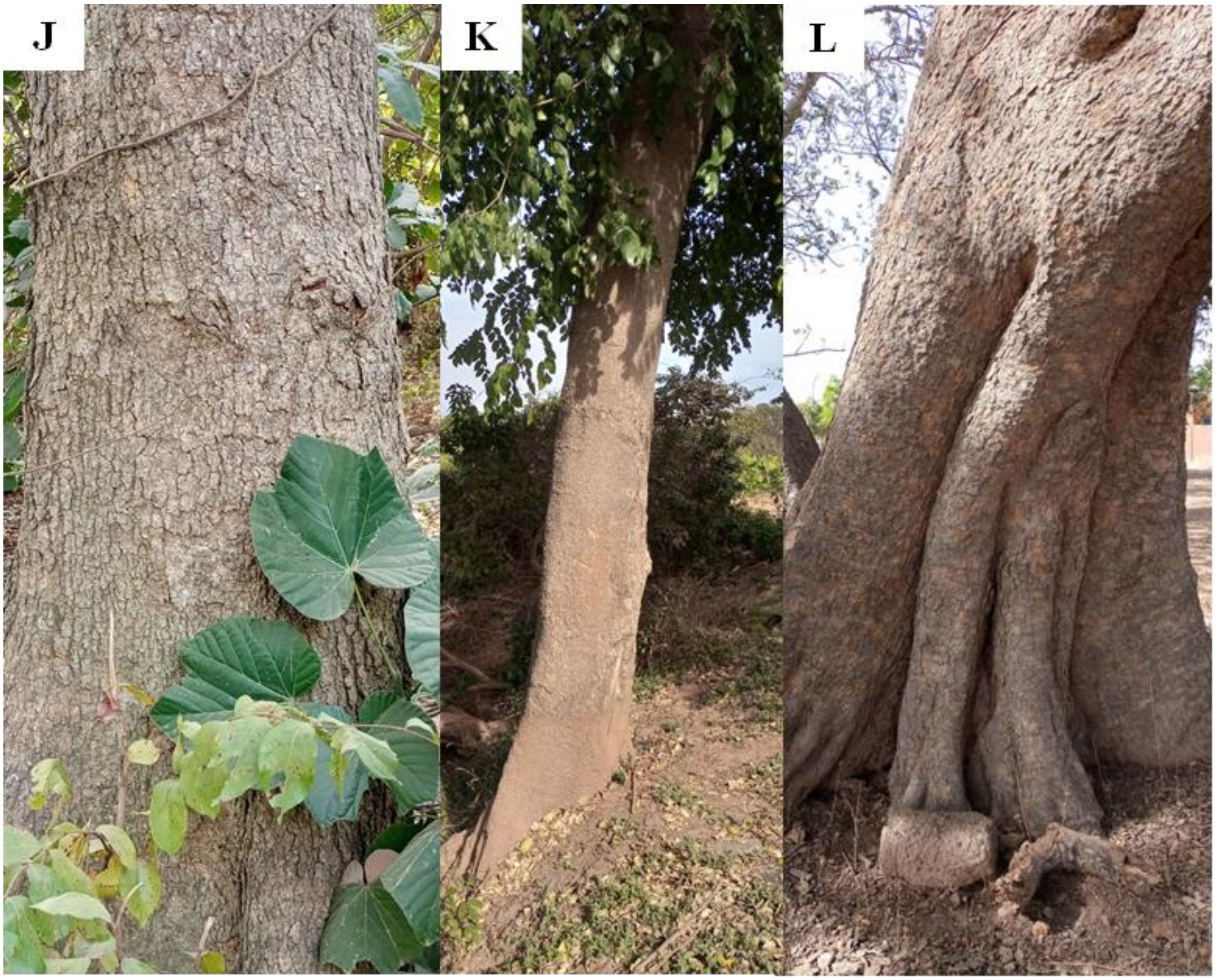
Ashen colour with a smooth and rough texture (A), Light green colour with a rough texture (B), and black colour with a rough texture (C). Pictures: Dabré, 2020



Light gray colour with a rough texture (D), ash green colour with a smooth texture (E), and light gray colour with a smooth texture (F). Pictures: Dabré, 2020 (E, F) and 2021 (D)



Light black colour with both rough and smooth textures (G), ash light colour with both rough and smooth texture (H), and ashen yellow colour with a rough texture (I). Pictures: Dabré, 2020 (H); 2021 (G) and 2022 (I)



Ashen colour with a rough texture (J), red colour with a smooth texture (K), and Light ashy yellow colour with a rough texture (L). Pictures: Dabré, 2020 (J, K) and 2022 (L).

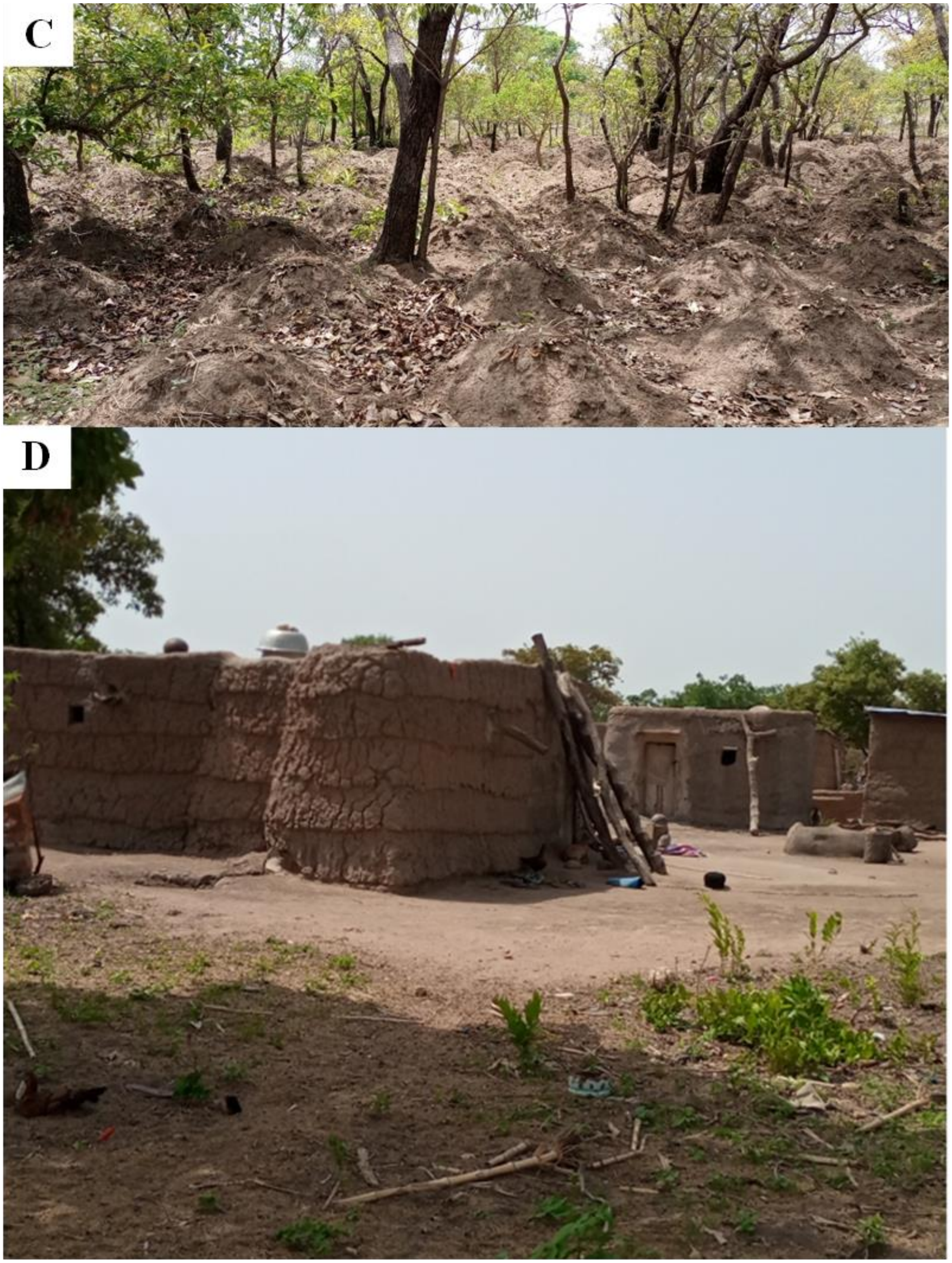
Appendix 4: View of some different threats encountered affecting *Celtis toka* tree in Burkina Faso.

Mining activity under *Celtis toka*in PA (A), and flood action uprooting *Celtis toka* in PA (B).

Pictures: Dabré, 2020 (A) and 2021 (B).

Appendix 5: Factors affecting the protected areas in Burkina Faso

Traditional mining (A) and deforestation (B) in the protected areas of the Sudanian climatic zone. Pictures: Dabré, 2021



Potatoes and yam farms (C) and compounds (D) in the protected areas of the Sudanian climatic zone. Pictures: Dabré, 2021

Animal grazing (E and F) and pipe (F) in the protected areas of the Sudanian climatic zone.

Pictures: Dabré, 2021

Animal grazing (G) in the protected areas of the Sudano-Sahelian climatic zone. Picture: Dabré, 2021

Appendix 6: Woody species that occurred with *Celtis toka* natural stand throughout climatic zones and land use types

Land use types	Species	Family	IVI
	Sudanian climatic zone		
PA	*Diospyros mespiliformis* Hochst. ex A. Rich.	*Ebenaceae*	**16.96**
PA	*Cordia myxa* L.	*Boraginaceae*	**15.24**
PA	*Anogeissus leiocarpa* (DC.) Guill. & Perr.	*Combretaceae*	**9.53**
PA	*Vitellaria paradoxa* Gaertn. f.	*Sapotaceae*	**8.42**
PA	*Lannea microcarpa* Engl. et K.Krause	*Anacardiaceae*	**5.91**
PA	*Parkia biglobosa* (Jacq.) R.Br. ex G.Don	*Fabaceae-mimosoideae*	**5.01**
PA	*Acacia seyal* Del.	*Fabaceae-mimosoideae*	**4.91**
PA	*Saba senegalensis* (A.DC.) Pichon	*Apocynaceae*	**4.64**
PA	*Mitragyna inermis* (Willd.) Kuntze	*Rubiaceae*	**4.62**
PA	*Dichrostachys cinerea* (L.) Wight et Arn.	*Fabaceae-mimosoideae*	**4.57**
PA	*Faidherbia albida* (Delile) A.Chev. *****	*Fabaceae-mimosoideae*	**4.4**
PA	*Acacia macrostachya* Rchb. ex DC.	*Fabaceae-mimosoideae*	**4.22**
PA	*Berlinia grandiflora* (Vahl) Hutch. & Dalzie	*Fabaceae-caesalpinioideae*	**3.7**
PA	*Feretia apodanthera* Del.	*Rubiaceae*	**3.41**
PA	*Piliostigma reticulatum* (DC.) Hochst.	*Fabaceae-caesalpinioideae*	**3.27**
PA	*Khaya senegalensis* (Desr.) A.Juss.	*Meliaceae*	2.69
PA	*Piliostigma thonningii* (Schumach.) Milne-Redh.	*Fabaceae-caesalpinioideae*	2.69
PA	*Acacia nilotica* (L.) Willd. ex Delile *****	*Fabaceae-mimosoideae*	2.56
PA	*Tamarindus indica* L.	*Fabaceae-caesalpinioideae*	2.41
PA	*Cassia siamea* Lam.	*Fabaceae-caesalpinioideae*	2.35
PA	*Cordia sinensis* Lam.	*Boraginaceae*	2.35
PA	*Strophanthus sarmentosus* DC.	*Apocynaceae*	2.19
PA	*Ficus sur* Forssk. *****	*Moraceae*	2.14
PA	*Acacia ataxacantha* DC.	*Fabaceae-mimosoideae*	2.01
PA	*Combretum collinum* Fresen.	*Combretaceae*	1.97
PA	*Acacia sieberiana* DC.	*Fabaceae-mimosoideae*	1.92
PA	*Strychnos spinosa* L.	*Loganiaceae*	1.88
PA	*Garcinia livingstonei* T.Anderson	*Clusiaceae*	1.83
PA	*Sclerocarya birrea* (A.Rich.) Hochst.	*Anacardiaceae*	1.72
PA	*Ficus glumosa* Delile *****	*Moraceae*	1.69
PA	*Adansonia digitata* L.	*Malvaceae*	1.68
PA	*Cassia sieberiana* DC.	*Fabaceae-caesalpinioideae*	1.64
PA	*Bombax costatum* Pellegr. et Vuill.	*Malvaceae*	1.64
PA	*Pericopsis laxiflora* (Benth.) Meeuwen	*Fabaceae-faboideae*	1.62
PA	*Vitex doniana* Sweet	*Lamiaceae*	1.58
PA	*Afzelia africana* Sm. ex Pers.	*Fabaceae-caesalpinioideae*	1.46

PA	*Philenoptera laxiflora* (Guill. & Perr.) Roberty *****	*Fabaceae-faboideae*	1.43
PA	*Guiera senegalensis* J.F.Gmel.	*Combretaceae*	1.41
PA	*Zanthoxylum zanthoxyloides* (Lam.) Zepern. & Timler *****	*Rutaceae*	1.4
PA	*Cola cordifolia* (Cav.) R.Br.	*Malvaceae*	1.39
PA	*Spondias mombin* L. *****	*Anacardiaceae*	1.36
PA	*Combretum nioroense* Aubrév. ex Keay *****	*Combretaceae*	1.17
PA	*Ficus dicranostyla* Mildbr. *****	*Moraceae*	1.13
PA	*Garcinia ovalifolia* Oliv.	*Clusiaceae*	1.1
PA	*Acacia dudgeonii* Craib ex Holland	*Fabaceae-mimosoideae*	1.09
PA	*Elaeis guineensis* Jacq.	*Arecaceae*	1.08
PA	*Cissus populnea* Guill. et Perr. *****	*Vitaceae*	1.08
PA	*Combretum fragrans* F. Hoffm.	*Combretaceae*	1.04
PA	*Ficus thonningii* Blume *****	*Moraceae*	0.97
PA	*Ficus trichopoda* Baker *****	*Moraceae*	0.95
PA	*Gardenia erubescens* Srapf et Hutch. *****	*Rubiaceae*	0.93
PA	*Phyllanthus muellerianus* (Kuntze) Exell	*Phyllanthaceae*	0.93
PA	*Annona senegalensis* Pers.	*Annonaceae*	0.93
PA	*Ceiba pentandra* (L.) Gaertn.	*Malvaceae*	0.88
PA	*Uapaca togoensis* Pax *****	*Phyllanthaceae*	0.87
PA	*Hexalobus monopetalus* (A.Rich.) Engl. et Diels *****	*Annonaceae*	0.81
PA	*Bridelia scleroneura* Müll.Arg. *****	*Phyllanthaceae*	0.77
PA	*Hyphaene thebaica* (L.) Mart. *****	*Arecaceae*	0.74
PA	*Albizia zygia* (DC.) J.F.Macbr. *****	*Fabaceae-mimosoideae*	0.64
PA	*Prosopis africana* (Guili. et Perr.) Taub. *****	*Fabaceae-mimosoideae*	0.64
PA	*Sterculia setigera* Delile	*Anacardiaceae*	0.63
PA	*Ficus exasperata* Vahl *****	*Moraceae*	0.62
PA	*Crossopteryx febrifuga* (Afzel. ex G.Don) Benth.	*Rubiaceae*	0.62
PA	*Kigelia africana* (Lam.) Benth. *****	*Bignoniaceae*	0.62
PA	*Raphia sudanica* A.Chev. *****	*Arecaceae*	0.59
PA	*Lecaniodiscus cupanioides* Planch. *****	*Sapindaceae*	0.57
PA	*Balanites aegyptiaca* (L.) Del.	*Zygophyllaceae*	0.51
PA	*Borassus aethiopum* Mart. *****	*Arecaceae*	0.51
PA	*Erythrina senegalensis* A.DC. *****	*Fabaceae-faboideae*	0.5
PA	*Acacia ehrenbergiana* Hayne	*Fabaceae-mimosoideae*	0.5
PA	*Leptadenia hastata* (Pers.) Decne. *****	*Apocynaceae*	0.48
PA	*Terminalia laxiflora* Engl. & Diels	*Combretaceae*	0.48
PA	*Vitex chrysocarpa* Planch. ex Benth.	*Lamiaceae*	0.48
PA	*Terminalia brownii* Fresen. *****	*Combretaceae*	0.48
PA	*Sarcocephalus latifolius* (Sm.) E.A.Bruce *****	*Rubiaceae*	0.48
PA	*Hymenocardia heudelotii* Müll.Arg. *****	*Phyllanthaceae*	0.48
PA	*Ziziphus abyssinica* A.Rich.	*Rhamnaceae*	0.48
PA	*Saba comorensis* (Bojer ex A.DC.) Pichon *****	*Apocynaceae*	0.47

PA	*Flacourtia indica* (Burm.f.) Merr.	*Salicaceae*	0.47
PA	*Alchornea cordifolia* (Schumach. & Thonn.) Müll.Arg. *****	*Euphorbiaceae*	0.47
PA	*Ancylobotrys amoena* Hua *****	*Apocynaceae*	0.47
PA	*Jasminum obtusifolium* Baker	*Oleaceae*	0.47
PA	*Landolphia heudelotii* A.DC. *****	*Apocynaceae*	0.47
PA	*Bridelia micrantha* (Hochst.) Baill. *****	*Phyllanthaceae*	0.47
PA	*Dalbergia melanoxylon* Guill. et Perr *****	*Fabaceae-faboideae*	0.47
PA	*Gardenia sokotensis* Hutch. *****	*Rubiaceae*	0.47
PA	*Margaritaria discoidea* (Baill.) G.L.Webster *****	*Phyllanthaceae*	0.47
PA	*Phyllanthus reticulatus* Poir.	*Phyllanthaceae*	0.47
PA	*Pseudocedrela kotschyi* (Schweinf.) Harms	*Meliaceae*	0.47
PA	*Combretum adenogonium* Steud. ex A.Rich.	*Combretaceae*	0.47
PA	*Oxytenanthera abyssinica* (A.Rich.) Munro *****	*Poaceae*	0.47
PA	*Gymnosporia senegalensis* (Lam.) Loes.	*Celastraceae*	0.47
PA	*Combretum tomentosum* G. Don *****	*Combretaceae*	0.47
PA	*Entada africana* Guill. et Perr.	*Fabaceae-mimosoideae*	0.47
PA	*Opilia amentacea* Roxb.	*Opiliaceae*	0.47
PA	*Vernonia colorata* (Willd.) Drake *****	*Asteraceae*	0.47
UPA	*Anogeissus leiocarpa* (DC.) Guill. & Perr.	*Combretaceae*	**25.82**
UPA	*Dialium guineense* Willd. *****	*Fabaceae-caesalpinioideae*	**23.16**
UPA	*Diospyros mespiliformis* Hochst. ex A. Rich.	*Ebenaceae*	**21.69**
UPA	*Mitragyna inermis* (Willd.) Kuntze	*Rubiaceae*	**21.05**
UPA	*Ceiba pentandra* (L.) Gaertn.	*Malvaceae*	**14.54**
UPA	*Flacourtia indica* (Burm.f.) Merr.	*Salicaceae*	**8.74**
UPA	*Cola laurifolia* Mast. *****	*Malvaceae*	**8.14**
UPA	*Lepisanthes senegalensis* (Juss.ex Poir.) Leenh	*Celastraceae*	**7.43**
UPA	*Detarium senegalense* J.F.Gmel. *****	*Fabaceae-caesalpinioideae*	**6.38**
UPA	*Philenoptera cyanescens* (Schumach. & Thonn.) Roberty *****	*Fabaceae-faboideae*	**6.14**
UPA	*Oncoba spinosa* Forssk. *****	*Rutaceae*	**4.86**
UPA	*Acacia sieberiana* DC.	*Fabaceae-mimosoideae*	**4.36**
UPA	*Cassia sieberiana* DC.	*Fabaceae-caesalpinioideae*	**4.05**
UPA	*Berlinia grandiflora* (Vahl) Hutch. & Dalzie	*Fabaceae-caesalpinioideae*	**3.42**
UPA	*Pterocarpus santalinoides* DC. *****	*Fabaceae-faboideae*	**3.4**
UPA	*Tamarindus indica* L.	*Fabaceae-caesalpinioideae*	**3.24**
UPA	*Rourea minor* (Gaertn.) Alston *****	*Connaraceae*	**3.16**
UPA	*Manilkara multinervis* (Baker) Dubard *****	*Sapotaceae*	**3.12**
UPA	*Elaeis guineensis* Jacq.	*Arecaceae*	**3.09**
UPA	*Cola cordifolia* (Cav.) R.Br.	*Malvaceae*	**3.01**
UPA	*Carapa procera* DC. *****	*Meliaceae*	**3.01**
UPA	*Acacia dudgeonii* Craib ex Holland	*Fabaceae-mimosoideae*	2.97
UPA	*Xeroderris stuhlmannii* (Taub.) Mendonça et E.C.Sousa *****	*Fabaceae-faboideae*	2.85
UPA	*Crateva adansonii* DC.	*Capparaceae*	2.79

UPA	*Cynometra vogelii* Hook.f.	*Leguminosae-caesalpinioideae*	2.76
UPA	*Afzelia africana* Sm. ex Pers.	*Fabaceae-caesalpinioideae*	2.35
UPA	*Morelia senegalensis* A.Rich. *****	*Rubiaceae*	2.3
UPA	*Combretum adenogonium* Steud. ex A.Rich.	*Combretaceae*	2.26
UPA	*Combretum collinum* Fresen.	*Combretaceae*	1.99
UPA	*Holarrhena floribunda* (G.Don) T.Durand & Schinz *****	*Apocynaceae*	1.88
UPA	*Combretum paniculatum* Vent. *****	*Combretaceae*	1.83
UPA	*Acacia ataxacantha* DC.	*Fabaceae-mimosoideae*	1.8
UPA	*Lannea velutina* A.Rich. *****	*Anacardiaceae*	1.76
UPA	*Sarcocephalus latifolius* (Sm.) E.A.Bruce	*Rubiaceae*	1.73
UPA	*Khaya senegalensis* (Desr.) A.Juss.	*Meliaceae*	1.56
UPA	*Pericopsis laxiflora* (Benth.) Meeuwen	*Fabaceae-faboideae*	1.51
UPA	*Vitex doniana* Sweet	*Lamiaceae*	1.48
UPA	*Cassia siamea* Lam.	*Fabaceae-caesalpinioideae*	1.47
UPA	*Acacia gourmaensis* A.Chev.	*Fabaceae-mimosoideae*	1.44
UPA	*Uvaria chamae* P.Beauv *****	*Annonaceae*	1.42
UPA	*Strophanthus sarmentosus* DC.	*Apocynaceae*	1.28
UPA	*Vitex chrysocarpa* Planch. ex Benth.	*Lamiaceae*	1.13
UPA	*Andira inermis* (W.Wright) DC. *****	*Fabaceae-faboideae*	1.08
UPA	*Senna singueana* (DeLile) Lock *****	*Fabaceae-caesalpinioideae*	1
UPA	*Allophylus africanus* P.Beauv *****	*Sapindaceae*	0.98
UPA	*Tacazzea apiculata* Oliv. *****	*Apocynaceae*	0.97
UPA	*Lannea microcarpa* Engl. et K.Krause	*Anacardiaceae*	0.9
UPA	*Saba senegalensis* (A.DC.) Pichon	*Apocynaceae*	0.86
UPA	*Opilia amentacea* Roxb.	*Opiliaceae*	0.84
UPA	*Pterocarpus erinaceus* Poir. *****	*Fabaceae-faboideae*	0.77
UPA	*Garcinia livingstonei* T.Anderson	*Clusiaceae*	0.7
UPA	*Feretia apodanthera* Del.	*Rubiaceae*	0.69
UPA	*Borassus aethiopum* Mart.	*Arecaceae*	0.64
UPA	*Daniellia oliveri* (Rolfe) Hutch. et Dalziel	*Fabaceae-caesalpinioideae*	0.6
UPA	*Flemingia faginea* (Guill. & Perr.) Baker	*Fabaceae-faboideae*	0.58
UPA	*Dichrostachys cinerea* (L.) Wight et Arn.	*Fabaceae-mimosoideae*	0.54
UPA	*Acacia macrostachya* Rchb. ex DC.	*Fabaceae-mimosoideae*	0.54
UPA	*Capparis tomentosa* Lam. *****	*Capparaceae*	0.54
UPA	*Lannea barteri* (Ollv.) Engl. *****	*Anacardiaceae*	0.53
UPA	*Bobgunnia madagascariensis* (Desv.) J.H.Kirkbr. et Wiersema*	*Fabaceae-faboideae*	0.52
UPA	*Piliostigma thonningii* (Schumach.) Milne-Redh.	*Fabaceae-caesalpinioideae*	0.48
UPA	*Entada africana* Guill. et Perr.	*Fabaceae-mimosoideae*	0.47
UPA	*Garcinia ovalifolia* Oliv.	*Clusiaceae*	0.46
UPA	*Pouteria alnifolia* (Baker) Roberty	*Sapotaceae*	0.45
UPA	*Rauvolfia vomitoria* Afzel. *****	*Apocynaceae*	0.45

UPA	*Quassia undulata* (Guill. & Perr.) F.Dietr. *****	*Simaroubaceae*	0.45
UPA	*Crossopteryx febrifuga* (Afzel. ex G.Don) Benth.	*Rubiaceae*	0.44
UPA	*Piliostigma reticulatum* (DC.) Hochst.	*Fabaceae-caesalpinioideae*	0.44
UPA	*Phyllanthus reticulatus* Poir.	*Phyllanthaceae*	0.44
UPA	*Parkia biglobosa* (Jacq.) R.Br. ex G.Don	*Fabaceae-mimosoideae*	0.44
UPA	*Xylopia acutiflora* (Dunal) A.Rich. *****	*Annonaceae*	0.44
UPA	*Cordia myxa* L.	*Boraginaceae*	0.43
UPA	*Olax subscorpioidea* Oliv. *****	*Olacaceae*	0.43
UPA	*Acacia polyacantha* Willd. *****	*Fabaceae-mimosoideae*	0.43
UPA	*Jasminum dichotomum* Vahl	*Oleaceae*	0.43
UPA	*Combretum fragrans* F. Hoffm.	*Combretaceae*	0.42
UPA	*Pseudocedrela kotschyi* (Schweinf.) Harms	*Meliaceae*	0.42
UPA	*Loeseneriella africana* (Willd.) N.Hallé	*Celastraceae*	0.42
UPA	*Phyllanthus muellerianus* (Kuntze) Exell	*Phyllanthaceae*	0.42
	Sudano-Sahelian climatic zone		
PA	*Combretum micranthum* G. Don	*Combretaceae*	**38.4**
PA	*Balanites aegyptiaca* (L.) Del.	*Zygophyllaceae*	**33.09**
PA	*Acacia erythrocalyx* Brenan	*Fabaceae - mimosoideae*	**17.98**
PA	*Tamarindus indica* L..	*Fabaceae-caesalpinioideae*	**17.29**
PA	*Acacia seyal* Del.	*Fabaceae-mimosoideae*	**13.87**
PA	*Anogeissus leiocarpa* (DC.) Guill. & Perr.	*Combretaceae*	**9.88**
PA	*Diospyros mespiliformis* Hochst. ex A. Rich.	*Ebenaceae*	**7.89**
PA	*Adansonia digitata* L.	*Malvaceae*	**7.12**
PA	*Saba senegalensis* (A.DC.) Pichon	*Apocynaceae*	**5.61**
PA	*Ximenia americana* L. *****	*Ximeniaceae*	**4.81**
PA	*Feretia apodanthera* Del.	*Rubiaceae*	**4.59**
PA	*Dichrostachys cinerea* (L.) Wight et Arn.	*Fabaceae-mimosoideae*	**3.46**
PA	*Loeseneriella africana* (Willd.) N.Hallé	*Celastraceae*	**3.1**
PA	*Pterocarpus lucens* Lepr. ex Guill. & Perr.	*Fabaceae-faboideae*	2.52
PA	*Vitex chrysocarpa* Planch. ex Benth.	*Lamiaceae*	2.39
PA	*Khaya senegalensis* (Desr.) A.Juss.	*Meliaceae*	2.12
PA	*Ziziphus mauritiana* Lam.	*Rhamnaceae*	2.02
PA	*Capparis sepiaria* L. *****	*Capparaceae*	1.98
PA	*Garcinia ovalifolia* Oliv.	*Clusiaceae*	1.52
PA	*Sclerocarya birrea* (A.Rich.) Hochst.	*Anacardiaceae*	1.48
PA	*Combretum fragrans* F. Hoffm.	*Combretaceae*	1.34
PA	*Boscia senegalensis* (Pers.) Lam. *****	*Capparaceae*	1.19
PA	*Crateva adansonii* DC.	*Capparaceae*	1.04
PA	*Lannea acida* A.Rich. *****	*Anacardiaceae*	0.97
PA	*Mitragyna inermis* (Willd.) Kuntze	*Rubiaceae*	0.95
PA	*Acacia ataxacantha* DC.	*Fabaceae-mimosoideae*	0.91

PA	*Piliostigma reticulatum* (DC.) Hochst.	*Fabaceae-caesalpinioideae*	0.83
PA	*Commiphora africana* (A. Rich.) Engl. *****	*Burseraceae*	0.8
PA	*Garcinia livingstonei* T.Anderson	*Clusiaceae*	0.78
PA	*Pterocarpus santalinoides* DC.	*Fabaceae-faboideae*	0.75
PA	*Vitellaria paradoxa* Gaertn. f.	*Sapotaceae*	0.54
PA	*Combretum nigricans* Lepr. ex Guill. et Perr. *****	*Combretaceae*	0.47
PA	*Annona senegalensis* Pers.	*Annonaceae*	0.47
PA	*Combretum collinum* Fresen.	*Combretaceae*	0.47
PA	*Lannea microcarpa* Engl. et K.Krause	*Anacardiaceae*	0.47
PA	*Terminalia laxiflora* Engl. & Diels *****	*Combretaceae*	0.45
PA	*Acacia dudgeonii* Craib ex Holland	*Fabaceae-mimosoideae*	0.43
PA	*Opilia amentacea* Roxb.	*Opiliaceae*	0.42
PA	*Ziziphus abyssinica* A.Rich.	*Rhamnaceae*	0.4
PA	*Ziziphus mucronata* Willd.	*Rhamnaceae*	0.4
PA	*Boscia angustifolia* A.Rich. *****	*Capparaceae*	0.4
PA	*Strychnos spinosa* L.	*Loganiaceae*	0.4
PA	*Grewia flavescens* Juss. *****	*Malvaceae*	0.4
UPA	*Tamarindus indica* L..	*Fabaceae-caesalpinioideae*	**61.38**
UPA	*Acacia seyal* Del.	*Fabaceae-mimosoideae*	**18.38**
UPA	*Diospyros mespiliformis* Hochst. ex A. Rich.	*Ebenaceae*	**14.09**
UPA	*Grewia bicolor* Juss. *****	*Malvaceae*	**12.94**
UPA	*Combretum micranthum* G. Don	*Combretaceae*	**10.74**
UPA	*Anogeissus leiocarpa* (DC.) Guill. & Perr.	*Combretaceae*	**10.01**
UPA	*Vitellaria paradoxa* Gaertn. f.	*Sapotaceae*	**8.83**
UPA	*Acacia erythrocalyx* Brenan	*Fabaceae-mimosoideae*	**8.77**
UPA	*Balanites aegyptiaca* (L.) Del.	*Zygophyllaceae*	**8.42**
UPA	*Adansonia digitata* L.	*Malvaceae*	**6.81**
UPA	*Ziziphus mauritiana* Lam.	*Rhamnaceae*	**6.73**
UPA	*Piliostigma reticulatum* (DC.) Hochst.	*Fabaceae-caesalpinioideae*	**5.71**
UPA	*Acacia ataxacantha* DC.	*Fabaceae-mimosoideae*	**4.55**
UPA	*Mitragyna inermis* (Willd.) Kuntze	*Rubiaceae*	**3.89**
UPA	*Sclerocarya birrea* (A.Rich.) Hochst.	*Anacardiaceae*	2.8
UPA	*Lannea microcarpa* Engl. et K.Krause	*Anacardiaceae*	2.72
UPA	*Ficus sycomorus* subsp. *****	*Moraceae*	2.6
UPA	*Bombax costatum* Pellegr. et Vuill.	*Malvaceae*	2.54
UPA	*Feretia apodanthera* Del.	*Rubiaceae*	2.34
UPA	*Cordia myxa* L.	*Boraginaceae*	2.16
UPA	*Ziziphus mucronata* Willd.	*Rhamnaceae*	1.91
UPA	*Cordia sinensis* Lam.	*Boraginaceae*	1.68
UPA	*Acacia sieberiana* DC.	*Fabaceae-mimosoideae*	1.68
UPA	*Saba senegalensis* (A.DC.) Pichon	*Apocynaceae*	1.32
UPA	*Sterculia setigera* Delile	*Malvaceae*	1.06

UPA	*Cassia sieberiana* DC.	*Fabaceae-caesalpinioideae*	1.06
UPA	*Pseudocedrela kotschyi* (Schweinf.) Harms	*Meliaceae*	1.05
UPA	*Ficus platyphylla* Delile *****	*Moraceae*	1.05
UPA	*Stereospermum kunthianum* Cham.	*Bignoniaceae*	1.04
UPA	*Lannea velutina* A.Rich.	*Anacardiaceae*	1.03
UPA	*Moringa oleifera* L. *****	*Moringaceae*	1.02
UPA	*Loeseneriella africana* (Willd.) N.Hallé	*Celastraceae*	1.02
UPA	*Gymnosporia senegalensis* (Lam.) Loes.	*Celastraceae*	1.02
UPA	*Annona senegalensis* Pers.	*Annonaceae*	1.02
UPA	*Guiera senegalensis* J.F.Gmel.	*Combretaceae*	1.02
UPA	*Terminalia macroptera* Guill. et Perr. *****	*Combretaceae*	1.02
UPA	*Gardenia aqualla* Stapf et Hutch. *****	*Rubiaceae*	1.02

No stars: common faithful woody species to *Celtis toka*; Red stars (*): uncommon reliable species to *Celtis toka* by climatic zones and land use types

Appendix 7: Ethnobotanical survey sheet

Survey card addressed to household N°…………….
Date………………… ……………X: ……………………………. Y:…………………………….

A. Identification

Surname and first name of the investigator …………………………………………………….
Surname and first name of the respondent……………………………………………………….
Region………………………. ……………….. Province/Department …………………………….
a) Commune ……………………b) Village ……………………….. Age: ………………...years; Ethnic: ……………………………Statue: 1. Autochthon……… 2. Migrant ………… Sex: 1. Male ………. 2. Female …………………school's level…………….
Matrimonial regime: 1. Monogamous………. 2. Polygamous ……………………
Fundamental work: 1. Agriculture…….2. Breeding………3. Hunt ……….4. hand worker………5. others (precise)………………………………………………………

B. Use patterns of *Celtis toka*

Vernacular name of the species: ....
Meaning of this name in your local:

Dom. Org.	Fo.	Pharm.	Med. Mag./ spiritual tree	F.	buil.	Ener.	Magic	Sacred	Shade
Roots									
Bark									
Wood									
Leaves									
Flowers									
Fruits									
Shade									
others									

Ener. =Energy; Org.=Organs; Fo= Food; Pharm.=Pharmacopoeia; Med. Mag.=Medico-magic; F=Fodder; Buil. = building.

Notes:……………………………………………………………..…………………………...
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

C. Causes of the threat of *Celtis toka*

1. Do you know *Celtis toka*? Yes: ……… No: …….

2. Do you think that the species (*Celtis toka*) risks disappearing one day?

a. Yes b. Non…………

If yes, what are the reasons of its disappearance:

a. Climate change
b. Agriculture
c. Deforestation
d. Settle of infrastructures
e. Others(precise)…………………………………………………………………
…………………………………………………………………………………

If yes, how many times?..

3. Do you plan to cultivate this resource? 1. Yes …2. No…………….

4. What is the current management of *Celtis toka* in your village?

a. Collective management ……; b. Individual management …… c. State management ….; d. Other…………………….

5. What is the solution to preserve this resource so that it still serves you?

Comment..
....
....
....
.......................………………………………………………………………………...
....
....
.......................………………………………………………………………………...
....

Where can we find *Celtis toka* population in this area?

Appendix 8: Dendrometry inventory in *Celtis toka* populations

List N° Date………/……/…………………………

Vegetation type …………………………Locality……………………………………. Geographic coordinates: X: ………………………………. Y: ……… ………………………..Altitude………..

Average recovery (%): trees: shrubs: grasses: ……………….

A. Dendrometry inventories

				Crown diameter				
Species	DBH	BD_{20}	Height	BD	SD	THE	T. A	F

DBH: Diameter at breast height, THE: Trace of Human Exploitation, BD_{20}: basal diameter (diameter at 20 cm above the ground level) SD: Small diameter, BD: big diameter, T.A = Traces of Animal, F = Fire

B. Phytosociology inventories

Species	Vegetation cover (Braun-Blanquet method)

+: cover less than 1%

1: cover between 1-5%

2a: cover between 5- 15%

2b: cover between 15 – 25 %

3: cover between 25- 50 %

4: Cover between 50 -75%

5: cover between 75 – 100%

C. Natural regeneration of *Celtis toka*

Subplot 1

Celtis toka	Diameter at the collar	Height	Type of regeneration
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			

Subplot 2

Celtis toka	Diameter at the collar	Height	Types of regeneration
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
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22			
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32			
33			
34			
35			
36			
37			
38			
39			

Clonality (Bognounou *et al*., 2010)

Types of regeneration

1- True seedling: a juvenile (young plant) coming directly from the seed of *Celtis toka*
2- Seedling sprout: an individual that comes from the seed but is cut and regrown from the root collar of the seedling.
3- Root sucker: an individual that arises vertically from the superficial lateral root.
4- Coppice: an individual arising from the cut mature tree whose diameter at breast height is superior to 10 cm.
5- Water sprout: an individual developed from the base of alive mature *Celtis toka*.
6- Layer: an individual developed from low-hanging lateral branch layers that arise from adventitious buds.

Appendix 9: Stem discs harvesting sheet for dendrochronology purposes.

List N° Date………/……/…………………………

Vegetation type …………………………Locality……………………………………. Geographic coordinates: X: ……………………………… Y: …………………………… Altitude……….

Average recovery (%): trees: shrubs: grasses: ……………………

			Health status of *Celtis toka*						
Celtis toka	DBH	Height	T. A	F	D	P	DP	WA	O
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									

DBH: Diameter at breast height, T.A = Traces of Animal, F = Fire, D: Debarking, P: Pruning, DP: Debarking and Pruning, WA: Wind's action, O: others.