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Subject

Impact of Climate Change on Honey Bees and The Distribution of Key Melliferous Plant Species in The Southern Area of Mali

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DEDICATION

With the expression of my gratitude, I dedicate this modest work to my parents, those whom I owe my life and my success, who have never said no to my whims and have spared no effort to make me happy.

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ABSTRACT:

Climate change poses significant challenges to ecosystems, biodiversity and sustainable development in sub-Saharan Africa. However, the specific impact on honey bees and melliferous plants, as well as the perceptions and adaptation strategies of honey producers in response to climate change, have not been adequately explored.

This study aimed to evaluate the effects of climate change on bees and the distribution of three key host species in the southern part of Mali.

The study combined beekeeper perceptions and spatial distribution analysis of some key plants. Surveying 209 beekeepers in the Sudanian zone of Mali's Bougouni region revealed that climate change could have adverse effects on bee populations, colony health and productivity due to the rise of temperature, reduction of rainfall and melliferous species loss. The study also emphasized the Maximum Entropy (MaxEnt) approach and Geographic Information System tools to predict future distribution areas of three plant species using two climatic models BC_BCC-CSM1-1 and HD_HadGEM2-AO.

From all the models, results highlighted negative effect of climate change on the future environmental distribution of the three species and the models have predicted very good performance for all the species with a value of Area under Curve greater than 90%.

Finally it is recommended to: (i) Establish bees database for Mali; (ii) Collaborate with scientists by promoting formation and information about the importance of bees among beekeepers and general public to find innovative solution and effective conservation strategies;(iii) Protect and conserve natural habitats for providing suitable environments for melliferous species; (iv) Encourage farmers to adopt bee-friendly agricultural practices, such as reducing or avoiding the use of pesticides during flowering periods.

Keywords: Honey bees, melliferous species, Species Distribution Modeling, Climate change, Pollination, MaxEnt.

RESUME :

Le changement climatique présente des défis importants pour les écosystèmes, la biodiversité et le développement durable en Afrique subsaharienne. Cependant, l'impact spécifique sur les abeilles et les plantes mellifères, ainsi que les perceptions et les stratégies d'adaptation des apiculteurs en réponse au changement climatique, n'ont pas été suffisamment explorés.

Cette étude visait à évaluer les effets du changement climatique sur les abeilles et la distribution de trois principales espèces mellifères dans le sud du Mali. L'étude a combiné les perceptions des apiculteurs et l'analyse de la distribution spatiale de quelques espèces mellifères. L'enquête menée auprès de 209 apiculteurs dans la zone soudanienne de la région de Bougouni au Mali a révélé que le changement climatique pourrait avoir des effets néfastes sur les populations d'abeilles, la santé des colonies et la productivité due à l'élévation de la température, de la réduction des précipitations et de la perte d'espèces mellifères. L'étude a également mis en évidence l'utilisation de l'Algorithme d' Entropie Maximale (MaxEnt) et les outils du Système d'Information Géographique pour prédire les futures zones de distribution des trois espèces végétales en utilisant deux modèles climatiques, BC_BCC-CSM1-1 et HD_HadGEM2-AO.Les résultats des deux modèles ont montré que le changement climatique pourrait avoir un effet négatif sur la future distribution environnementale des espèces, et les modèles ont prédit une très bonne performance pour toutes les trois espèces avec une valeur supérieure à 90 %.

Enfin, il est recommandé de : (i) Établir une base de données sur les abeilles au Mali ; (ii) Collaborer avec les scientifiques en promouvant la formation et l'information sur l'importance des abeilles auprès des apiculteurs et du grand public pour trouver des solutions innovantes et des stratégies de conservation efficaces ; (iii) Protéger et conserver les habitats naturels pour fournir des environnements appropriés aux espèces mellifères ; (iv) Encourager les agriculteurs à adopter des pratiques agricoles respectueuses des abeilles, telles que réduire ou éviter l'utilisation de pesticides pendant les périodes de floraison.

Mots-clés : Abeilles mellifères, espèces mellifères, modélisation de la distribution des espèces, changement climatique, pollinisation, MaxEnt.

ACRONYMS AND ABBREVIATIONS

AUC: Area under Curve

BCC_CSM1.1: Beijing Climate Center Climate System Model version 1.1

CRRA : Centre Régional de la Recherche Agronomique

DNEF : Direction Nationale des Eaux et Forets

ECOFIL: Economies des Filières

FAO: Food and Agriculture Organization

GBIF: Global Biodiversity Information Facility

HD_HadGEM2-AO : Hadley Centre Global Environnement Model version 2

ICC : Informatics for Climate Change

ID-Sahel : Ingénierie pour le Développement du Sahel

IPBES: Intergovernmental Platform on Biodiversity and Ecosystem Services

IPR/IFRA : Institut Polytechnique Rural de Formation et de la Recherche Appliquée

MOBIOM : Mouvement Biologique du Mali

MAXENT : Maximum Entropy

RCP: Representative Concentration Pathway

SDM: Species Distribution Modeling

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1-INTRODUCTION

1.1- STATEMENT OF THE RESEARCH PROBLEM

The intricate relationship between insects, particularly bees, and a wide range of food crops and wild flowering plants is fundamental to the functioning of ecosystems and the global food supply. Bees, as primary pollinators, play a critical role in facilitating the reproduction of plant species through the transfer of pollen, enabling fertilization and subsequent seed production (Klein et al., 2007 ; Ollerton et al., 2010). In fact, approximately 73 percent of the world's cultivated crops rely on pollination by bees (Abrol, 2009). This mutualistic partnership has evolved over centuries, benefiting both natural terrestrial ecosystems and human-managed agroecosystems.

However, in recent years, concerns have arisen regarding the decline of pollinators, with honey bees, in particular, facing significant challenges. The decline in pollinators and the flowering plants they depend on has prompted extensive research efforts to identify the threats they face and analyze the implications of their decline for agricultural and natural systems(Papanikolaou et al., 2017; Winfree et al., 2009).Bees, including other pollinators, are confronted with mounting pressures resulting from intensified land use, the introduction of alien species, the spread of pests and pathogens, and the far-reaching consequences of climate change (Kearns et al., 1998; Potts et al., 2010).The escalating threats to pollinators have serious implications for human food security, health, and overall ecosystem functioning.

In addition to the ecological and agricultural significance, pollinators are essential for the maintenance of biodiversity. Pollinators, such as bees, are necessary for the successful reproduction of approximately 88 percent of angiosperms and 87 out of the 115 most significant food items (Klein et al., 2007; Ollerton et al., 2011). The intricate web of interactions between plants and pollinators has coevolved over time, resulting in specialized relationships and mutual dependencies. However, the rapid pace of climate change poses a formidable challenge to these coevolved interactions, as neither plants nor pollinators can adapt quickly enough to keep pace with the changing environmental conditions (Yurk & Powell, 2009).

Climate change is a key driver that exacerbates the challenges faced by bees and their floral resources. As ectothermic organisms, the biology, behavior, and distribution of honey bees are strongly influenced by temperature variations in their surroundings (Thuiller et al., 2005).

Climate change-induced alterations in temperature and precipitation patterns can have profound impacts on flower development, nectar production, and flowering phenology (Thuiller et al., 2005).Such changes can lead to mismatches between bees and their preferred floral resources, disrupting the delicate synchrony necessary for successful pollination (Visser & Both, 2005; Doi et al., 2008). These temporals (phenological) and spatial (distributional) mismatches can have severe demographic consequences for both pollinators and plant species involved (Memmott et al., 2007; Tylianakis et al., 2008). The resulting reduction in insect visitation and pollen deposition can impact plant reproduction, while pollinators experience reduced food availability, potentially leading to population declines and cascading effects throughout the ecosystem.

Predictions based on greenhouse gas emissions indicate that global temperatures may increase by an average of 2 to 4 °C by 2050 (Pachauri et al., 2014).Such changes in climate are projected to disrupt the geographic distribution patterns of both pollinators and flowering plant species, posing threats to future food security (Pablo et al., 2017, Thuiller et al., 2005). Species' responses to local climate change can vary, with possible outcomes including adaptation to new conditions, migration to more suitable regions, or even extinction. However, the rapid pace of climate change and the associated disruptions in species interactions present challenges for successful adaptation (Yurk & Powell, 2009). In terms of biodiversity, agriculture, climate change adaptation, and all other ecosystem services, pollinators are crucial agents for ecosystems functioning and humanity.

In the context of Mali, a country with a rich heritage of beekeeping, the impacts of climate change on honey bees and the distribution of key melliferous plant species assume particular significance. Beekeeping has deep cultural roots in Mali, contributing to livelihoods, income generation, and ecological benefits (FAO, 2014).

However, modern agricultural practices, pesticide use, and the escalating effects of climate change pose formidable challenges to honey bee populations and traditional beekeeping practices (FAO, 2014).

Given the importance of pollinators for biodiversity, agriculture, and climate change adaptation, it is crucial to investigate their presence and interactions comprehensively. In this context, the present study aims to provide baseline information on the effects of changing climatic conditions on bees and their key host plants and seeks to contribute to the preservation of biodiversity, the reduction of bee species extinctions, and the assurance of income and food security, ultimately promoting sustainable development in Mali and beyond.

1.2-RESEARCH QUESTIONS

This research will answer the following questions:

-What is the perception of local communities on the impact of climate change on honeybees in the southern part of Mali?

-What factors influence the distribution and abundance of bees in the region?

-How climate change affects the spatial distribution of three key host plants species?

1.3-RESEARCH HYPOTHESES

To answer the research questions, the following hypotheses will be tested:

-Local people perceive that climate change can have negative effect on population and abundance of bees.

-Conservation of bees can significantly improve the sustainability of local resources, such as crop pollination and honey production, in Bougouni.

-Climate change reduce the distribution range of key host plant species in south of Mali

1.3-RESEARCH OBJECTIVE

The main objective of this study is to evaluate the effects of climate change on honey bees and the distribution of key host species in the southern part of Mali.

The specific objectives are:

-To describe beekeepers' demographic profile.

-To assess the perception of local communities on the impact of climate change on honey bees in the southern part of Mali.

-To determine factors that influences the distribution and abundance of honey bees in the region.

-To analyze the impact of climate change on the spatial distribution of three key host plant species in Mali.

CHAPTER 1

1.1- LITERATURE REVIEW

Apis mellifera is one of the most successful species in the animal kingdom and occupies vast and varied geographical areas. Its native distribution extends from Scandinavia to the Cape of Good Hope and from Dakar in the west to southern Oman in the east and adapts to a very wide range of climatic conditions (Rutter, 1998), covering Europe, West Asia and Africa (Garnery *et al*., 1992) .

Apis mellifera is the pollinator of greatest economic importance for crops worldwide. Bees are also essential in maintaining biodiversity by pollinating many plant species whose fertilization requires an obligate pollinator. Apis mellifera is a species that has shown great adaptive potential since it is found almost everywhere in the world and in very different climates (Conte & Navajas, 2008).

The co-evolution and diversity of species that we see now are a result of the mutualism (mutually beneficial relationships) between bees and flowers (Crepet & Niklas, 2009). More than 20,000 bee species worldwide contribute to the survival and evolution of more than 80% of plant species (Conte & Navajas, 2008; Vaissière, 2005).

A study carried out in Burkina Faso showed that the habitats alteration affect the pollinator insects. The availability of forages for these insects may vary according to climatic area. Recent studies showed that some pollinators follow the climate change by migrating in latitude and altitude while some don't (Scaven & Rafferty, 2013) cited by (Frédéric *et al*., 2021). A change in climatic conditions will undoubtedly have an impact on the survival of these ecotypes or bee species strongly linked to their environment. Migrations and changes in their life cycle and behavior could allow them to survive in new biotopes (Conte & Navajas, 2008).

The activity related to the search for food of potential pollinating insects showed a negative correlation with climatic factors: maximum temperature and annual rainfall. This shows that pollinating insects could be sensitive to the temperature of the environment. Further studies conducted Pollination Biology Biodiversity Conservation and Agricultural Production. Ramesh Kumar *et al* (2012) reported that the foraging activity of Megachile lanata on flowers of Crotalaria juncea L. was positively correlated with air temperature, light intensity, solar radiation and nectar sugar but was negatively correlated with relative humidity, soil temperature. As a result, the increase in temperature would result in a decrease in the number of pollinating insects. Precipitation and temperature significantly affect the composition and importance of pollinators but differently depending on the habitats considered (Frédéric *et* *al.*, 2021).

Bee biodiversity and abundance both appear to be productivity determinants for entomophilous crops nowadays (Klein *et al.*, 2002*;* Roubik, 2002). In 1996, the FAO (United Nations) sounded the alarm to all governments to safeguard this pollinating fauna and promote the survival of these auxiliaries who contribute to our daily menu as well as to the beauty of our most cherished landscapes (Vaissière, 2005).

Gaps: So far from all literature we review that few studies have been investigated on the impact of climate change on honey bees in Mali. By this updated scientific evidence and information on the global phenomena (such as CC, biodiversity loss, and food security) and the inter- action and linkage among the components are helpful to have global solutions or insights. Similarly, this paper is aimed to create a better understanding and communication among the scientific communities, researchers, national, and international policymakers about the links between CC, biodiversity, and food security (Muluneh, 2021) .

Keys Melliferous species

Vitellaria paradoxa, commonly known as Shea tree, is a valuable resource for honey bees. The nutritious nuts produced by Shea trees serve as an important food source for honey bees. Additionally, Shea trees provide suitable nesting sites for honey bee colonies (Smith, 2001). *Detarium microcarpum*, also known as the African locust bean, attracts honey bees with its fragrant flowers. The flowers of *Detarium* serve as a source of nectar collection for honey bees. This nectar sustains honey bees and contributes to honey production (Olayiwola et al., 2017). *Parkia*, commonly referred to as the African locust bean tree, produces vibrant and highly attractive flowers. These flowers serve as an abundant source of nectar for honey bees. Honey bees are attracted to the nectar of *Parkia* flowers and rely on it for sustenance (Ajeigbe et al., 2013). The mutualistic relationship between honey bees and these host species highlights the interdependence between pollinators and flowering plants. Conserving these species is crucial for maintaining biodiversity and ensuring sustainable ecosystem functioning (Smith, 2001; Olayiwola et al., 2017; Ajeigbe et al., 2013).

1.2-CONCEPTS AND DEFINITIONS

Bees Colony: Bees Colony is a group of bees, a set of bees living together in the hive or nest from the same family. Distinct varieties of bees have distinct roles in bee colonies. The only female bee capable of laying eggs and producing new bees is the queen bee. She is the mother of the colony's bees. Worker bees are female bees that perform a variety of tasks inside and outside of the hive, including feeding the queen and her young, constructing wax cells, gathering nectar and pollen, and defending the colony. Drone bees are male bees that mate with the queen or other colonies' young queens.

Honeybees: Honey bees are the bees that produce honey.

Honey: Honey is a sticky and sweet amber-colored liquid produced by bees from floral nectar or honeydew. Bees produce and store honey to feed their colonies. Bees make honey by collecting and purifying the sugary secretions of plants (mainly floral nectar) or the secretions of other insects, such as aphid honeydew.

Pollen: Pollen is a tiny powdery substance composed of microscopic grains produced by the male reproductive organs (anthers) of blooming plants (angiosperms). It is an important aspect of the plant's reproductive process and serves an important role in pollination.

Pollen is essential for plant reproduction and pollination. It is also used by bees to make honey, as well as by humans for food and medicinal. Some people, however, are allergic to pollen and may experience symptoms such as sneezing, itching, and watery eyes.

Pollination: Pollination is the process by which pollen grains are transmitted from the male reproductive organs (anthers) of a flower to the female reproductive organs (stigma) of the same or a different flower. It is a critical phase in the sexual reproduction of flowering plants (angiosperms).

Pollination can occur by a variety of mechanisms and agents, including as wind, water, animals, or even self-pollination within a single bloom. Animals, notably insects like bees, butterflies, moths, and beetles, are the most numerous and effective pollinators. Birds, bats, and small mammals are also significant pollinators.

Pollination is critical for the sexual reproduction and survival of many plant species. It improves genetic variation among plant populations, increases fruit and seed production, and contributes to ecosystem biodiversity. Furthermore, pollination is critical for the development of many agricultural products that rely on insect or animal pollinators, such as fruits, vegetables, nuts, and oilseeds.

Biodiversity: Biodiversity refers to the variety of living organisms on Earth, which includes plants, animals, microbes, and fungi. While the Earth's biodiversity is so diverse that many species have yet to be identified, many species are in jeopardy of extinction as a result of human actions, leaving the planet's wonderful variety at risk.

Biodiversity conservation is the protection and management of biodiversity to ensure its long-term usage and benefits for current and future generations. It entails efforts at several levels, from local to global, such as creating protected areas, restoring ecosystems, decreasing risks, promoting sustainable usage, raising awareness, and funding research and monitoring. Biodiversity protection is a common duty of all people and sectors of society.

Melliferous plants: Melliferous plants are those that produce a significant quantity of nectars and pollens.

Species Distribution Modeling (SDM): is an empirical or mathematical approximation to the ecological niche of a species (Barbosa et al., 2012). SDM relates physiological or chorological (i.e. species location) data to environmental variables using statistical methods or theoretically derived response surfaces, with the aim of describing, understanding and/or predicting the distribution of species (Franklin, 2010; Peterson et al., 2011; Guisan et al., 2017).

CHAPTER 2: MATERIALS AND METHODS

2.1 STUDY AREAS

The research was carried out in Bougouni a region located in the Southern part of Mali. During the study five villages were intentionally selected such as Bougoulafara, Flaboula, N'Tjila, Sido and Sogola based on the geographic location of the villages and mainly around the complex Bougouni-Foulaboula Protected Forest; Bougouni is the most important region for beekeeping with about more than 8000 beekeepers with 10 000 traditional hives and 6 000 Kenyan hives according to Mouvement Biologique du Mali (MOBIOM 2022).

Bougouni is a commune and city in Mali, the administrative center of Bougouni Cercle, which is in turn found in the administrative region of Sikasso. Bougouni is located 170 km south of Bamako and 210 km west of the city of Sikasso (Loi Creation Cercle Reg, 1999). According to the Law N ° 2023-00 7 of March 13, 2023 on the Creation of Territorial Collectivities in the Republic of Mali Bougouni has become the Fifteen Administrative Region of Mali.

Bougouni, like many cities of Mali, enjoys sufficient rainfall for regular farming. Cotton and honey are produced in the region around the town, making it a center for processing and transport. The Bougouni-Foulaboula Protected Forest (Forêt Classée de Bougouni-Foulaboula) begins just to the southwest of the town.

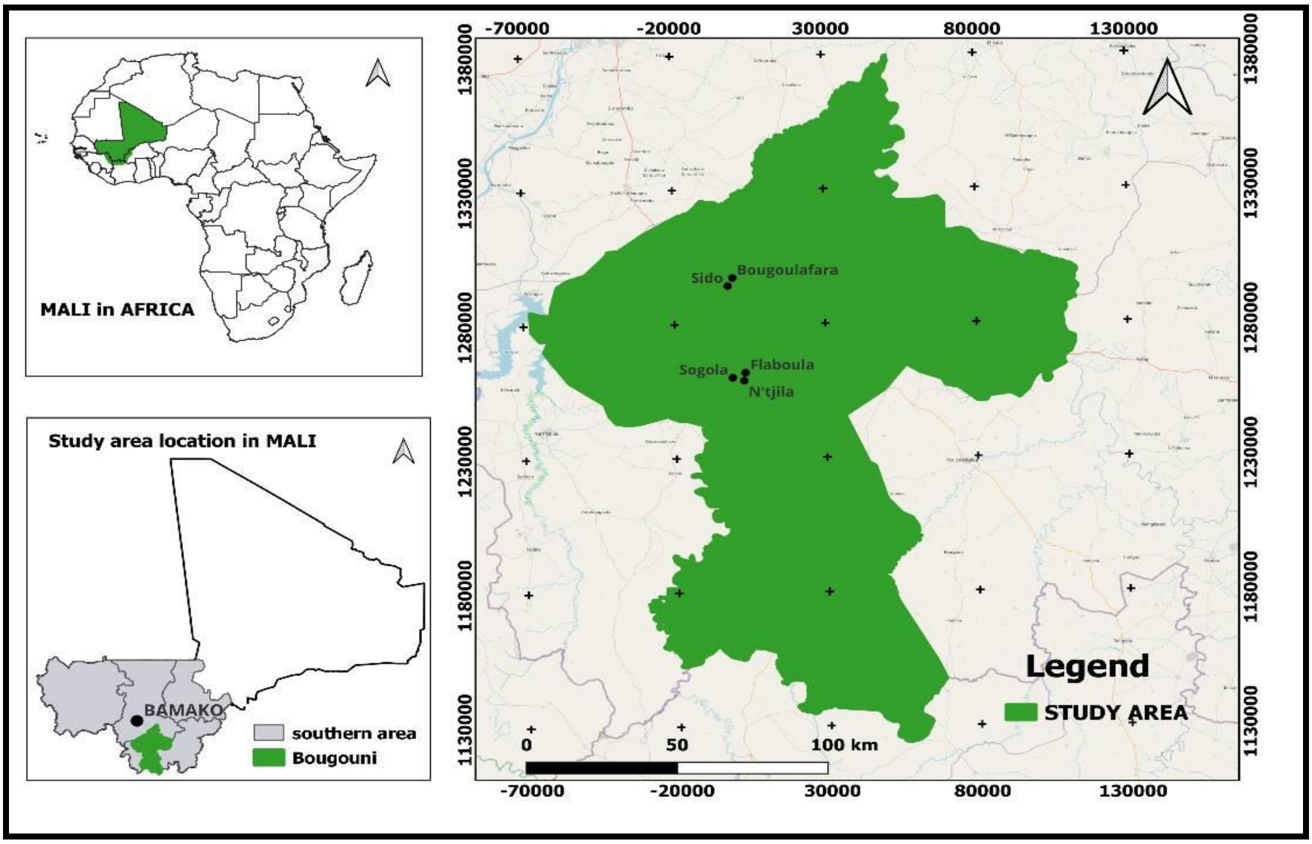


Figure 1: Study area

2.1.1 Bougouni Climate

In Bougouni, there is a dry season from November to April and a rainy season that lasts roughly from May to October. The climate is tropical, warm, and humid all year long.

Before the rain falls, the hottest time is from March through May.

The highest amount of rain from the African monsoon falls in the region of Bougouni; 350 meters above sea level, the city is situated in Mali's southwest.

For assessing the impact of climate change on the distribution of key host species, the entire country of Mali was considered, with focus on the southern part.

An historical data of three climatic variables were also collected from Mali Meteo to see the evolution of those parameters over the thirty years.

2.1.1.1 Bougouni Maximum and Minimum Temperature Evolution 1990-2019

Temperature plays a crucial role in influencing the behavior and distribution of bees, and it has been identified as a significant factor in the context of climate change impacts on pollinators. Rising temperatures can have various effects on bee populations and their interactions with plants.

Research on the impact of temperature on bees suggests that changes in temperature can disrupt the availability of floral resources, which are vital for bees' food supply. As temperatures rise, the timing and duration of flowering seasons may change, leading to a potential mismatch between bees and their food sources (Kearns et al., 1998).This can have adverse effects on the reproductive success and survival of both bees and plants.

Heat stress and extreme temperature events are also of concern for bee populations. High temperatures can negatively affect bees' foraging behavior, impair their cognitive abilities, and even lead to increased mortality rates (Kearns et al., 1998).These temperature-induced impacts on bee populations can have significant implications for the pollination of flowering plants and, consequently, for ecosystem functioning and food security.

The figure 2 below shows increase of temperature in Bougouni region over the last thirty years with some extreme events almost in every year. The consequences of these can potentially affect the complex plants and pollinators' diversity by causing the decrease of bees' population and the modification of the flowering season of the plants and also the deterioration of the flowers due to sharp rise in temperature.

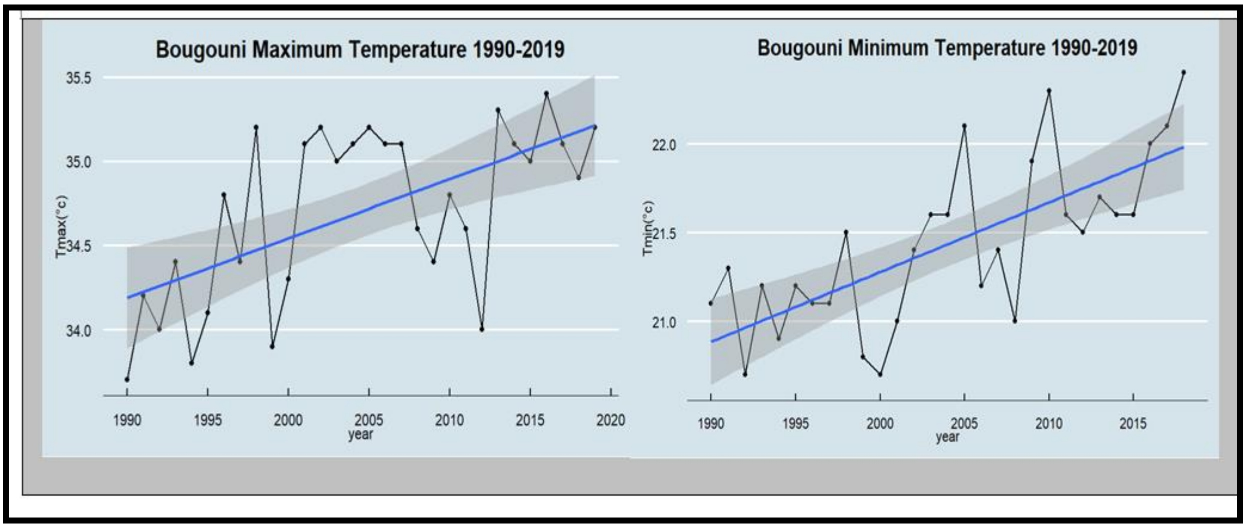


Figure 2: Bougouni maximum and minimum temperature 1990-2019

2.1.1.2. Bougouni evolution of the Precipitation 1990-2019

Precipitation is crucial and essential for life on earth.

Figure below, shows an enormous decrease in precipitation over the time in Bougouni region. From the period of 2000 up to 2019 we can observed a speedy reduction of the precipitation with extreme events.

Bees, which are vital pollinators in ecosystems and for agricultural output, can be affected in a number of ways by a decrease in precipitation**.** A decrease in precipitation can lead to drought conditions, resulting in reduced availability and quality of floral resources. A decrease in precipitation has the potential to cause drought, which would affect the quantity and quality of floral resources. This scarcity of flowers may negatively affect bees' ability to forage and eat, which could result in a decline in population size and reproductive success.

Bees need water for a variety of reasons, such as regulating their body temperature, cooling the hive, and diluting honey that has been stored. Reduced precipitation may reduce the amount of water available, which makes it harder for bees to locate acceptable water sources. This may have detrimental effects on the health of bees and the general operation of the hive.

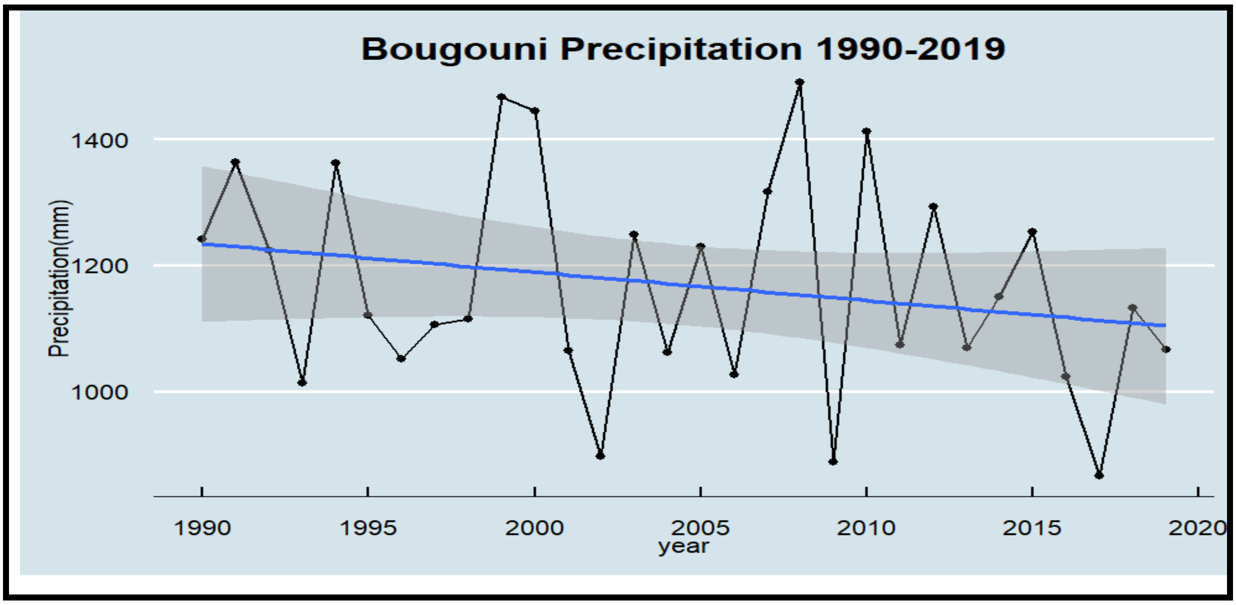


Figure 3: Bougouni Precipitation 1990-2019

2.1.1.3. Bougouni evolution of the Mean Wind Speed 1990-2019

Wind is a natural factor that influences bees' foraging behavior and performance. Wind makes flying more difficult and energy-intensive for bees because they must modify their body angle, wing movements, and speed to maintain stability and orientation. Wind may also decrease the availability and quality of floral resources by causing flower damage, reducing nectar production, and dispersing pollen.

Figure below shows that in Bougouni over the last 30 years the wind speed frequency was increasing with different extreme events which can have significant negative effects on bees' foraging activities per day or even reduce the number of bees by taking them away during its passage.

Several studies have found that wind can have a negative impact on bee foraging efficiency and success. For instance, (Hennessy et al., 2020) discovered that when honeybees were exposed to increasing wind speeds in a laboratory setting, they visited less artificial flowers and took longer to leave them. (Burnett et al., 2022) found that when bees fly above a field of obstacles in windy conditions, honeybees moved faster and had larger lateral excursions than when flying in calm air, revealing that wind affected their navigation and visual feedback.

These studies imply that wind can be a substantial issue for bees, particularly in the context of global warming, which is expected to increase the frequency and intensity of extreme weather events such as storms and heat waves. Wind can also interact with other environmental elements such as temperature, humidity, and light to influence bee foraging decisions and outcomes. Understanding how wind affects bees is therefore critical for protecting and managing these key pollinators.

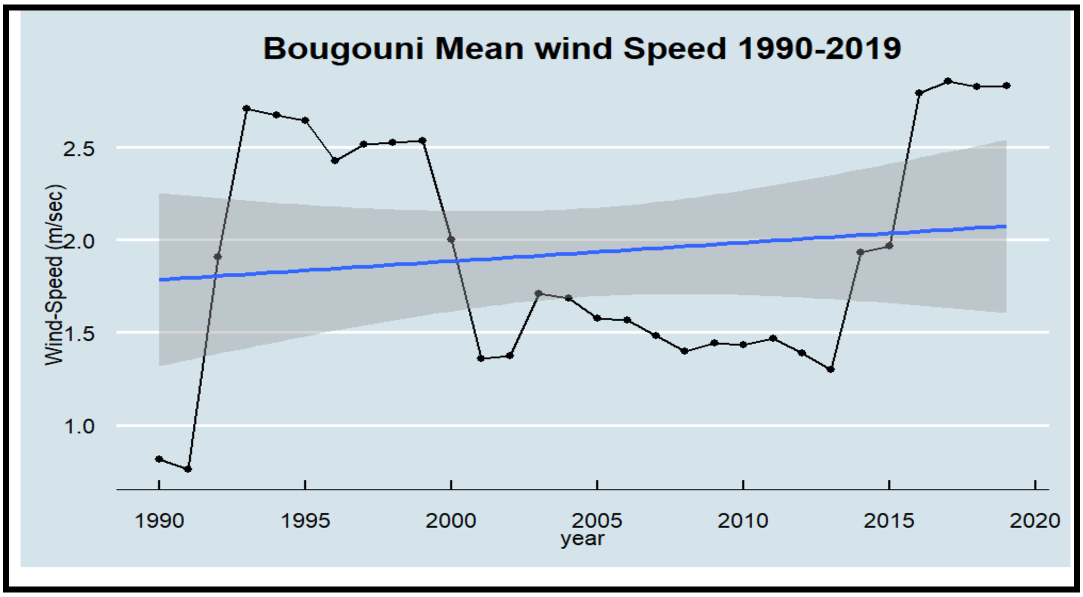


Figure 4: Bougouni evolution of the mean wind speed 1990-2019

2.2 DATA COLLECTION

The research was based both on secondary and primary data collection methods. During the first phase of the study, a thorough secondary data review was conducted, which was substantiated with preliminary discussions with actors knowledgeable about the situation on beekeepers based in Bougouni region. Primary data collection took place in five villages of Bougouni region.

2.2.1 Secondary data review

Secondary data research is a very popular research technique, employed in study designs or as a way to begin your research process if you intend to undertake primary research later (George, 2023).

Secondary data review was assigned to draw Research design to see however the previous research based on bees were processed, by defining the context, setting up research questions, hypothesis and objectives, and also develop questionnaires for primary data collection. Further secondary data sources have been used to explain deeply the results from primary data collected.

The data sources were mainly Google scholars, Worldclim for bioclimatic variables Global Biodiversity Information Facilities (GBIF) for occurrence data on visited species, Mali Meteo, FAO, Faostat, national sources of Mali, and sometimes Google research.

2.2.2 Questionnaires

The data were gathered using a questionnaire created specifically for this study. It was divided into three major sections, as follows: The first section included participants' socio-demographic characteristics such as gender, age, marital status, location of residence, housing situation, and occupation. The second section dealt with some questions about dynamic of bees' population evolution and beekeeping over the time. The third and final section was beekeepers' perception about Climate Change and the use of pesticides.

2.2.3 Primary data Collection

Since it was the best time to question beekeepers based on their availability in April, primary data were gathered during that month. The researcher and one of the researcher's bachelor's degree students, along with two agents from Bougouni, undertook this investigation. These interested persons received basic training on how to utilize the data collection technology and how to translate the survey questions into the local language before to the survey day.

The pre-test of the questionnaires was completed following the training. Pre-testing the input forms included into smartphones was done with two goals in mind: first, to become accustomed by using tablets, and second, to fix any flaws in the collection tool forms.

The following figure 5 shows the interview for primary data collection.

Figure 5: Primary data collection using Kobo collect (*Kassambara 2023*)

2.2.3.1 Sampling

Sampling is a process in statistical analysis where researchers take a predetermined number of observations from a larger population. The main objective of sampling is to draw inferences about the larger group based on information obtained from the small group and the main way to achieve this is to select a representative sample.

The number of individuals in the sample depends on various factors such as the research design, the size and variability of the population, the tolerable error, the average percentage of non-responses and the available budget.

The simple random sample was chosen, where every member of the population had an equal chance of being selected, while the respondents were randomly selected during the survey the sample was consisted of men and women.

The sample size was carried out using the following formula:

$$N = \frac{(Z^2 * P * Q)}{E^2}$$

Where:

N is the required sample size

Z is the z-score associated with the 95% confidence interval, which is typically 1.96

P is the estimated proportion of the population with the characteristic of interest (for example, the proportion of the beekeepers in a given population)

Q is the complementary proportion of the population (i.e. 1 - p).

E is the desired margin of error.

$$N = \frac{((1.96 * 1.96) * (0.2 * 0.48))}{(0.04 * 0.04)} = 200 \text{ Beekeepers}$$

With a confidence interval of 95% and a margin of error of 4%, the calculation of the sample size gives 200 respondents.

The sample calculation was done through excel by using the Solver function; we first set the calculation objective which represent the sample size with the expecting value of N (200).

By changing variables cells E11 (Z) and E14 (E) we set the subject to the constraints with:

Z =1.96;

P <= 0.5;

P >= 0.2;

Then by making unconstrained variables non-negative the Generalized Reduced Gradient (GRG) algorithm, which is an optimization method used to solve non-linear optimization problems was selected. It's a common approach for solving optimization problems where the objective function and/or constraints are non-linear and finally clicked on **Solve** then the result were automatically generated in the excel sheet by giving an respective value to the unknown variables to get the approximate or expected sample size.

Figure 6 below shows the process in the Solver parameters.

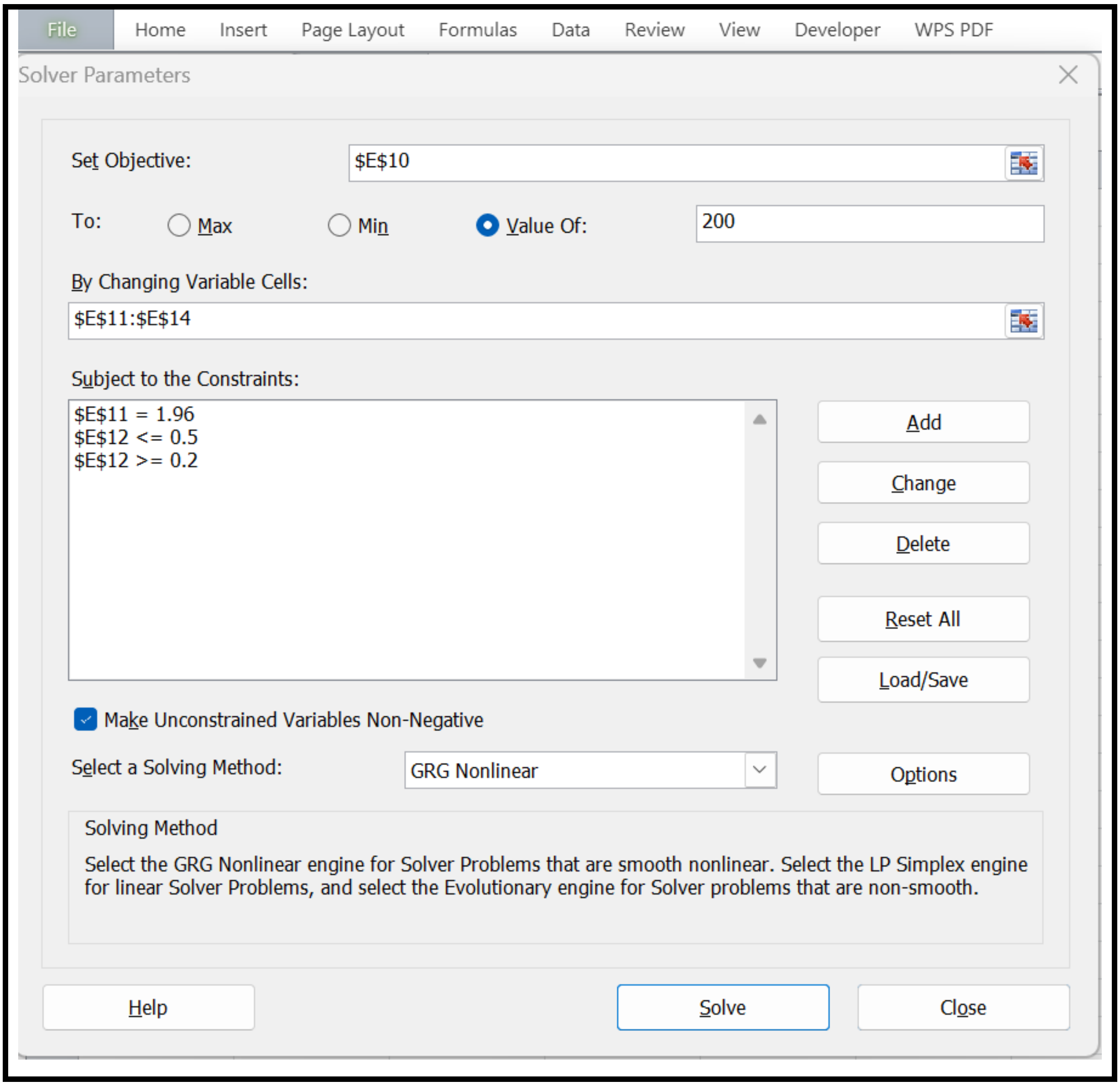


Figure 6: Sample calculation process using Excel solver

To avoid any disagreement in the sample size during the survey we looked for +-10 respondents to do not miss the sample calculated after data cleaning process.

2.2.4 Population of Interested and type of Interview

2.2.4.1 Population of Interested

This phase of the study was divided into two steps: first Information and awareness of targeted actors in the region of Bougouni, and secondly Validation of the survey plans by the chief of the village, thirdly and lastly feedback to the chief of the villages about the level of the field finding. To avoid any risk of no availability of respondents', information about the survey day of every village was fixed and sent to the Chief of each village. For security issue the Interview was conducted in a safe and secure space such as: their usual space for meeting.

2.2.4.2 Type of Interview

The survey included both semi-structured and structured interview before the survey day a brief meeting has been held with the chief of the concerned villages to inform them about the arrival and explain the purpose of the survey.

2.2.5 Tools

The primary data for the study has been gathered via Computer-Assisted Personal Interviews (CAPI). The information was gathered using a smartphone and sent to the server for storage. Kobo toolbox was the server of choice during the research. At the end, data were exported in excel file and use under R for analysis.

2.2.6. Schedule of the research

In order to achieve the research objective, the following timetable has been established. It is important to note that the following timeline is a schedule for research.

Phase 1: Preparatory phase

This phase of research includes literature review, the Schedule of research planning, meeting with supervisors, and also implementation of data collection tool.

Literature review

-Development of the data collection plan (indicator, sampling, data collection methodology, purpose and period of data collection);

-Validation of the data collection plan by supervisors;

-Establishment of a list of person resource for data collection;

-Organization for field activities.

Phase 2: Data collection phase

This phase of the study is divided into two (2) steps:

Step1: Information and awareness of the locality's chiefs and beekeepers in advance before the collect day.

Step 2: Data collection in the field and feedback of field findings to the supervisors.

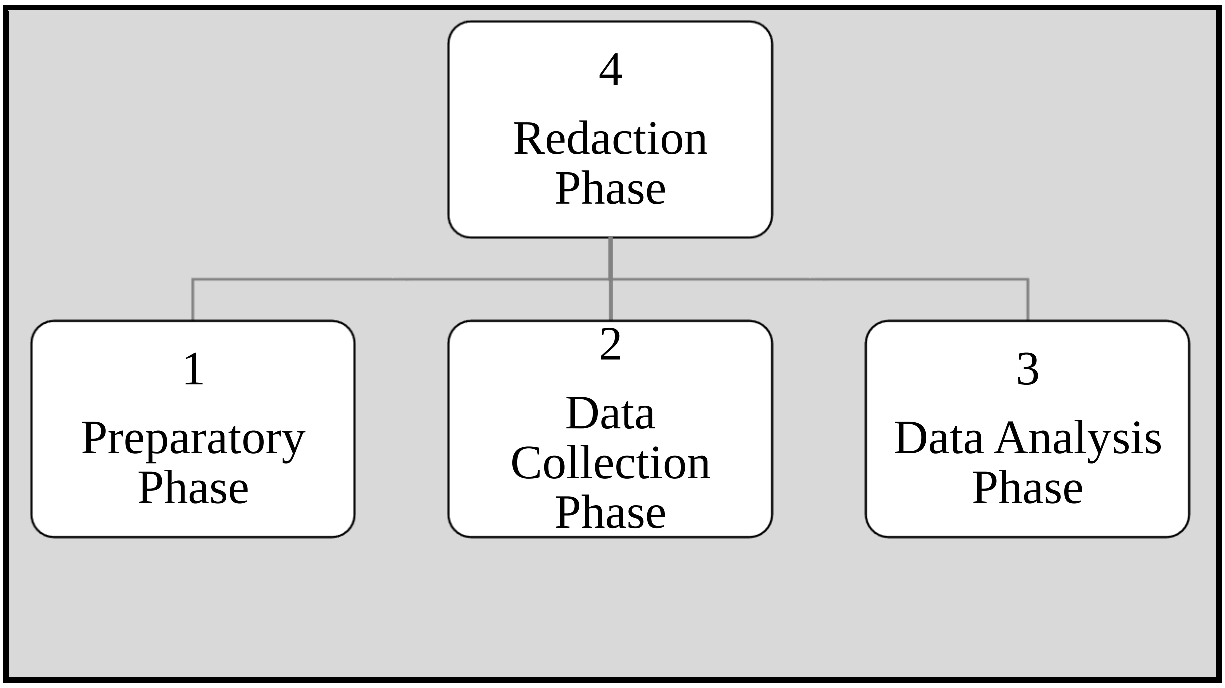


Figure 7: Schedule of Research

Phase 3: Data analysis

This phase includes the analysis of documents provided by some authors, people's resources related to beekeeping, analysis of primary data including beekeepers' and farmer's perception of climate change and how this can affect bee population and foraging activities.

Another part of this phase is an adaptation solution for beekeepers due to climate change. This involves Forest management practices that could help reduce bee losses caused by climate change.

Phase 4: Redaction phase

This phase involves presenting the work (preliminary report) to the supervisors for approval, followed by the ultimate submission to the educational institution. The report adheres to the specific formatting requirements of the school.

2.2.6. Data Processing and Analysis

2.2.6.1. Indicators and Variables

The initiation of data analysis begins with the development of an analysis plan that centered on a collection of objectively measurable indicators. These indicators are designed to accomplish the research objectives.

The following table indicates the main variables to measure the research objectives.

Table 1: Indicators and Variables

Indicators	Variables
Occupation	Occupation of the respondents
Education Level	Education level of the respondents
Main Source of Income	Main Source of Income
Cooperative membership	Cooperative membership
Hive installation	Hive installation
Years of experience	Years of experience of beekeepers
Average gain per hive	Average gain per hive
Average income per village	Average income per village
Perception of beekeepers on bees' population	Perception of beekeepers on bees' population
The quantity of honey production.	The quantity of honey production
Perception of beekeepers on CC	Perception of beekeepers on CC
Links	Link between bees and yield production
	Link between bees and trees

2.2.6.2. Data Analysis

The collected data were analyzed by applying descriptive statistic, inferential statistic and also Generalized Linear Model methods. Descriptively, mean, percentage, and frequency were used; inferentially, the hypothetic-test was performed in particular; such as Chi-Square to see how variables are dependent, and a generalized linear model was used to examine the effect of variables such as membership organization, ethnic group, education level, and village on the temporal dynamics of bee populations and the level of honey production by using binomial distribution function.

CHAPTER 3: RESULTS AND DISCUSSION

3.1-DEMOGRAPHIC SITUATION

3.1.1-Beekepers surveyed in term of sex

In the surveyed beekeeper's population of these villages, women beekeepers currently represent only 9.1%, while men make up the majority at 90.9%. This gender imbalance can be attributed to historical practices where women were excluded from various beekeeping activities. Traditionally, tasks such as hive installation, hive monitoring, and honey harvesting took place in the forest and often involved night-time operations, which were considered unsafe for women to leave their families.

Furthermore, cultural norms enforced strong restrictions on women approaching sacred places within the forests, further limiting their participation in beekeeping. However, with the advent of modernization and the establishment of beekeeping organizations, women have begun to play a limited role in the transformation of beeswax.

3.1.2- Level of Education

Education plays a crucial role in improving the quality of training and meeting the developmental needs of a country. Figure 8 illustrates the educational level of the respondents, with many bee farmers having completed primary school. However, it is worth noting that a significant portion of beekeepers surveyed did not receive any formal education.

It is important to emphasize that success is not solely determined by one's educational background. However, education is a valuable tool for personal and professional development at every stage of life.

For beekeepers, education can have various benefits. It can enhance their production capabilities by providing access to new, modern, and practical production tools. Furthermore, education opens avenues to connect with potential funding partners in beekeeping, which can lead to increased financial resources. Additionally, being well-educated allows beekeepers to navigate markets in larger cities, enabling them to sell their products at competitive prices.

In summary, while formal education is not the sole determinant of success, it plays a significant role in the development of beekeepers. Education equips them with valuable knowledge and skills, enabling them to enhance their production, engage with funding partners, and capitalize on market opportunities.

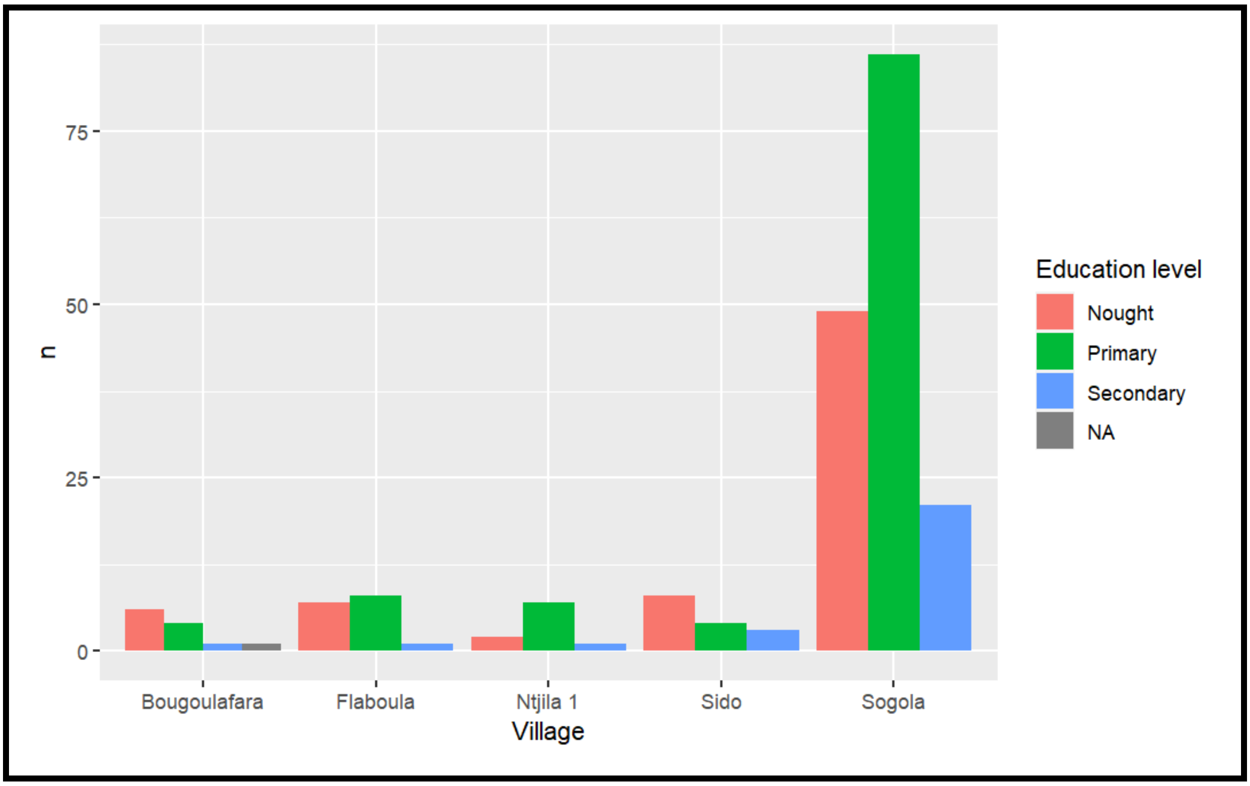


Figure 8: Education level

3.1.3- Respondents Occupation

According to the survey, table 2 shows that the majority of respondents in Bougouni engage in Agri-apiculture, with 98.1% identifying themselves as Agri-apiculturists. This indicates that they combine both agricultural activities and beekeeping in their occupation. On the other hand, a smaller percentage, 1.9%, is identified as fully dedicated beekeepers.

The prevalence of Agri-apiculture in Bougouni suggests that the local population primarily focuses on two main activities: agriculture and beekeeping. This combination of practices has given Bougouni a reputation as an area with a strong Agri-apiculture vocation, highlighting the significance of both agriculture and beekeeping in the local economy and livelihoods of the community.

Table 2: Respondents Occupation

Village	Agri-apiculturists	Apiculturists	Total
Bougoulafara	11 (91.7%)	1 (8.3%)	12 (100.0%)
Flaboula	16 (100.0%)	0 (0.0%)	16 (100.0%)
Ntjila 1	10 (100.0%)	0 (0.0%)	10 (100.0%)
Sido	15 (100.0%)	0 (0.0%)	15 (100.0%)
Sogola	152 (98.1%)	3 (1.9%)	155 (100.0%)
Total	204 (98.1%)	4 (1.9%)	208 (100.0%)

3.1.4 Main Source of Income

Figure 9 below, indicates the main source of income.

It is evident that agriculture plays a vital role in the economy of Bougouni and Mali as a whole. As stated by the beekeepers, agriculture serves as the primary source of income for each beekeeper in Bougouni. Given that agriculture is the main sector of the economy, it is also a crucial source of livelihood for the majority of the population in Bougouni.

The cultivation of crops such as cotton, maize, sorghum, and millet mentioned by the beekeepers highlights the importance of staple crops for both subsistence and commercial purposes. These crops are likely integral to the local food supply and contribute significantly to the national agricultural output.

In Mali, agriculture is considered the cornerstone of the economy and holds immense potential for widespread economic growth and opportunities. With approximately 80 percent of the population depending on agriculture for sustenance and livelihoods, it emphasizes the significant role this sector plays in the lives of Malian people.

Given the agricultural significance in Bougouni particularly and the whole Mali generally, supporting and investing in the agricultural sector can lead to enhanced food security, improved incomes, and overall economic development.

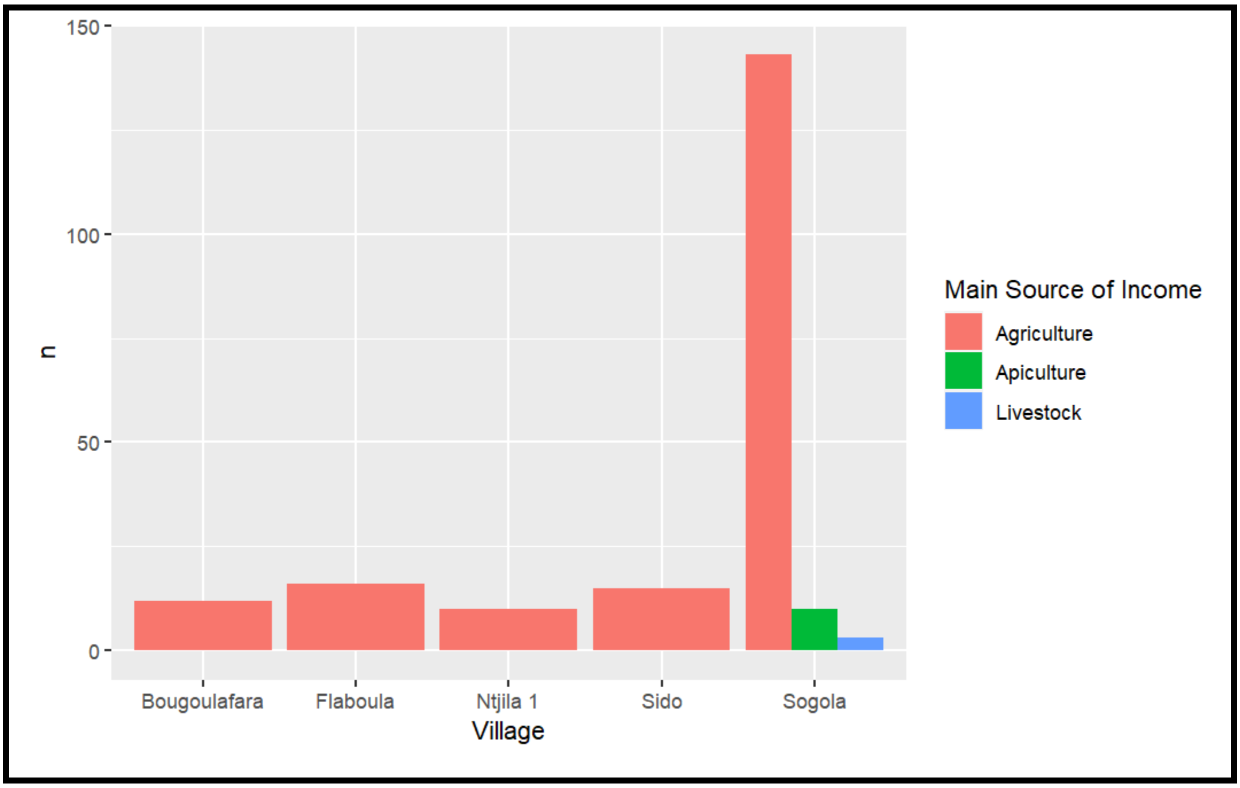


Figure 9: Main source of income

3.2-BEES POPULATION AND BEEKEEPING EVOLUTION OVER BOUGOUNI REGION

3.2.1-Member of Organization

Figure 10 below shows that most of the respondents are member of an organization.

The Pearson's Chi-squared test with p-value=0.0004229 highlights the significant impact of being a member of a production organization in supporting personal and environmental development within the context of beekeeping. With the p-value < 0.05 then the test is significant, however hive installation Conditions is significantly linked to the membership of production organization. Among those who have the necessary conditions for installing a hive, a substantial majority of 92.73% are members of a production organization, while only 7.27% of those without hive installation conditions are part of such organizations.

This finding emphasizes the importance of being part of a production organization in beekeeping. Membership in such organizations enables beekeepers to improve their apiculture techniques, transitioning from traditional hives to modern ones. This shift can lead to increased productivity rates and facilitate the sale of beekeeping products such as honey, beeswax, royal jelly, and propolis in the market.

Being a member of a production organization also provides advantages in terms of quantity and quality of the products. The collective support and knowledge-sharing within the organization can contribute to the overall improvement of beekeeping practices and product standards.

Additionally, being part of an organization opens doors for networking opportunities, allowing beekeepers to connect with new organizations and gain access to new funding sources. This access to funding can further support the development and expansion of beekeeping activities, enabling beekeepers to enhance their production capabilities and achieve sustainable growth.

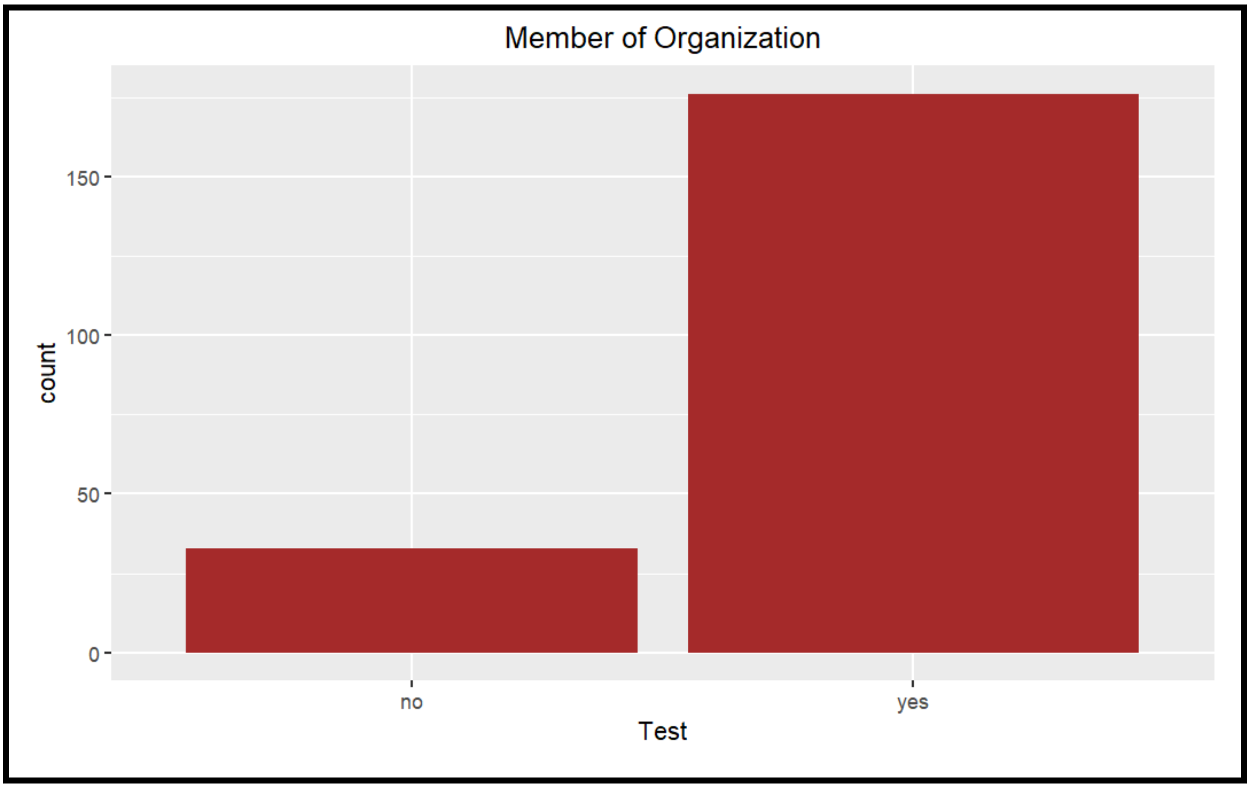


Figure 10: Member of Organization

3.2.1- Years of experience in Beekeeping

Figure 11 below indicates the average mean number of years of experience in beekeeping in each village provides valuable insights into the significance of experience in the success of beekeepers. Beekeeping is indeed a complex and specialized field that requires a deep understanding of bee behavior, hive management, and honey production.

The data shows that the average mean number of years of experience in beekeeping is more than 20 years in each village. Notably, Flaboula exhibits a higher mean compared to the other villages. There could be several factors contributing to this disparity.

One factor could be the seniority of beekeepers in Flaboula in terms of age. It is possible that beekeeping has been a long-standing tradition in Flaboula, with beekeepers accumulating knowledge and experience over generations. This extensive experience gives them a substantial advantage in terms of skills and understanding of beekeeping practices.

Another factor could be the time it took for other villages to start their beekeeping activities. The interviewees mentioned that Flaboula was the first village to initiate beekeeping activities in their respective localities. Therefore, the beekeepers in Flaboula had a head start in terms of experience, having engaged in beekeeping for a longer period before others began.

The Pearson's Chi-squared test with a p-value = 2.2e-16 less than a chosen significance level (often 0.05) this result indicates that there is a statistically significant relationship between the age of beekeepers and their years of experience, suggesting that these two variables are not independent and that changes in one variable may influence changes in the other.

The higher average mean in Flaboula could suggests that the beekeepers in this village have a wealth of knowledge and practical expertise, which likely contributes to their success and effectiveness in beekeeping. However, it is important to recognize that experience alone may not guarantee success, as other factors such as access to resources, training, and supportive networks also play crucial roles.

Understanding the impact of experience in beekeeping highlights the value of knowledge transfer and mentorship programs within beekeeping communities. It also emphasizes the need to support new beekeepers by providing training and opportunities for skill development to ensure the continued growth and sustainability of beekeeping practices across all villages.

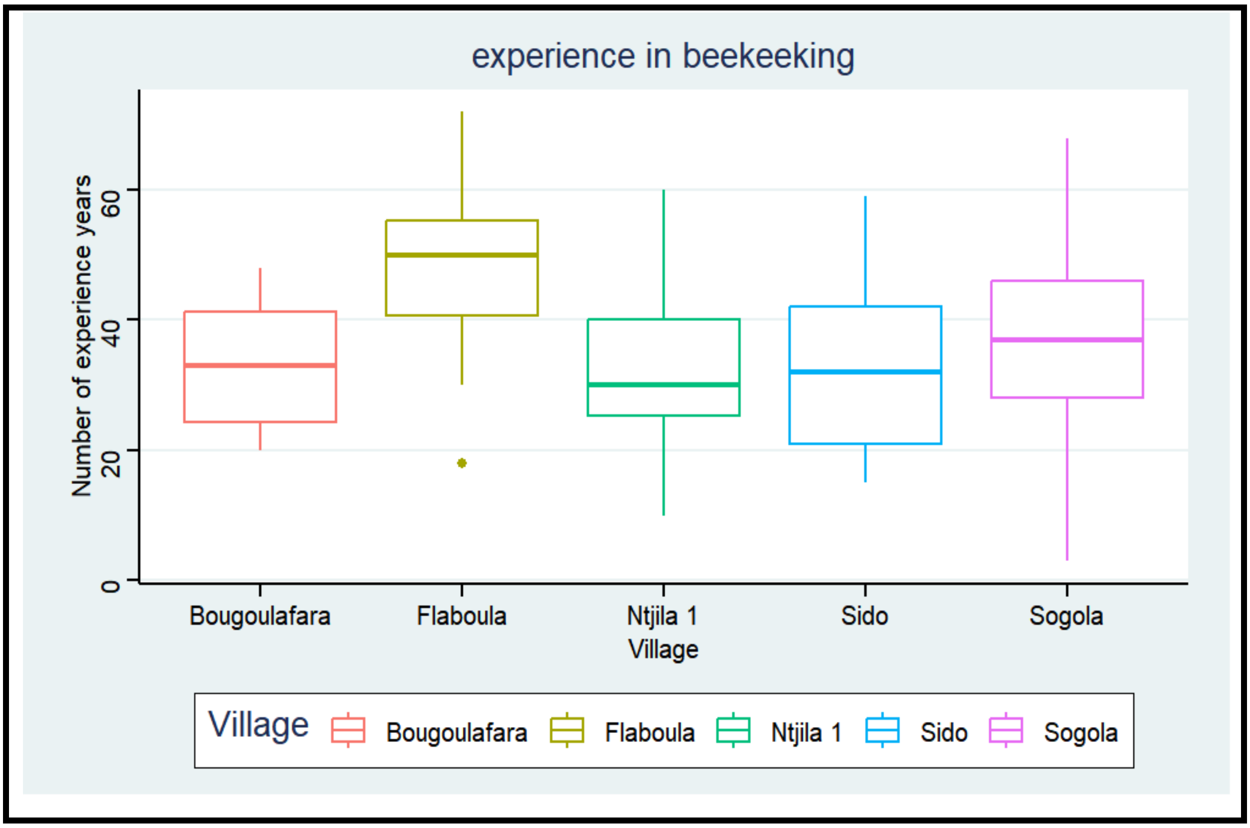


Figure 11: Experience in beekeeping

3.2.2-Average gain per Hive

Maintaining normal conditions in beekeeping plays a pivotal role in ensuring the overall well-being and productivity of honey bee colonies. These conditions encompass creating an environment that closely mimics the natural habitat and behaviors of bees. These aspects can notably influence the quantity of honey produced per hive. In the localities of Bougoulafara and Sido, the average yield falls below 10 Kg, while in Flaboula, N'tjila, and Sogola, the average stands at 10 Kg. This variance may depends on a range of factors including geographical location, climatic conditions, temperature, prevalence of parasites, local plant life, number of hive within each village, and the dedication of beekeepers in tending to the hives.

Additionally, noteworthy instances of higher-than-average production are observed in Sogola, N'tjila, and Flaboula. The presence of these positive outliers could potentially have a beneficial impact on the income generated from hive-related activities.

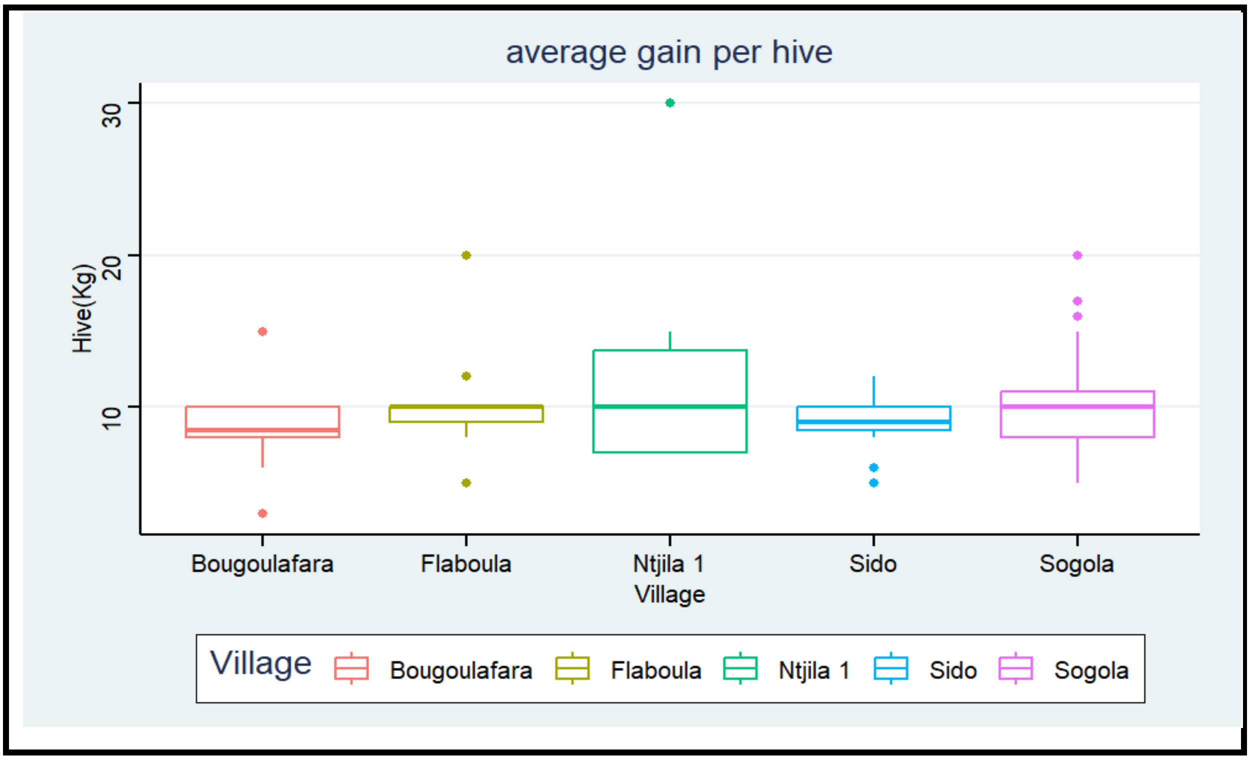


Figure 12: Average gain per hive

3.2.3-Average Income per Village

Honey is an extremely popular and marketable product in beekeeping, making it the primary source of income for beekeepers. Additionally, other bee-related products such as beeswax also contribute to the overall income. Honey enjoys high demand among consumers, which further enhances its market value.

When considering the income generated from beekeeping activities over the past 12 months, Sogola, Sido, N'tjila, and Bougoulafara exhibit mean average incomes below 250,000 XOF. On the other hand, Flaboula stands out with a mean average income of 250,000 XOF.

Furthermore, it is worth noting that there are positive outliers in Bougoulafara and Sogola. These outliers can be attributed to various factors. Firstly, the presence of communication networks and organizational groupings among beekeepers in these villages can contribute to higher annual incomes. The ability to share knowledge, resources, and market opportunities can positively impact their overall earnings.

Moreover, the geographical positioning of these villages along major roads may also play a role in their income levels. Being located on transportation routes could facilitate the marketing and sale of honey and other bee products, potentially leading to increased earnings.

In summary, honey serves as a significant source of income for beekeepers due to its high popularity and marketability. The mean average income in Sogola, Sido, N'tjila, and Bougoulafara is below 250,000 XOF, while Flaboula stands at that threshold. Positive outliers in Bougoulafara and Sogola could be attributed to factors such as communication networks, organizational groupings, and the favorable geographical positions of these villages along major roads.

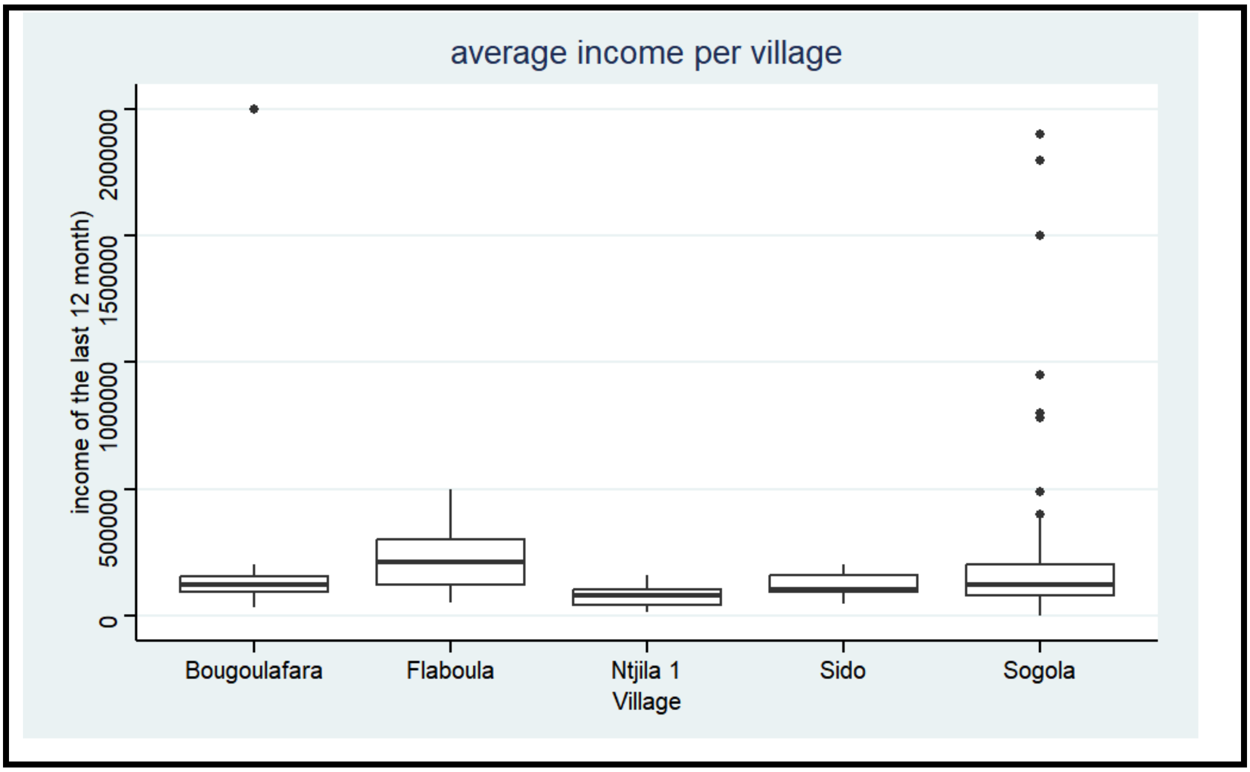


Figure 13: Average income per Village

3.2.4-Socioeconomic Importance of Bees

Bees are renowned for their significant contributions in providing high-quality food sources, such as honey, royal jelly, pollen, as well as valuable products like beeswax, propolis, and honey bee venom. Additionally, bees play a crucial role in biodiversity, which is vital for the survival of all living beings. The recognition of bees' importance is evident in sacred passages found in major world religions, signifying their significance to human societies throughout history, as stated in a May 2019 report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Beekeeping, in particular, serves as an important source of income and livelihood, especially in rural areas. It allows communities to derive economic benefits from bee-related products and services, contributing to their overall well-being and sustainability. Among pollinators, the western honeybee stands out as the most common livestock pollinator worldwide. The IPBES report highlights that approximately 81 million beehives globally produce about 1.6 million tons of honey annually, underscoring the significant role of beekeeping in honey production on a global scale. This further emphasizes the economic importance of beekeeping as a thriving industry.

In summary, bees and beekeeping are indispensable for their contributions to food production, biodiversity, and livelihoods. Their products have been cherished for centuries, and the economic value of beekeeping is evident in the substantial honey production figures worldwide. Understanding and supporting bees and beekeeping practices are crucial for the well-being of ecosystems, agriculture, and communities.

3.2.5 Evolution of honey bees’ population over the past fifteen years

The information presented in Table 3 depicts the trend in bee population as perceived by beekeepers. A significant majority of the participants (79.9%) reported a decline in bee numbers over the past fifteen years, as evident from their accounts. According to their observations, this decline could be attributed to various factors. These include fluctuations in climate patterns, escalating temperatures, insufficient rainfall leading to plant water stress, the adverse impact of bee hunting for harvesting, and the detrimental effects of deforestation. Of particular concern is the alarming increase in the utilization of pesticides, which is viewed as a particularly hazardous factor.

Climate change can affect foraging activity, body size, and longevity of pollinating insects

(Scaven & Rafferty, 2013). For example, increasing the ambient temperature reduces the body size of bees (Schweiger et al., 2010).

Since 1995, we have been seeing heavy mortality among Apis mellifera worldwide. The consensus among researchers is that a combination of factors is responsible for this honey bee mortality. Pesticides kill many colonies every year. New pathogens have been added to the already long list of honey bee diseases. However, researchers agree that the bees' environment and stress, both of which are influenced by climate change, have been decisive factors in this heavy mortality (Oldroyd, 2007; Pettis et al., 2007).

Table 3: Beekeepers Perception on the evolution of honey bees' population over the last 15 years

Village	downward	on_the_rise	Total
Bougoulafara	(91.7%) 11	(8.3%) 01	(100.0%) 12
Flaboula	(87.5%) 14	(12.5%) 02	(100.0%) 16
Ntjila 1	(80.0%) 08	(20.0%) 02	(100.0%) 10
Sido	(86.7%) 13	(13.3%) 02	(100.0%) 15
Sogola	(77.6%) 121	(22.4%) 35	(100.0%) 156
Total	(79.9%) 167	(20.1%) 42	(100.0%) 209

3.2.6- Relationship between bees and trees

From table 4 below all beekeepers perceived the interdependence between bees and trees. Trees serve as vital shelter for bees, while bees rely on tree flowers as a food source, extracting raw materials from the flowers while simultaneously pollinating the plants. This pollination process contributes to the transition from flowering to fruiting, enabling the plants to produce mature fruits. The presence of trees also supports an increased number of bees, demonstrating a mutually beneficial relationship.

The relationship between plants and pollinators, including bees, is of great ecological significance. Without pollinators, many plant species would struggle to set seed and reproduce, while the absence of plants providing pollen, nectar, and other rewards would lead to population declines in various animal species, with subsequent impacts on other interconnected organisms (Kearns et al., 1998).

According to Tiina Vahanen, Chief of FAO's Forest Resources and Policy Division, forests and trees play a vital role as habitats for wild bees, bats, butterflies, and other pollinators. They are crucial for maintaining ecosystems, biodiversity, agricultural productivity, and ultimately ensuring human food security. All bees are hymenopteran, vegetarian, and foraging insects, highlighting their dependence on plant-based resources

Damien Bertrand, an FAO expert on forests and a co-author of a study, stresses the importance of effective forest and landscape management in preserving pollinator populations. The study suggests that practices such as selective logging, targeted pruning, and planned burning that promote tree group variability can have positive effects on pollinators and forest biodiversity.

Ensuring the availability of pollinators is crucial for enhancing the productivity and resilience of both forestry and agriculture. Recognizing the value of pollinators and implementing measures to protect and support their populations are essential steps toward sustainable and productive land management, he added.

Table 4: The presence of trees increases the number of bees

Village	Yes	No	Total
Bougoulafara	(100.0%) 12	(100.0%) 0	(100.0%) 12
Flaboula	(100.0%) 16	(100.0%) 0	(100.0%) 16
Ntjila 1	(100.0%) 10	(100.0%) 0	(100.0%) 10
Sido	(100.0%) 15	(100.0%) 0	(100.0%) 15
Sogola	(100.0%) 156	(100.0%) 0	(100.0%) 156
Total	(100.0%) 209	(100.0%) 0	(100.0%) 209

3.2.6 Bees and Yield Production

From the figure below whatever the specific village selected, Beekeepers uniformly hold the view that the presence of bees within agricultural fields could contributes to enhanced crop yields. Beekeepers firmly believe that bees play a pivotal role in pollinating crops, with over 70% of our harvests being directly influenced by pollination. The sight of these bees within fields is regarded as an auspicious indication, suggesting a sense of contentment. The proximity of bees to one's field is indicative of an improved yield potential, attributed to their diligent pollination of flowers.

The presence of these bees in the field is a good sign that can insinuate happiness having the bees near your field means that the yield would be better, because they pollinate the flowers.

This finding aligns with the results of this study (Ollerton et al., 2011) also the statement of FAO reported that: more than 75 percent of the world's food crops depend on pollination, and bees help improve our diets by providing us with foods rich in micronutrients. Indeed, many highly nutritious foods, rich in micronutrients, such as fruits and some vegetables, seeds, nuts and oils, would be doomed to disappear without pollinators. Wild bee species are key not only to the sexual reproduction of hundreds of thousands of wild plant species but also to the yield of about of all cultivated crops (Ollerton et al., 2011).

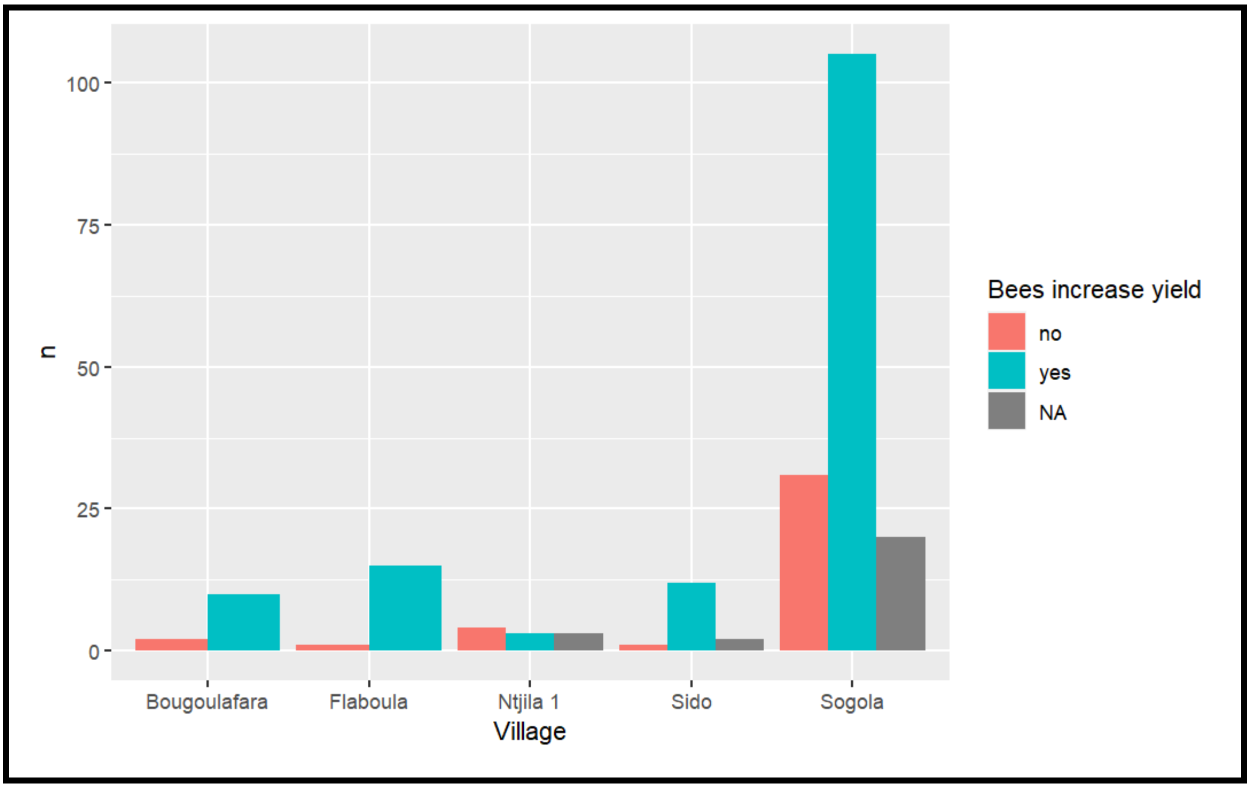


Figure 14: Presence of bees increase Yield

3.2.6- Quantity obtain from honey production

Figure 15 reveals a consistent decrease in the quantity of honey production across the entire village over the past fifteen years, as perceived by beekeepers. This decrease could be attributed to a range of factors, including a decrease in precipitation accompanied by rising temperatures leading to drought conditions, deforestation of the area for different agricultural activities, Engaging in deforestation as a survival strategy significantly impacts the production of honey (Gebrehiwot, 2015).The scarcity of water sources, and line with agricultural activities, the utilization of pesticides in close proximity to the hives or their installation areas could also affects beekeeping activities. These cited factors might collectively contribute to a notable decline in bee population, consequently resulting in the decrease of honey production. This finding aligns with the results of (Kerealem *et al* 2009); (Arage 2018) and (Shale *et al* 2018).

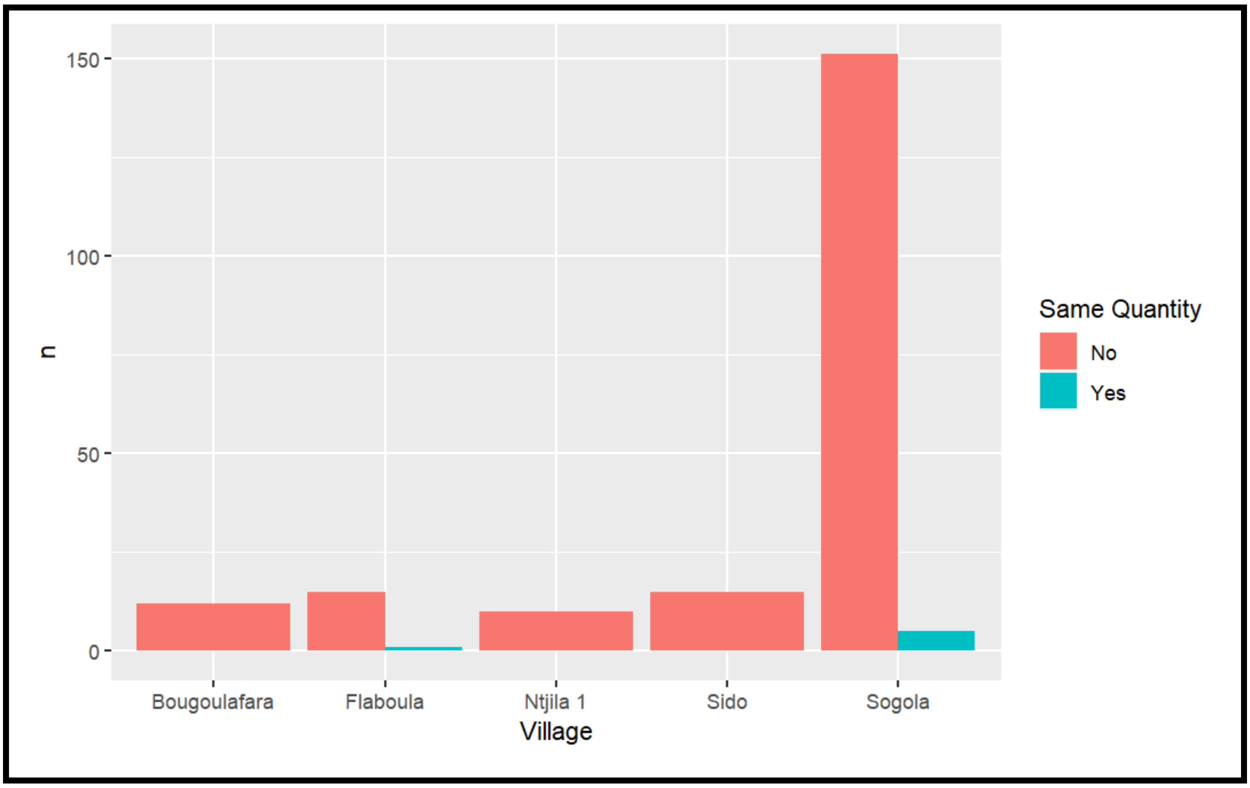


Figure 15: Quantity obtain from honey production

3.3. **Beekeepers Perception on Climate Change**

Climate Change perception is a complex process that encompasses a range of psychological constructs such as knowledge, beliefs, attitudes and concerns about if and how the climate is changing (Whitmarsh & Capstick, 2018).

Approximately 92.3% of beekeepers perceived that climate change could be all change in the period, which encompasses various alterations in weather patterns, including shifts in precipitation patterns, the both decreases and flooding, the occurrence of strong winds, droughts, and increases in temperature. They attribute these changes to human activities such as urbanization, deforestation, and animal pasturing.

Climate change is a global phenomenon and crosses geographical boundaries.

Industrialization and deforestation, which eliminate the ozone layer and increase the concentration of carbon dioxide in the atmosphere, appear to be the main drivers of this process. Global climate change is defined as a permanent change in the statistical distribution of weather patterns from decades to millions of years. This may be a change in the average weather conditions or in the distribution of events around this average (for example, more or less extreme weather events). The Intergovernmental Panel on Climate Change (IPCC) reports an approximate increase in temperature of around 1.1 to 6.4 ° C by the end of this century. The IPCC has documented increasing global temperatures, decreasing snow and ice cover, and changes in the frequency and intensity of precipitation as major impacts of climate change (*AR4 Climate Change 2007*, n.d.).But the increase in temperature is considered as the most significant effect of climate change, with respect to plant-pollinator effects(Kjøhl et al., 2011).

Table 5: Heard about climate change

Village	No	Yes	Total
Bougoulafara	(8.3%) 1	(91.7%) 11	(100.0%) 12
Flaboula	(0.0%) 0	(100.0%) 16	(100.0%) 16
Ntjila 1	(0.0%) 0	(100.0%) 10	(100.0%) 10
Sido	(20.0%) 3	(80.0%) 12	(100.0%) 15
Sogola	(7.7%) 12	(92.3%) 144	(100.0%) 156
Total	**(7.7%) 16**	**(92.3%) 193**	**(100.0%) 209**

From table 6 below, 54.5% of respondents strongly-agree that use of pesticides could really affect the bees' colonies by reducing their population and also affecting the quality of honey. The use of pesticides has detrimental effects on pollinator populations, including bees. These effects could range from slowing development and causing malformations to disrupting orientation abilities, hindering bees' ability to find their hives and recognize flowers. Pesticides can also weaken their immune defenses, making them more susceptible to diseases and other threats. In agreement with the study of (Desneux et al., 2007) reported that in terms of toxicity, insecticides can be categorized as acute or lethal when they cause severe effects that lead to rapid death. On the other hand, sub-acute or sublethal toxicity refers to effects that may not result in immediate death but have long-term impacts on the physiology and behavior of the studied population. These effects can include deterioration of the learning process, changes in behavior, and other neurological impairments.

Research indicates that despite a decrease in the overall quantity of pesticides used, the toxic impact of pesticides on bees and other pollinators has actually increased over the past decade. Modern pesticides may have lower toxicity to humans, wild mammals, and birds, and they may be applied in smaller quantities. However, their impact on invertebrates, including pollinators, is notably higher (Carrington & editor, 2021).This highlights the urgent need to address the issue of pesticide use and its impact on pollinators. Mitigating the risks associated with pesticide use, adopting more environmentally friendly alternatives, and promoting sustainable agricultural practices that prioritize the protection of pollinators are essential for the conservation of these vital species and the health of ecosystems.

Table 6: Perception about the effect of Pesticide

Village	**agree**	**Desagree**	**strongly_agree**	**strongly_desagree**	**Total**
Bougoulafara	(33.3%) 4	(33.3%) 4	(33.3%) 4	(0.0%) 0	(100.0%) 12
Flaboula	(37.5%) 6	(0.0%) 0	(62.5%) 10	(0.0%) 0	(100.0%) 16
Ntjila 1	(20.0%) 2	(10.0%) 1	(70.0%) 7	(0.0%) 0	(100.0%) 10
Sido	(26.7%) 4	(13.3%) 2	(60.0%) 9	(0.0%) 0	(100.0%) 15
Sogola	(30.1%) 47	(9.0%) 14	(53.8%) 84	(7.1%) 11	(100.0%) 156
Total	(30.1%) 63	(10.0%) 21	(54.5%) 114	11 (5.3%)	209 (100.0%)

PART 2: SPECIES DISTRIBUTION MODELING

1. Species Occurrence

Species occurrence refers to the observed distribution of a species across the region at any point in time. Species occurrence records data (or occurrence records) of *Detarium microcarpum, Parkia biglobosa* and *Vitellaria paradoxa* were compiled from both field survey carried out throughout the species distribution area in the Southern part of Mali and from GBIF data base. The locations of individual trees of the species were georeferenced using a GPS (Global Positioning System, Garmin 64) with at least 1 km between trees. The collected occurrence records were supplemented by data from GBIF depending on the available data of the species of *Parkia biglobosa* and *Detarium microcarpum*. A total dataset of 538 occurrence records were obtained, of which 300 records (55.76%) were collected from field surveys 100 points for *Detarium microcarpum, Parkia biglobosa* 100 occurrences also *Vitellaria paradoxa* 100 occurrences; 239 records were downloaded from the Global Biodiversity Information Facilities repository (GBIF) (44.23% of the total) while 67 occurrences for *Parkia biglobosa* and 171 occurrences for *Detarium microcarpum*.

The selection of species was not made randomly; we referred to a list of around ten melliferous species present in the area. It is based on this list that the species were chosen, according to the frequency of respondents during the survey. Below is the table 7

Table 7: Melliferous Species

Species	**Family**	**Frequency**
Annea acida	Anacardiaceae	10
Detarium microcarpum	Fabaceae	43
Diospyros mespiliformis	Ebenaceae	05
Isoberlinia doka	Fabaceae	03
Magifera Indica	Anacardiaceae	19
Parkia biglobosa	Fabaceae	68
Pterocarpus erinaceus	Fabaceae	06
Pseudocedrela kotschyi	Meliaceae	0
Tamarindus indica	Fabaceae	05
Vitellaria paradoxa	Sapotaceae	50

Species studies

In Mali, from the Fabaceae family *Parkia biglobosa* is one of the most important parkland tree species, the distribution range of *Parkia biglobosa* extends from the north and the south of Sudanian Zones in the regions of Kayes, Koulikoro, Ségou, Sikasso; and in the north Guinean zones in the regions of Kayes and Sikasso (FAGUI, 2015). It is a dry forest tree species which regenerates naturally. It is a useful, multi-purpose type of forest tree that provides sustenance for people (the pulp and grains are used to make the spice known as "soumbala" or "dawadawa"). *P. biglobosa* fights poverty by generating revenue for rural communities and providing food for animals as well. Additionally, it offers medicine and occasionally woodcraft (mostly in the Mali regions that are belong to the North and South Sudanese).

Detarium microcarpum is an important fruit-bearing species extended in the south of Mali, a forest species very appreciated by the West African populations. *Detarium microcarpum* is an African tree belonging to the family Fabaceae; it is a tiny tree or shrub that can grow up to 15 meters tall. In its native settings, *Detarium microcarpum* plays an important ecological role. The tree offers shade and shelter to a variety of animal species, and its flowers attract pollinators such as bees and butterflies.

Vitellaria paradoxa is most likely pollinated by moths because the blooms open near sunset, emitting a strong fragrance and nectar. Honeybees forage in vast numbers on this plant from now until well after dusk, and again from daybreak until well after sunrise. Wasps, moths, and birds come to the plant for the nectar. During the flowering of *Vitellaria paradoxa,* beekeepers harvest large quantities of honey.

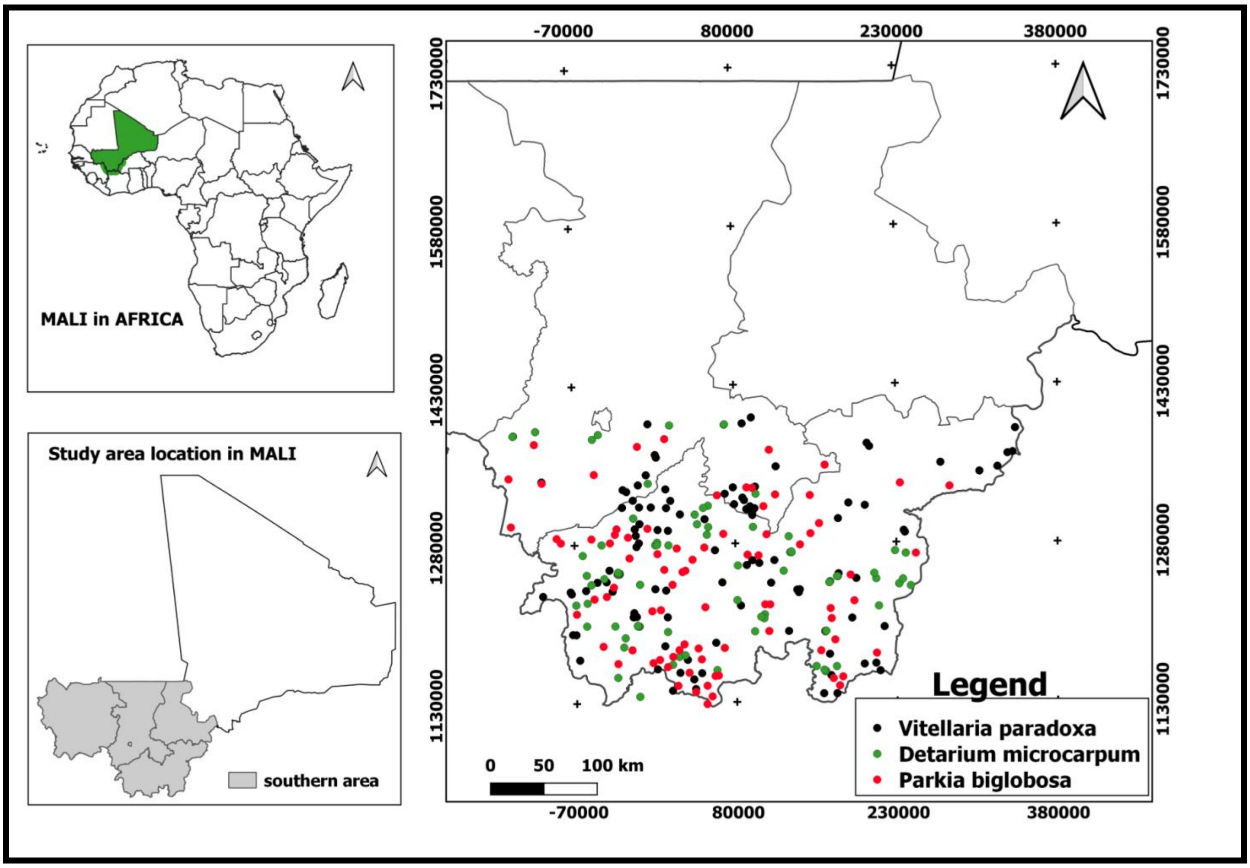


Figure 16: Occurrences points of the melliferous species in the southern part of Mali

2. Environmental data and Climate Scenario

Variables were composed of both climatic and non-climatic variables, climatic variables were downloaded from Worldclim database version 1.4 including 19 bioclimatic variables (11 temperature and eight precipitation metrics) (Hijmans et al., 2005, http: //www.worldclim.org). The 19 bioclimatic variables were derived from interpolated averages of minimum and maximum temperature and rainfall (Hijmans et al., 2005). For future climate projections, two Global Climate Models (GCMs) (BC_BCC-CSM1-1 involved in CMIP5 and HD_HadGEM2-AO) from the Coupled Model Inter-comparison Project phase 5 (CMIP5) were selected.

Climate models were downloaded at a spatial resolution of 30 s (approx... 1 km x 1 km) under the representative concentration pathways (RCP) 2.6 and 8.5 at the horizons 2050 and 2070. The two emission scenarios (RCP 2.6 and RCP 8.5) were considered to capture the range of emission uncertainties (Harris et al., 2014). However, the RCP 2.6 describes the lowest emission scenario, whereas the RCP 8.5 describes the highest emission scenario.

The following table shows the 19 bioclimatic variables.

Table 8: List of Environnemental variables

Codes	Variables	Units
Ev	Elevation	m
Soil	Soil types	-
bio-01	Annual Mean Temperature	°C
bio-02	Mean Diurnal Range	°C
bio-03	Isothermality	°C
bio-04	Temperature Seasonality	°C
bio-05	Maximum Temperature of Warmest Month	°C
bio-06	Minimum Temperature of Coldest Month	°C
bio-07	Temperature Annual Range	°C
bio-08	Mean Temperature of the Wettest Quarter	°C
bio-09	Mean Temperature of the Driest Quarter	°C
bio-10	Mean Temperature of Warmest Quarter	°C
bio-11	Mean Temperature of the Coldest Quarter	°C
bio-12	Annual Precipitation	mm
bio-13	Precipitation of Wettest Month	mm
bio-14	Precipitation of the Driest Month	mm
bio-15	Precipitation Seasonality (Coefficient of Variation)	mm
bio-16	Precipitation of Wettest Quarter	mm
bio-17	Precipitation of the Driest Quarter	mm
bio-18	Precipitation of the Warmest Quarter	mm
bio-19	Precipitation of the Coldest Quarter	mm

3. MAXENT MODELING ALGORITHM

The study employed the Maximum Entropy (MaxEnt) algorithm, also known , as a machine learning method to model changes in species distribution (Phillips *et al.*, 2004, 2006). MaxEnt is a versatile and effective method for species distribution modeling, characterized by its straightforward mathematical formulation and several advantageous features.

MaxEnt utilizes georeferenced occurrence records and environmental variables to derive the probability distribution of species. Notably, it produces continuous output, which enhances its precision and applicability. One of the key advantages of MaxEnt is its capability to work with species presence-only data, allowing for efficient modeling even when absence data is lacking. Additionally, MaxEnt accommodates both continuous and categorical variables, offering flexibility in incorporating various types of environmental data into the modeling process (Baldwin, 2009)

Numerous studies have demonstrated the effectiveness of MaxEnt in accurately predicting species distribution across diverse ecological and geographical regions (Araújo & Guisan, 2006; Elith et al., 2006; Merow et al., 2013). Its robust performance and widespread application in species distribution modeling highlight its reliability and suitability for addressing research questions related to species habitat suitability and potential range shifts.

4. Data processing and model calibration: The presence data and the bioclimatic variables were processed in ArcGIS 10.8 (Brown, 2014; Brown et al., 2017). A total of 531 presence records were kept after removing the duplicated records, and then compiled into a single CSV file format under excel and convert into Dbf in R for further processing under ArcGIS . The 19 bioclimatic variables for the study area (Mali), were extracted from the global, the grid rectangle Mali was first extracted by mask from the global to 1km and resample into 10km then extracted by mask as GeoTIFF format and lastly converted from raster into ASCII format which is accepted by the algorithm. The Pearson correlation coefficient was used into R to test the colinearity between variables at each level, which allows excluding highly auto correlated variables. For instance, if a pair of variable has a correlation coefficient greater or equal to 0.9(>=0.9) then they were considered proxies of one another, and one of the variables was removed from the analysis, then ten bioclimatic variables such as bio2 (Annual Mean Diurnal Range) ,bio3 (Isothermality) ,bio5 (Max Temperature of Warmest Month), bio6 (Min Temperature of Coldest Month), bio7 (Annual Temperature Range), bio8 (Mean Temperature of Wettest Quarter), bio10 (Mean Temperature of Warmest Quarter), bio12 (Annual Precipitation), bio15(Precipitation Seasonality) and bio17 (Precipitation of Driest Quarter) were retained for the modeling. Area under the receiver operating characteristic curve, or AUC values, for training data was calculated for each species. Jackknife test was performed to measure variable importance and percent contributions of each variable to estimate the influence of environmental variables on each species. As the data were compiled from a variety of sources and likely to have some errors, the 10 percentile training presence logistic threshold was used to define the minimum probability of suitable habitat for the three species(*Detarium microcarpum, Parkia biglobosa and Vitellaria paradoxa*); (Phillips et al., 2006).The averaged outputs of MaxEnt obtained for each climate model under each scenario at each horizon were converted from ASCII format to raster, files were polygonized and maps of the species suitable areas were finally produced for current and future climatic conditions under the two scenarios RCP2.6 and RCP8.5 at the two horizons.

5. Results and Discussion

5.1. Model performance and variables Contribution

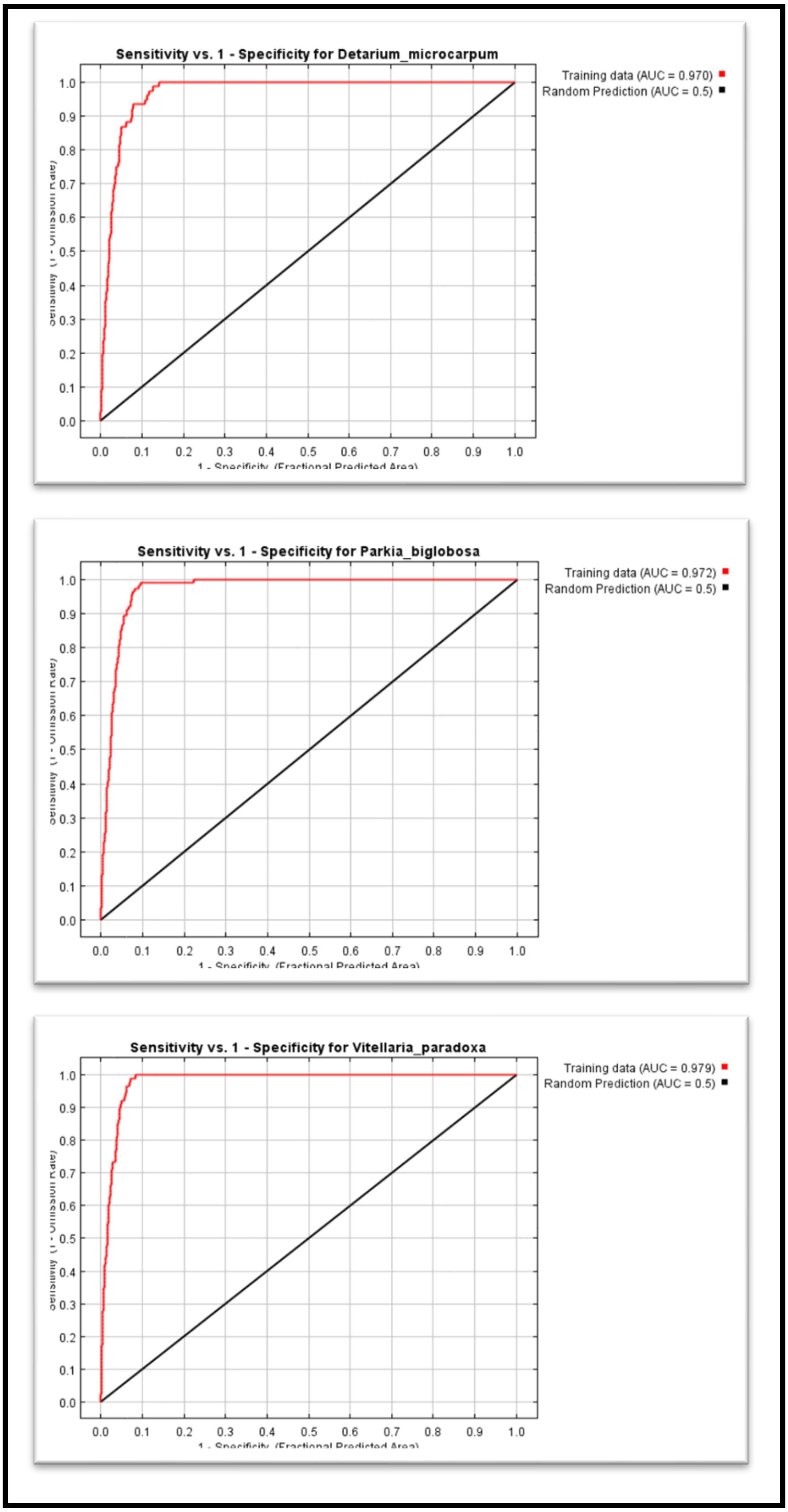


Figure 17: Model Performance for the three species

5.1.1 Model Performance

Figure 17 above shows that the models performed well, with significant AUC value. The area under the curve, which is an operating characteristic of the receiver showed high AUC value for all the three species with respectively *D. microcarpum* (AUC=0.97); *P. biglobosa* (AUC=0.97) and *V. paradoxa* (AUC=0.98). This condition shows a very good predictive ability of the model which generally proves good model performance.

5.1.2. Variables Contribution

For each given prediction variable, the corresponding green bar (without variable) shows how much the total gain is decreased in case this specific variable is excluded from the model. The blue bar (with only one variable) shows the gain obtained if the variable considered is used in isolation and the others are excluded from the model and the red bar indicates the gain obtained using all variables.

Figure18 below shows the results of the jackknife test of variable importance for the three species.

5.1.2. a) For *Detarium microcarpum*

Figure 18.A shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is bio_12 (Annual precipitation), which therefore appears to have the most useful information by itself. This is followed by Bio_8 (Temperature of Wettest Quarter), Bio_10 (Mean Temperature of Warmest Quarter), Bio_5 (Max Temperature of Warmest Month), Bio_3 (Isothermity), bio_7 (Annual Temperature Range), bio_15 (Precipitation Seasonality), bio_17 (Precipitation of Driest Quarter) bio_2 (Annual Mean Diurnal Range) bio_6 (Min Temperature of Coldest Month) and Bio_19 (Precipitation of coldest quarter). The environmental variable that decreases the gain the most when it is omitted is bio_15, which therefore appears to have the most information that isn't present in the other variables.

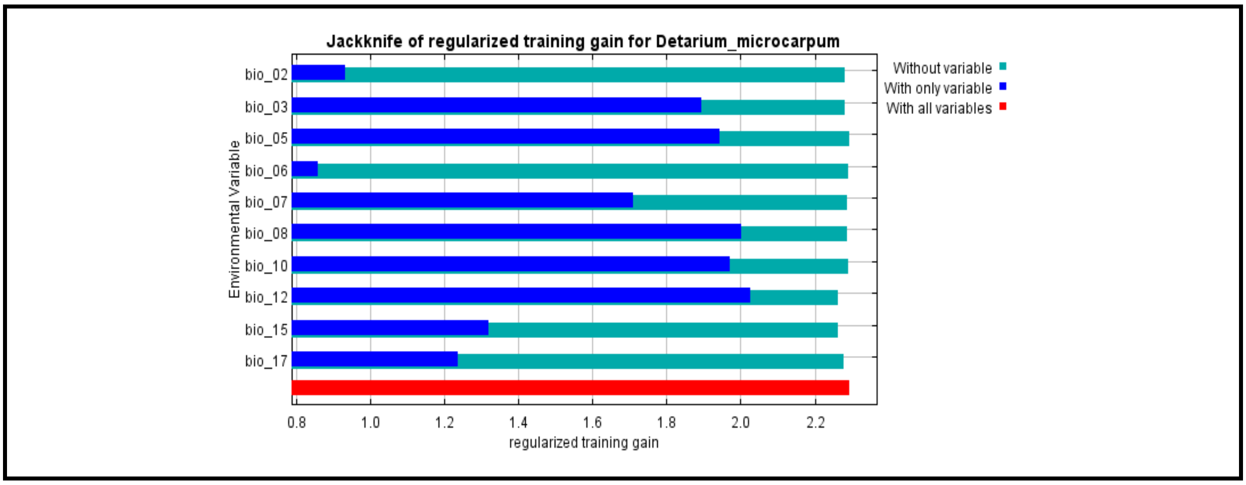
5.1.2. b) For *Parkia biglobosa*

From figure 18.B the results of the jackknife test of variable importance shows that the environmental variable with highest gain when used in isolation is bio_12. This is followed by Bio_5 (Max Temperature of Warmest Month), Bio_8 (Temperature of Wettest Quarter), Bio_10 (Mean Temperature of Warmest Quarter), Bio_3 (Isothermity), bio_7 (Annual Temperature Range), bio_17 (Precipitation of Driest Quarter), bio_15 (Precipitation Seasonality), bio_2 (Annual Mean Diurnal Range) bio_6 (Min Temperature of Coldest Month) and Bio_19 (Precipitation of coldest quarter). The environmental variable that decreases the gain the most when it is omitted is bio_15, which therefore appears to have the most information that isn't present in the other variables.

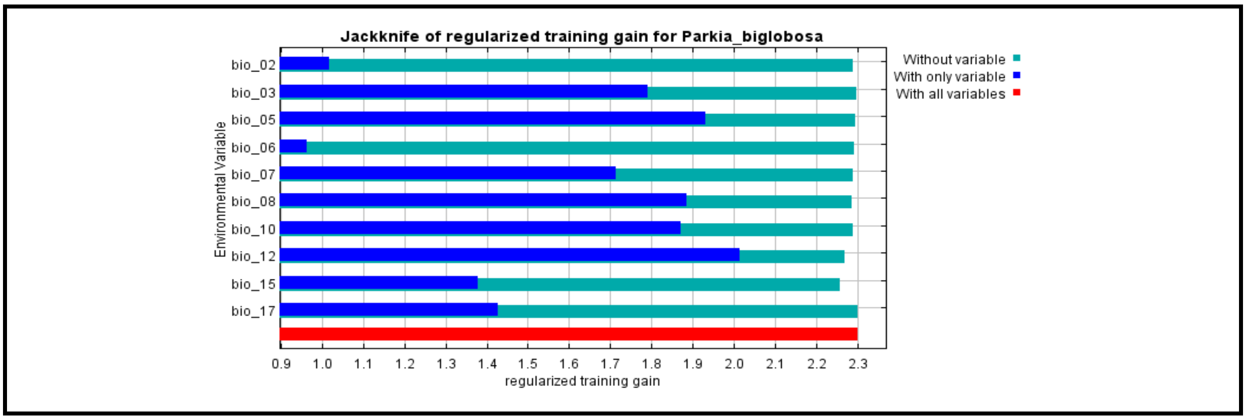
5.1.2. c) For *Vitellaria paradoxa*

Figure 18.C shows the results of the jackknife test of variable importance for *Vitellaria paradoxa*. The environmental variable with highest gain when used in isolation is bio_05, which therefore appears to have the most useful information by itself. This is followed by bio_12 (Annual precipitation), Bio_10 (Mean Temperature of Warmest Quarter), Bio_8 (Temperature of Wettest Quarter), bio_7 (Annual Temperature Range), Bio_3 (Isothermality), bio_17 (Precipitation of Driest Quarter), bio_15 (Precipitation Seasonality), bio_2 (Annual Mean Diurnal Range) bio_6 (Min Temperature of Coldest Month) and Bio_19 (Precipitation of coldest quarter).

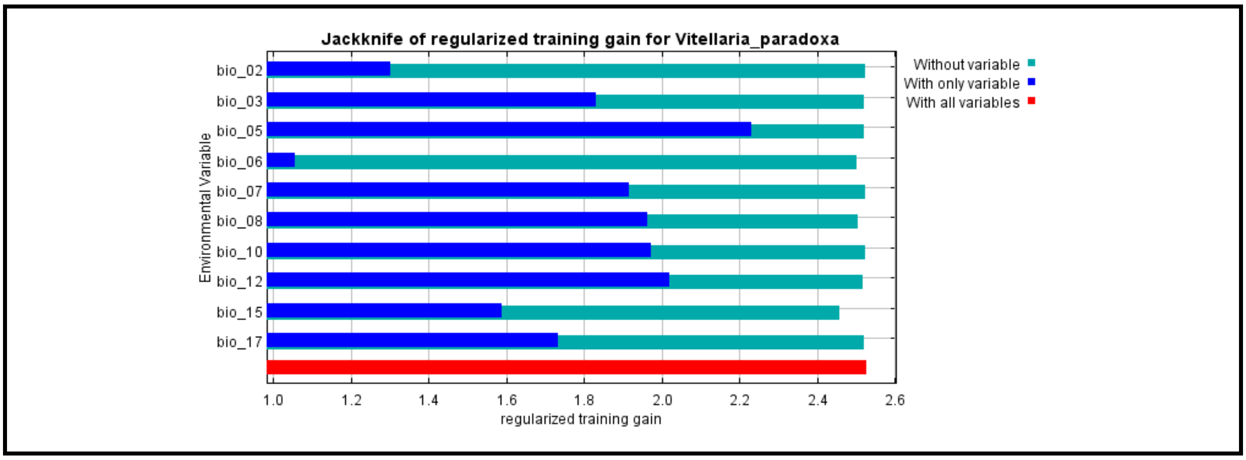
The environmental variable that decreases the gain the most when it is omitted is bio_15, which therefore appears to have the most information that isn't present in the other variables.



A. Jackknife test for Detarium microcarpum



B. Jackknife test for Parkia biglobosa



C. Jackknife test for Vitellaria paradoxa

Figure 18: Test of Jackknife Regularized training gain for the three species

5.2 FUTURE DISTRIBUTION OF THE SPECIES UNDER FUTURE CLIMATIC CONDITIONS

5.2.1 Future Distribution of *Detarium microcarpum* under future climatic condition

Indeed, the distribution of *Detarium microcarpum* (from Figure 19 below), a prominent species in Mali's southern region, is noteworthy, with two distinct scenarios projected for the future horizons of 2050 and 2070. Currently, *Detarium microcarpum* occupies 2.2% (28300 km2) of Mali's total area.

By 2050, climate model BC_BCC-CSM1-1 projected a reduction in suitable habitats for *Detarium microcarpum* under both RCP 2.6 (47.45% suitable, 52.55% loss) and RCP 8.5 (19.18% suitable, 80.82% loss). Notably, RCP 2.6 emerges as the more favorable scenario. Looking at 2070, RCP 2.6 remains suitable at 31.3%, while RCP 8.5 declines drastically to zero suitability.

In the HD_HadGEM2-AO model, 2050 projections show RCP 2.6 as the most suitable (48.4%) and RCP 8.5 with the highest loss (86.74%). By 2070, RCP 2.6 maintains 13.26% suitability, whereas RCP 8.5 reaches 100% unsuitability.

Between climate models, emission scenarios, and horizons, habitat loss predictions for *Detarium microcarpum* vary. Under RCP 8.5 and horizon 2070, both models foresee extensive habitat loss.

Future Climate conditions could negatively impact the future distribution of *Detarium microcarpum's*.

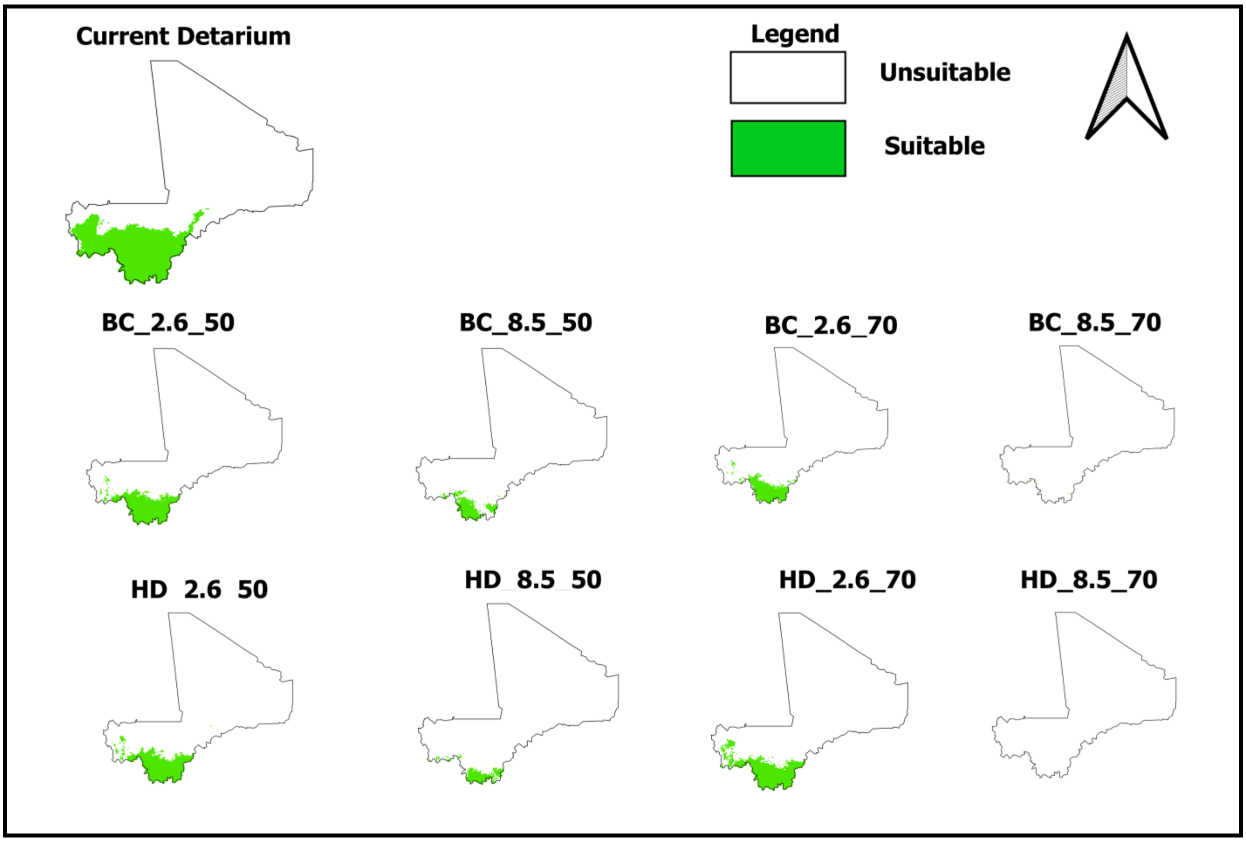


Figure 19: Geographic distribution of *Detarium microcarpum*

5.2.2 Future Distribution of *Parkia biglobosa* under future climatic condition

Indeed, the distribution of *Parkia biglobosa* (from Figure 20 below), a prominent species in the Southern part of Mali, is expected to undergo significant changes under two contrasting scenarios at two future horizons 2050 2070.

At the horizon 2050, the climate model BC_BCC-CSM1-1 projected under the RCP 2.6 a suitability in the size of the species' (*Parkia biglobosa*) was predicted with 66.16% while a loss of 33.83% of the species and the scenario 8.5 represented 68.86% of suitability against 31.14% of species losses which can explain that under the same horizon 2050, the scenario RCP8.5 represent the most suitable scenario for Parkia biglobosa at the horizon 2050, while the highest loss is observed in the 2.6.

In the concern of horizon 2070, the RCP2.6 recorded the highest suitable area for the species with 67.73% and 32.27% of losses, however under the RCP8.5 the species have lightly reduced with a suitability of 66.03 and 33.97 of species unsuitability. Whatever the chosen horizon under the model BC_BCC-CSM1-1 both of the scenario RCP2.6 and RCP8.5 under the entire horizon are all predicted to have more than 66% of *Parkia biglobosa* distribution suitability for all the scenarios and under the two horizons in the Southern part of Mali.

In the Model HD_HadGEM2-AO projected on the horizon 2050 under the RCP2.6 shows 87.13% of the species suitability and 14.87% of loss while the RCP8.5 showed the highest environmental suitability of species with 93.43% with lowest declining of 6.57%, the RCP8.5 would have been more suitable for the *Parkia biglobosa* under the Model HD_HadGEM2-AO in the horizon 2050.

In the horizon 2070, RCP2.6 shows the lowest suitable distribution of *Parkia biglobosa* with 43.8% while 8.5 highly predicted 86.75%.

The range of habitats loss predicted for the species differs between the two climate models, the two scenarios and the two horizons, climate change would lightly impact the future distribution of *Parkia biglobosa* in the Southern part of Mali under the two climate models BC_BCC-CSM1-1 and HD_HadGEM2-AO.

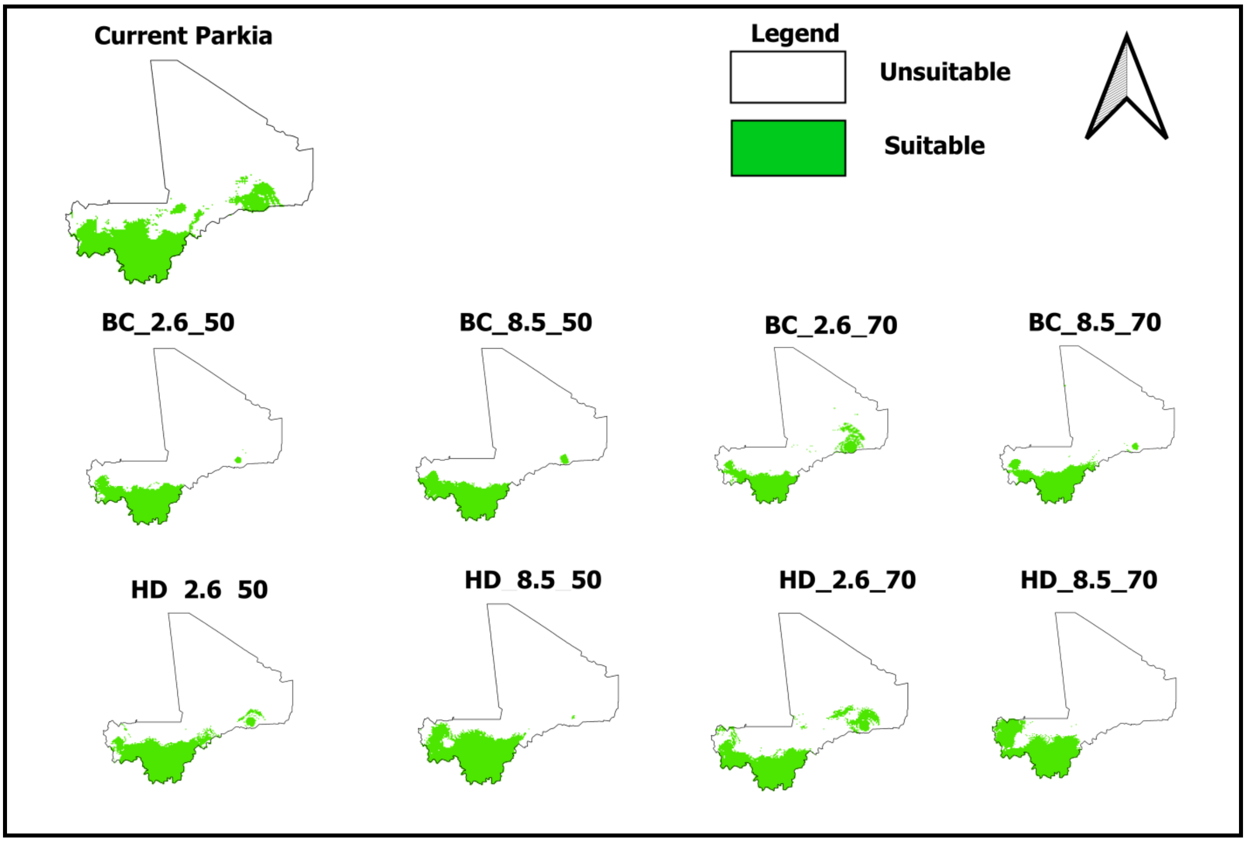


Figure 20: Future Distribution of *Parkia biglobosa*

5.2.3. Future Distribution of Vitellaria paradoxa under future climatic condition

The distribution of *Vitellaria paradoxa* or Shea tree (from Figure 21 below), in the southern part of Mali was studied using two climate models: BC_BCC-CSM1-1 and HD_HadGEM2-AO, with two horizons, 2050 and 2070. In the horizon 2050, under the RCP 2.6 scenario, it was projected that 57.53% of habitats would be suitable, but there would be a loss of 42.47% of the species. Similarly, under the RCP 8.5 scenario, 57.33% of habitats were predicted to be suitable, with a 42.67% species extinction rate. Moving to the horizon 2070, the RCP 2.6 scenario indicated 45.41% of suitable habitats, but a significant loss of 54.59% of the species. On the other hand, the RCP 8.5 scenario depicted 44.15% of suitable habitats and a 55.13% decline in the species population. These results suggest that in the horizon 2070, using the BC_BCC-CSM1-1 model, more species would be unable to survive compared to the horizon 2050.

For the HD_HadGEM2-AO climate model, the horizons 2050 and 2070 were analyzed to examine the species' response to different climate scenarios, RCP 2.6 and 8.5. In the horizon 2050, RCP 2.6 showed a 61.42% survival rate, indicating suitable conditions for the species, while 38.58% were considered unsuitable and at risk of extinction. RCP 8.5 indicated a 46.87% suitability rate and 53.13% unsuitability, suggesting that RCP 2.6 would support the survival of more species compared to RCP 8.5 in this horizon. Looking at the horizon 2070, the RCP 2.6 scenario indicated 43.74% suitability for the species, but with 56.26% deemed unsuitable. However, RCP 8.5 showed only 22.08% suitability and a significant 77.92% unsuitability, signifying that RCP 8.5 would lead to the loss of more species compared to RCP 2.6, with a high intensity and range of unsuitability.

Overall, the impact of the RCP 8.5 scenario in both horizons is expected to be severe, resulting in the loss of numerous species. The horizon 2070 is projected to have a more significant effect on the survival of many species compared to the horizon 2050.

When considering the future distribution of *Vitellaria paradoxa*, commonly known as Shea tree, in the southern part of Mali, it is preferable to focus on the horizon 2050 for both of the models studied. Under this timeframe, the suitable environmental distribution of *Vitellaria paradoxa* is projected to be lightly affected while more accurately represented than 2070. However, when selecting a model, it is worth noting that the BC_BCC-CSM1-1 model demonstrates greater suitability for *Vitellaria paradoxa* compared to the HD_HadGEM2-AO model. In overall future climate conditions could have a negative impact on the future distribution of *Vitellaria paradoxa.*

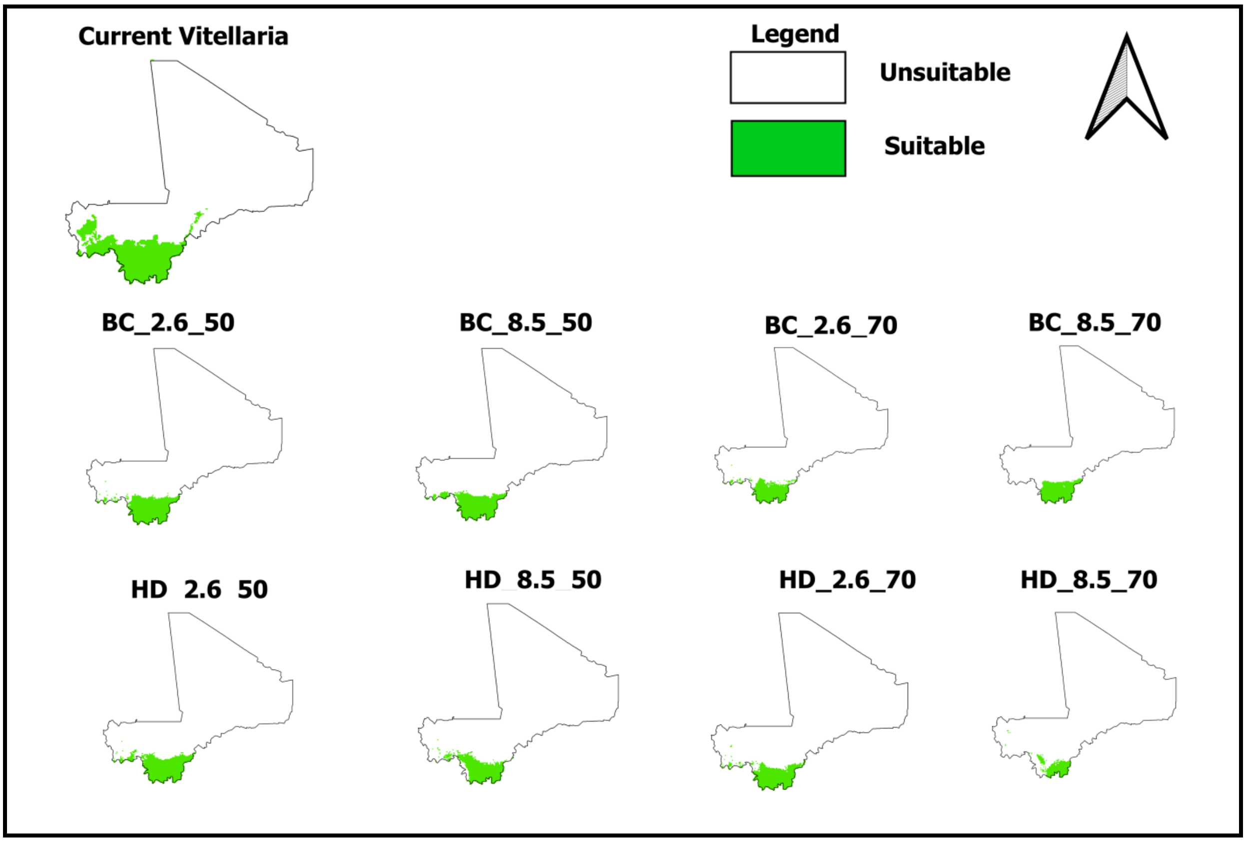


Figure 21: Future Distribution of *Vitellaria paradoxa*

6. DISCUSSION OF THE RESULTS ON THE FUTURE DISTRIBUTION OF THE THREE SPECIES

The study reveals that the future climate change would have diverse effects on the geographic distribution of the three species: *Detarium microcarpum, Parkia biglobosa, and Vitellaria paradoxa.* These effects were found to differ within and between two climate models, namely BC_BCC-CSM1-1 and HD_HadGEM2-AO, across two emission scenarios (RCP 4.5 and RCP 8.5), and two-time horizons (2050 and 2070).

Ten variables not highly correlated were considered in predicting geographic distribution of the species. Based on the Jackknife tests and the variables contribution table, the results showed that the most important factors affecting these species habitat suitability are Annual precipitation and precipitation of the driest quarter (bio_12, bio_17) for *Detarium microcarpum*; Maximum temperature of the warmest month and Annual precipitation for *Vitellaria paradoxa* (bio_05, bio_12), Parkia biglobosa with Annual precipitation and the mean temperature of the wettest quarter (bio_12, bio_08).

A lower value of the Mean temperature of the coldest quarter and a higher value of the maximum temperature of the warmest month would decrease habitat suitability. This finding confirms that the temperature seasonality is one of the significant climatic variables affecting plant species distribution as early shown (Pramanik *et al*., 2018) while working on Kigelia africana (Lam.) in Benin.

In Africa, several studies have been conducted to estimate the future geographic distribution of plant species, both at large-scale (continent-wide) and regional or local levels. Here are some examples Sommer (2008) conducted a study on the continent-wide scale, focusing on estimating the future distribution of plant species in Africa. In Southern Africa, studies by (Midgley *et al.*, 2002, Bomhard *et al*. 2005), and (Thuiller *et al.*, 2005) were conducted to assess the future geographic distribution of plant species in the region. In West Africa, (Da 2010, Bocksberger *et al*., 2016) conducted studies to estimate the future distribution of plant species, specifically focusing on the region of West Africa. At the local level, studies by (Gouwakinnou 2011, Heubes *et al*., 2013, Fandohan *et al.* 2013, and Gbesso *et al.* 2013) were conducted to assess the future geographic distribution of plant species in specific local areas within Africa, cited by (Dimobe *et al*., 2020).

From our findings all the models predicted a decrease of suitable environmental species distribution under the future climate projection at all horizons 2050 and 2070 there is evidence that species habitats suitability would be affected according to the scenarios used for all the species *Detarium microcarpum* , *Parkia biglobosa* and *Vitellaria paradoxa*; in agreement to the findings of (Pramanik *et al*., 2018) who reported that under the scenario of RCP 2.6and 8.5 for all the horizons (2050 and 2070) and selected climate model BCC-CSM1.1, these variables are expected to show an important changes, affecting large area of the current distribution to become very low potential by 2050, that gradually increases these low potential areas by 2070 . The findings indicate that future climate change may reduce the appropriateness of these species, particularly under the GHG scenario in which the gasses continue to grow at their current rate through the end of the twenty-first century; Also aligns with the results of (Gaisberger et al., 2017) reported that: (e.g., *Vitellaria paradoxa* C. F. Gaertn., *Tamarindus indica* L., *Detarium microcarpum* Guill. & Perr., *Parkia biglobosa* (Jacq.) G. Don are increasingly vulnerable to various drivers of change, such removal of trees in intensive cotton agriculture and increasing frequency and intensity of droughts. Climate change, in particular, is likely to intensify natural tree regeneration problems and progressively modify the future distribution of suitable habitats for several tree species

This future change on the three keys melliferous species could have negative impact on the honey bees in the Southern part of Mali; because trees are the main raw for bees and these three species are the main melliferous plants of the Southern part. In agreement with some findings reported that:

Climate has an impact on flower development, nectar and pollen production, and colony foraging activity and development (Morandin & Winston, 2005). Bees must accumulate sufficient honey stores to survive the winter. Nurse worker bees must ingest sufficient pollen to nourish the larvae via their pharyngeal glands. Changes in the distribution of flower species (Thuiller et al., 2005) on which honey bees rely for food are a major effect of climate change on honey bees. We are aware of the impact rain might have on bee honey gathering. For example, when acacia flowers are rinsed by rain, honey bees find them less appealing because the nectar is diluted too much. Similarly, an excessively dry climate reduces the generation of flower nectar for honey bees to harvest: lavender blossoms generate no nectar when the weather is too dry, making bee gathering essentially speculative. Honey bees can die of malnutrition in extreme cases if the beekeeper is not careful.

Therefore, it is important to be ready and avoid the future effects of climate change on our species.

7. CONCLUSION

This research assesses the intricate impact of climate change on honeybee populations and the prospective distribution of three crucial melliferous species. The findings indicate a potential adverse effect of climate change on honeybee populations even the quality, quantity of honey produce as perceived by 79.9% of beekeepers. Moreover, the modeling projections suggest that climate change could significantly impede the future distribution of the three key melliferous species. These outcomes validate the research hypotheses.

The model gave good performance with an AUC greater than 0.90 for all the three different species. By modeling various variables and using different methodologies, they provide insights into the potential shifts and changes in plant species distributions under future climate scenarios.

The two models BC_BCC-CSM1-1 and HD_HadGEM2-AO with the two Representative Concentration Pathways (RCP2.6 and RCP8.5) at the two-time horizons (2050 and 2070) have predicted an effective impact on the species environmental suitability habitat, such as decreasing of the habitat suitability of all the three species (*Detarium microcarpum, Parkia biglobosa, Vitellaria paradoxa*) or even the total decline of *Detarium microcarpum* under both of the models in the horizon 2070.

The findings suggest that SDMs are important tools for improving understanding of species richness gradients, even in areas with uneven distribution data availability.

8. PERSPECTIVES

To take care of our melliferous species distribution and their pollinators' it is essential to consider the following perspectives:

-Establishment of Bees database for Mali: for furthermore research on bees in Mali.

-Conservation of Natural Habitats: Protecting and conserving natural habitats is crucial for providing suitable environments for melliferous species. Preserving diverse ecosystems with a variety of flowering plants ensures a consistent supply of nectar and pollen for bees.

-Promotion of Native Plant Species: Encouraging the cultivation and restoration of native plant species supports the natural forage resources for bees. Native plants are well-adapted to the local environment and can provide abundant nectar and pollen sources.

-Reduction of Pesticide Use: Minimizing or eliminating the use of harmful pesticides, especially those with systemic properties, is vital for bee health. Promoting integrated pest management practices that prioritize natural pest control methods can help maintain a safe and favorable environment for bees.

-Provision of Water Sources: Providing clean and accessible water sources near bee habitats are crucial for the hydration and survival of bees. Beekeepers can install water stations or shallow dishes with floating objects for bees to safely drink water.

-Implementation of Bee-Friendly Farming Practices: Encouraging farmers to adopt bee-friendly agricultural practices, such as reducing or avoiding the use of pesticides during flowering periods, creating flowering field margins, and employing precision farming techniques, can greatly benefit bee populations.

-Education and Awareness: Promoting education and raising awareness among beekeepers, farmers, and the general public about the importance of bees and the significance of their role as pollinators can foster a culture of bee conservation. Educating individuals about proper beekeeping practices and the importance of maintaining healthy bee populations is vital for their long-term survival.

-Research and Collaboration: Supporting research initiatives on bee health, melliferous species, and their distribution can provide valuable insights for conservation efforts. Collaborating with scientists, beekeeping associations, and local communities can lead to innovative solutions and effective conservation strategies.

By adopting these perspectives and implementing appropriate measures, we can contribute to the well-being of bees, promote the distribution of melliferous species, and ensure the vital role of bees as pollinators in our ecosystems.

9. BIBLIOGRAPHY

1. Abrol, D. P. 2009. Plant-pollinator interactions in the context of climate change - an endangered mutualism. Journal of Palynology, 45:1-25.

AR4 Climate Change 2007: Synthesis Report — IPCC. (n.d.). Retrieved June 3, 2023, from https://www.ipcc.ch/report/ar4/syr/

2. Araújo, M. B., & Guisan, A. (2006). Five (or so) challenges for species distribution modelling. *Journal of Biogeography*, *33*(10), 1677–1688. https://doi.org/10.1111/j.1365-2699.2006.01584.x
3. Baldwin, R. A. (2009).Use of Maximum Entropy Modeling in Wildlife Research. *Entropy, 11* (4), Article 4. https://doi.org/10.3390/e11040854
4. Burnett, N. P., Badger, M. A., & Combes, S. A. (2022). Wind and route choice affect performance of bees flying above versus within a cluttered obstacle field. *PLOS ONE*, *17*(3), e0265911. https://doi.org/10.1371/journal.pone.0265911
5. Bocksberger, G., Schnitzler, J., Chatelain, C., Daget, P., Janssen, T., Schmidt, M., Thiombiano, A., & Zizka, G. (2016). Climate and the distribution of grasses in West Africa. *Journal of Vegetation Science*, *27*(2), 306–317. https://doi.org/10.1111/jvs.12360
6. Carrington, D., & editor, D. C. E. (2021, April 1). Toxic impact of pesticides on bees has doubled, study shows. *The Guardian*. https://www.theguardian.com/environment/2021/apr/01/toxic-impact-of-pesticides-on-bees-has-doubled-study-shows
7. Conte, Y. L., & Navajas, M. (2008). *Changements climatiques : Impact sur les populations d ' abeilles et leurs maladies L ' abeille, une espèce*. *27*(2), 485–497.
8. Crepet, W. L., & Niklas, K. J. (2009). Darwin's second "abominable mystery": Why are there so many angiosperm species? *American Journal of Botany*, *96*(1), 366–381. https://www.jstor.org/stable/27793093
9. Desneux, N., Decourtye, A., & Delpuech, J.-M. (2007). The Sublethal Effects of Pesticides on Beneficial Arthropods. *Annual Review of Entomology*, *52*, 81–106. https://doi.org/10.1146/annurev.ento.52.110405.091440
10. Dotchamou, F., ATINDOGBE, G., Sode, I., & Fonton, N. (2016). Density and spatial pattern of Parkia biglobosa under climate change: The case of Benin. *Journal of Agriculture and Environment for International Development*, *110*, 173–194. https://doi.org/10.12895/jaeid.20161.447

11. Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F., R. Leathwick, J., Lehmann, A., Li, J., G. Lohmann, L., A. Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., McC. M. Overton, J., Townsend Peterson, A., … E. Zimmermann, N. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, *29*(2), 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x
12. FAO. (2014). *Cibles et Indicateurs*. 12.
13. Frédéric, B. B., Madjelia, D. A. O., Ebou, C., Samuel, D. F., & Nomwine, D. A. (2021). *Influence des facteurs climatiques sur les insectes pollinisateurs potentiels du moringa oleifera lam. Au Burkina Faso Résumé*. *09*(2008), 47–54.
14. Gaisberger, H., Kindt, R., Loo, J., Schmidt, M., Bognounou, F., Da, S. S., Diallo, O. B., Ganaba, S., Gnoumou, A., Lompo, D., Lykke, A. M., Mbayngone, E., Nacoulma, B. M. I., Ouedraogo, M., Ouédraogo, O., Parkouda, C., Porembski, S., Savadogo, P., Thiombiano, A., … Vinceti, B. (2017). Spatially explicit multi-threat assessment of food tree species in Burkina Faso: A fine-scale approach. *PLOS ONE*, *12*(9), e0184457. https://doi.org/10.1371/journal.pone.0184457
15. Garnery, L., Cornuet, J.-M., & Solignac, M. (1992). Evolutionary history of the honey bee Apis mellifera inferred from mitochondrial DNA analysis. *Molecular Ecology*, *1*(3), 145–154. https://doi.org/10.1111/j.1365-294X.1992.tb00170.x
16. Gebrehiwot, N. (2015). *HONEY PRODUCTION AND MARKETING: THE PATHWAY FOR POVERTY ALLEVIATION THE CASE OF TIGRAY REGIONAL STATE, NORTHERN ETHIOPIA.*
17. Guisan, A., Thuiller, W., & Zimmermann, N. E. (2017). *Habitat Suitability and Distribution Models: With Applications in R* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781139028271
18. Hennessy, G., Harris, C., Eaton, C., Wright, P., Jackson, E., Goulson, D., & Ratnieks, F. (2020). Gone with the wind: Effects of wind on honey bee visit rate and foraging behaviour. *Animal Behaviour*, *161*, 23–31. https://doi.org/10.1016/j.anbehav.2019.12.018
19. Heubes, J., Schmidt, M., Stuch, B., García Márquez, J., Zizka, G., Thiombiano, A., Sinsin, B., Schaldach, R., & Hahn, K. (2013). The projected impact of climate and land use change on plant diversity: An example from West Africa. *Journal of Arid Environments*, *96*, 48–54. https://doi.org/10.1016/j.jaridenv.2013.04.008
20. Kearns, C. A., Inouye, D. W., & Waser, N. M. (1998). ENDANGERED

MUTUALISMS: The Conservation of Plant-Pollinator Interactions. *Annual Review of Ecology and Systematics*, *29*(1), 83–112. https://doi.org/10.1146/annurev.ecolsys.29.1.83

21. Kjøhl, M., Nielsen, A., & Stenseth, N. C. (2011). *Potential effects of climate change on crop pollination: Extension of knowledge base, adaptive management, capacity building, mainstreaming*. Food and Agriculture Organization of the United Nations.
22. Klein, A.-M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, *274*(1608), 303–313. https://doi.org/10.1098/rspb.2006.3721
23. *Klein et al., 2002. In: Zaid, A. Arias-Jimenez, E. J. Date palm cultivation. FAO plant production and protection paper, 156 rev.1. FAO, Rome | Feedipedia*. (n.d.). Retrieved July 3, 2023, from https://www.feedipedia.org/node/7416
24. Memmott, J., Craze, P. G., Waser, N. M., & Price, M. V. (2007). Global warming and the disruption of plant–pollinator interactions. *Ecology Letters*, *10*(8), 710–717. https://doi.org/10.1111/j.1461-0248.2007.01061.x
25. Merow, C., Smith, M. J., & Silander, J. A. (2013). A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. *Ecography*, *36*(10), 1058–1069. https://doi.org/10.1111/j.1600-0587.2013.07872.x
26. Midgley, G., Hannah, L., Millar, D., Rutherford, M. C., & Powrie, L. (2002). CLIMATE CHANGE AND CONSERVATION SPECIAL ISSUE Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology and Biogeography*, *11*, 445–451. https://doi.org/10.1046/j.1466-822X.2002.00307.x
27. Morandin, L. A., & Winston, M. L. (2005). Wild Bee Abundance and Seed Production in Conventional, Organic, and Genetically Modified Canola. *Ecological Applications*, *15*(3), 871–881. https://www.jstor.org/stable/4543402
28. Muluneh, M. G. (2021). Impact of climate change on biodiversity and food security: A global perspective—A review article. *Agriculture & Food Security*, 1–25. https://doi.org/10.1186/s40066-021-00318-5
29. Oldroyd, B. P. (2007). What's Killing American Honey Bees? *PLOS Biology*, *5*(6), e168. https://doi.org/10.1371/journal.pbio.0050168
30. Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos*, *120*(3), 321–326. https://doi.org/10.1111/j.1600-

0706.2010.18644.x

31. Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q. D., Dasqupta, P., Dubash, N. K., Edenhofer, O., Elgizouli, I., Field, C. B., Forster, P., Friedlingstein, P., Fuglestvedt, J., Gomez-Echeverri, L., Hallegatte, S., … van Ypersele, J.-P. (2014). *Climate change 2014 synthesis report. Contribution of working groups I, II, and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. IPCC.
32. Papanikolaou, A. D., Kühn, I., Frenzel, M., Kuhlmann, M., Poschlod, P., Potts, S. G., Roberts, S. P. M., & Schweiger, O. (2017). Wild bee and floral diversity co-vary in response to the direct and indirect impacts of land use. *Ecosphere*, *8*(11), e02008. https://doi.org/10.1002/ecs2.2008
33. *(PDF) 4. Ramesh Kumar.* et al (2012). "A study on turnover intention in Fast food industry: - Employees' fit to the organizational culture and the important of their commitment" International Journal-Academy Research in Business & Social Science Vol. 2, Issue 5.* (n.d.). Retrieved July 4, 2023, from https://www.researchgate.net/publication/261027855_4_Ramesh_Kumar_et_al_2012_A_study_on_turnover_intention_in_Fast_food_industry_-_Employees'_fit_to_the_organizational_culture_and_the_important_of_their_commitment_International_Journal-Academy_Researc
34. Pettis, J., Vanengelsdorp, D., & Cox-foster, D. L. (2007). Colony collapse disorder working group pathogen sub-group progress report. *American Bee Journal*, *147*(7), 595–597. http://www.scopus.com/inward/record.url?scp=34547340534&partnerID=8YFLogxK
35. Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, *190*(3–4), 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026
36. Phillips, S. J., Dudík, M., & Schapire, R. E. (2004). A maximum entropy approach to species distribution modeling. *Twenty-First International Conference on Machine Learning - ICML '04*, 83. https://doi.org/10.1145/1015330.1015412
37. Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution*, *25*(6), 345–353. https://doi.org/10.1016/j.tree.2010.01.007
38. Pramanik, M., Paudel, U., Mondal, B., Chakraborti, S., & Deb, P. (2018). Predicting climate change impacts on the distribution of the threatened Garcinia indica in the

Western Ghats, India. *Climate Risk Management*, *19*, 94–105. https://doi.org/10.1016/j.crm.2017.11.002

39. Roubik, D. (2002). Tropical agriculture: The value of bees to the coffee harvest. *Nature*, *417*, 708–708. https://doi.org/10.1038/417708a
40. Rutter, M. (1998). Developmental Catch-up, and Deficit, Following Adoption after Severe Global Early Privation. *Journal of Child Psychology and Psychiatry*, *39*(4), 465–476. https://doi.org/10.1017/S0021963098002236
41. Scaven, V. L., & Rafferty, N. E. (2013). Physiological effects of climate warming on flowering plants and insect pollinators and potential consequences for their interactions. *Current Zoology*, *59*(3), 418–426. https://doi.org/10.1093/czoolo/59.3.418
42. Schweiger, O., Biesmeijer, J. C., Bommarco, R., Hickler, T., Hulme, P. E., Klotz, S., Kühn, I., Moora, M., Nielsen, A., Ohlemüller, R., Petanidou, T., Potts, S. G., Pyšek, P., Stout, J. C., Sykes, M. T., Tscheulin, T., Vilà, M., Walther, G.-R., Westphal, C., … Settele, J. (2010). Multiple stressors on biotic interactions: How climate change and alien species interact to affect pollination. *Biological Reviews*, *85*(4), 777–795. https://doi.org/10.1111/j.1469-185X.2010.00125.x
43. Thuiller, W., Lavorel, S., Araújo, M. B., Sykes, M. T., & Prentice, I. C. (2005). Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(23), 8245–8250. https://doi.org/10.1073/pnas.0409902102
44. Vaissière, B. (2005). *Lépidoptères (papillons de jour pour les œillets*. 1–4.
45. Visser, M. E., & Both, C. (2005). Shifts in phenology due to global climate change: The need for a yardstick. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1581), 2561–2569. https://doi.org/10.1098/rspb.2005.3356
46. Whitmarsh, L., & Capstick, S. (2018). Perceptions of climate change. In *Psychology and climate change: Human perceptions, impacts, and responses* (pp. 13–33). Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-813130-5.00002-3
47. Winfree, R., Aguilar, R., Vázquez, D. P., LeBuhn, G., & Aizen, M. A. (2009). A meta-analysis of bees' responses to anthropogenic disturbance. *Ecology*, *90*(8), 2068–2076. https://doi.org/10.1890/08-1245.1
48. Yurk, B., & Powell, J. (2009). Modeling the Evolution of Insect Phenology. *Bulletin of Mathematical Biology*, *71*, 952–979. https://doi.org/10.1007/s11538-008-9389-z

10. WEBSITES

https://www.mybeeline.co/en/p Why bees need water and how you can safely provide it for them? - MyBeeLine (Visited on May 2023)

https://en.wikipedia.org/wiki/Pollen (Visited on April 2023)

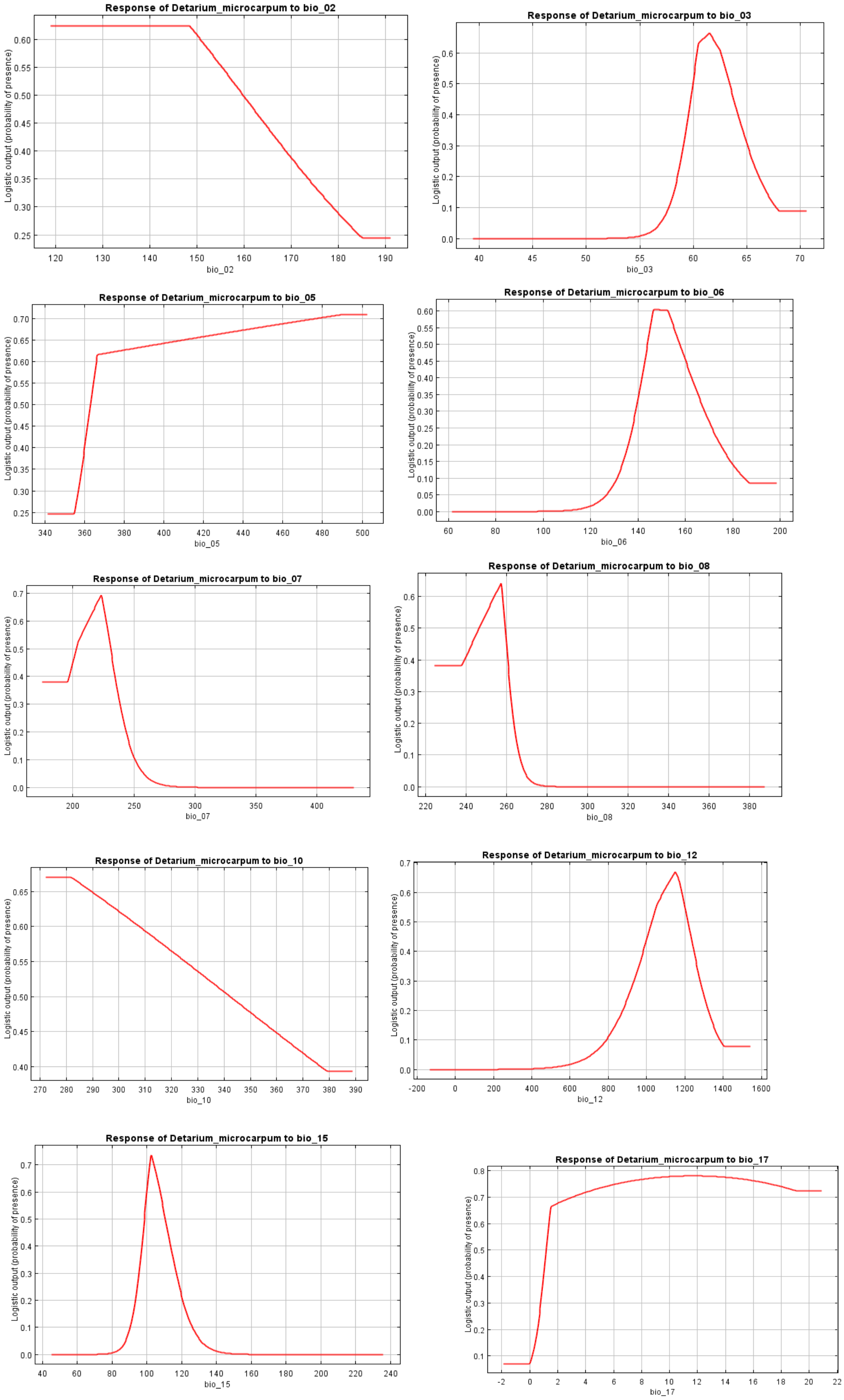
www.eionet.europa.eu.Retrieved2022-11-18 (Visited June 2023)

https://en.wikipedia.org/wiki/Spatial_distribution (Visited on June 2023)

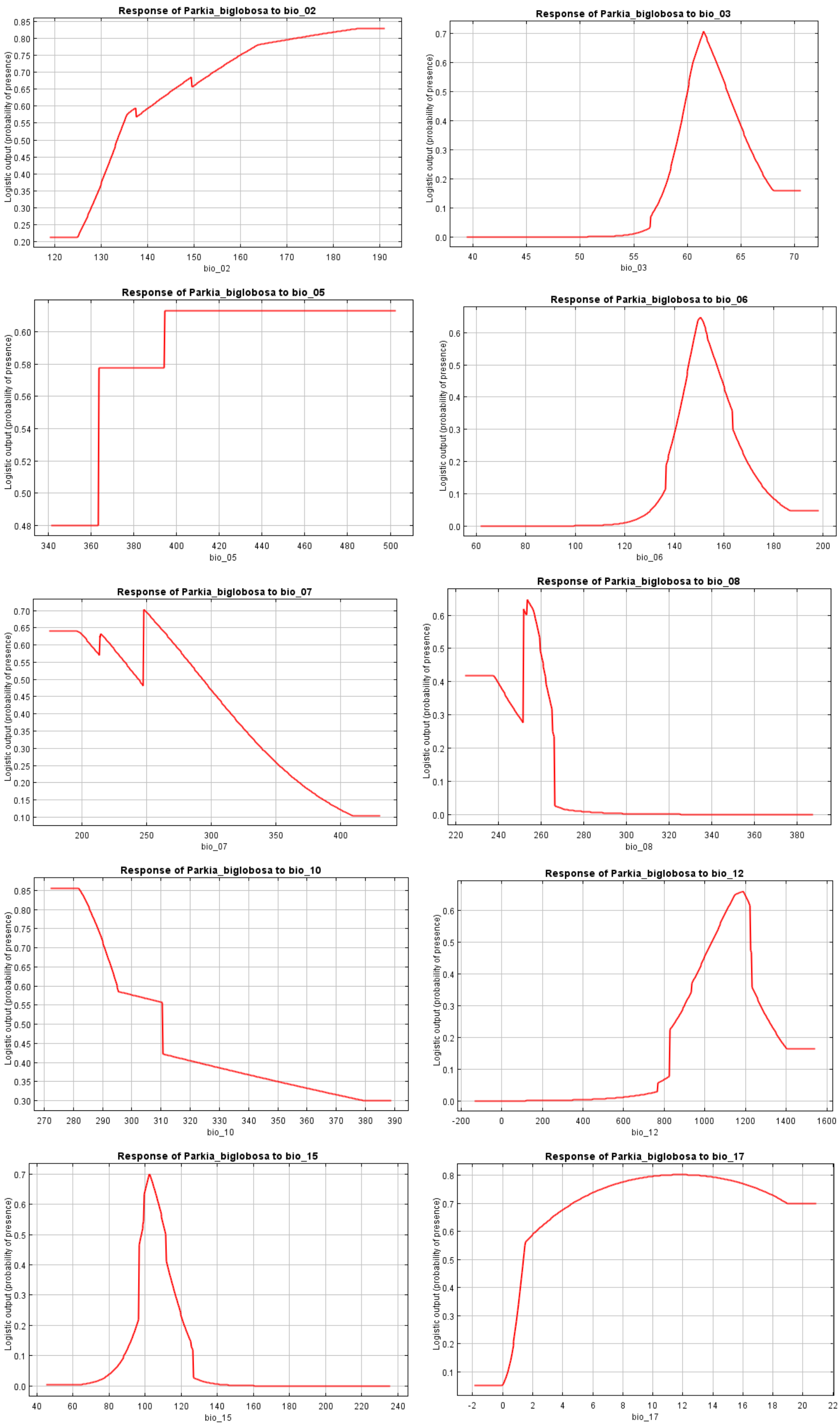
https://www.frontiersin.org/articles/10.3389/fevo.2021.658713/full (Visited on March 2023)

Bees may struggle in winds caused by global warming, study finds | Bees | The Guardian (Visited on May 2023)

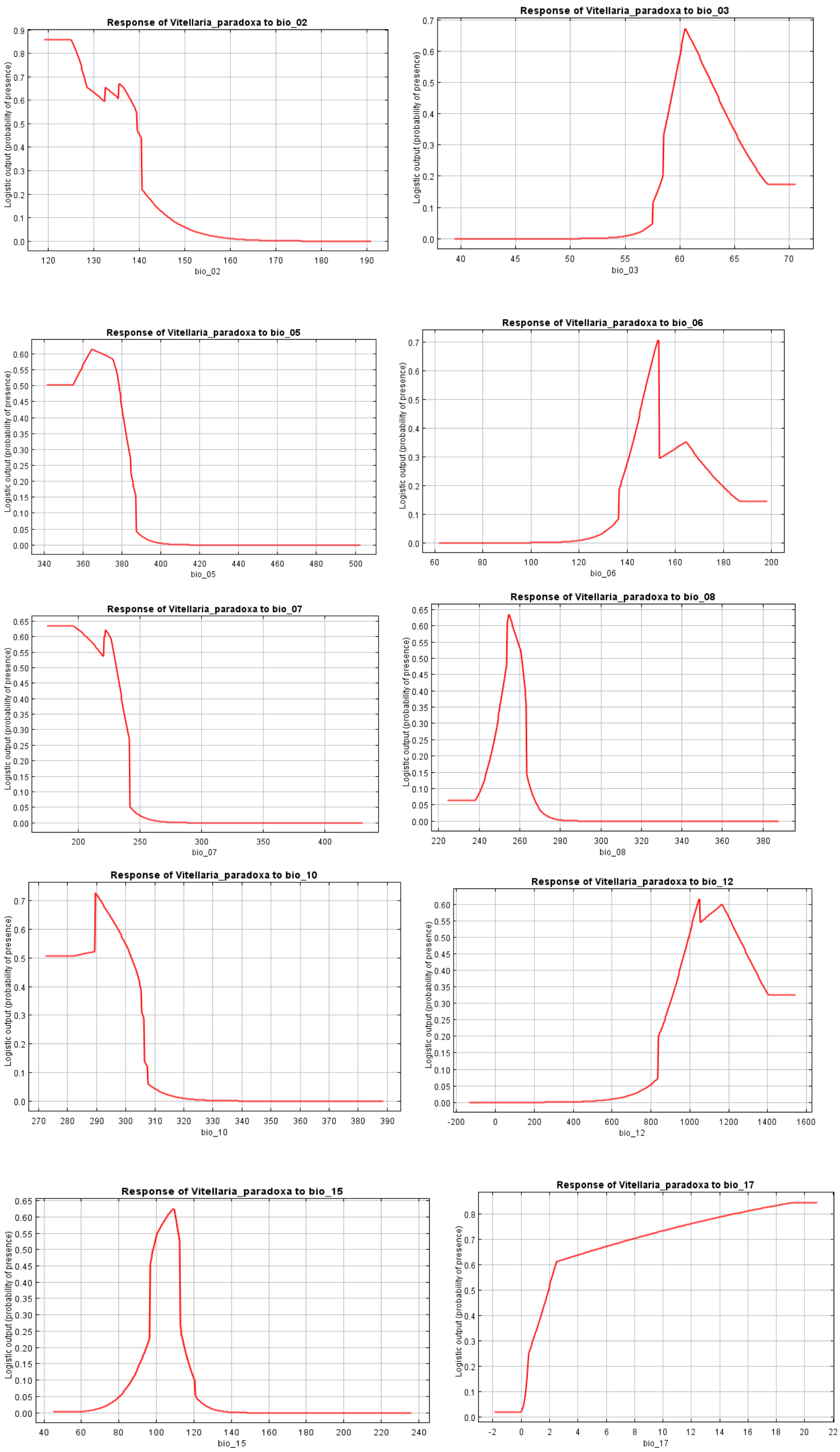
APPENDIX



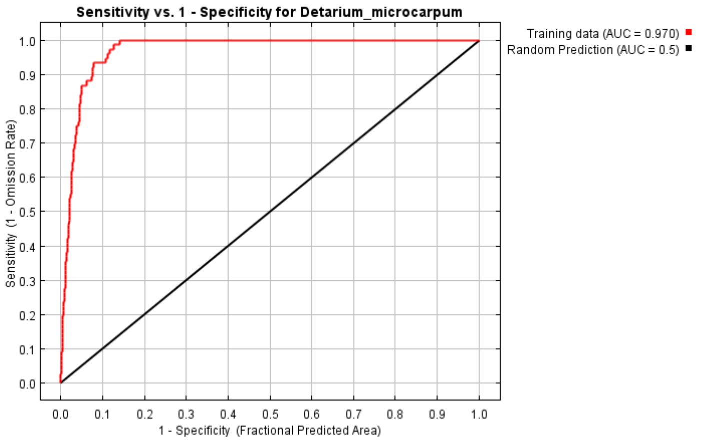
APPENDIX A: RESPONSE OF *DETARIUM MICROCARPUM* FOR BIOCLIMATIC VARIABLES

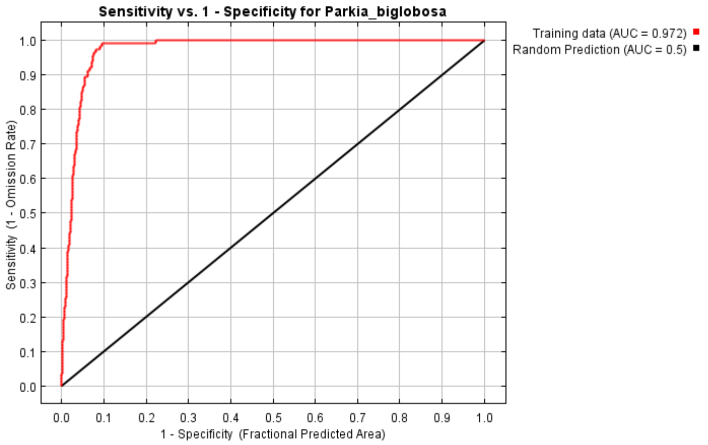


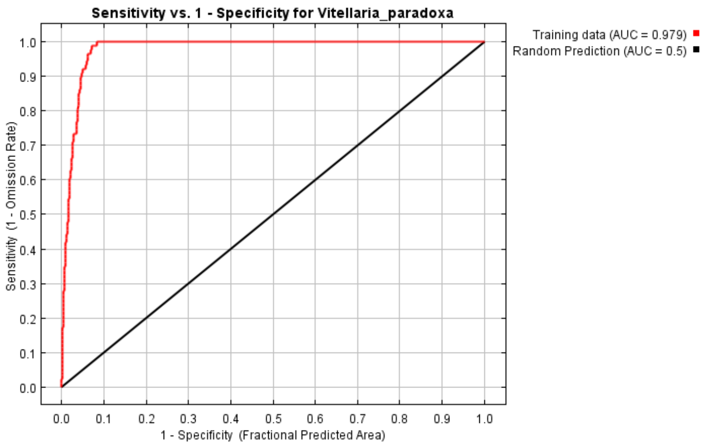
APPENDIX B : RESPONSE OF *PARKIA BIGLOBOSA* FOR BIOCLIMATIC VARIABLES



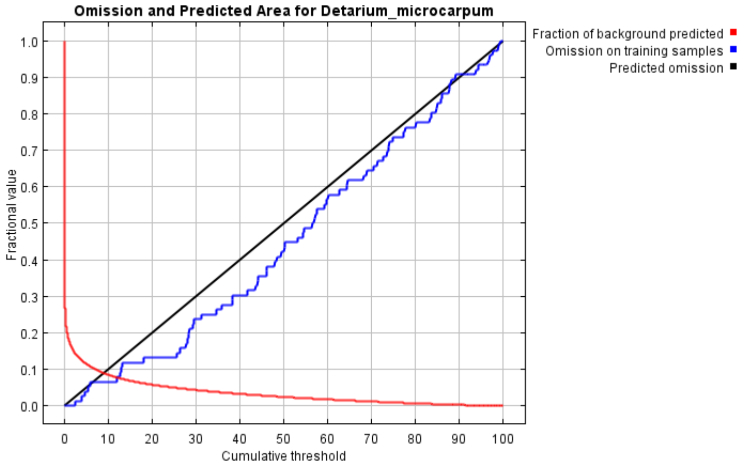
APPENDIX C : RESPONSE OF *VITELLARIA PARADOXA* FOR BIOCLIMATIC VARIABLES

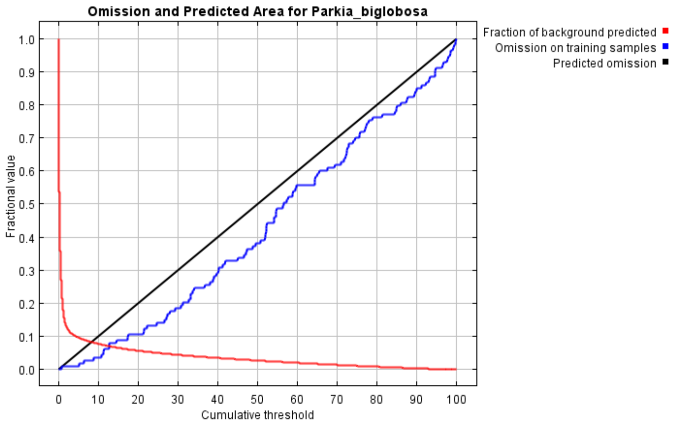

Sensitivity vs. 1 - Specificity for Detarium_microcarpum
Training data (AUC = 0.970)
Random Prediction (AUC = 0.5)
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)

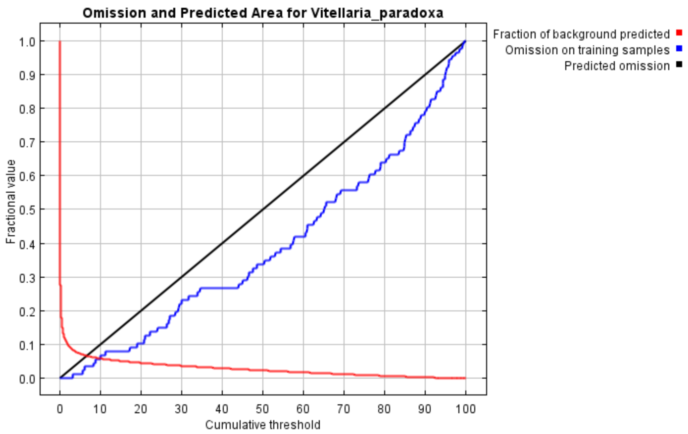

Sensitivity vs. 1 - Specificity for Parkia_biglobosa
Training data (AUC = 0.972)
Random Prediction (AUC = 0.5)
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)


Sensitivity vs. 1 - Specificity for Vitellaria_paradoxa
Training data (AUC = 0.979)
Random Prediction (AUC = 0.5)
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)

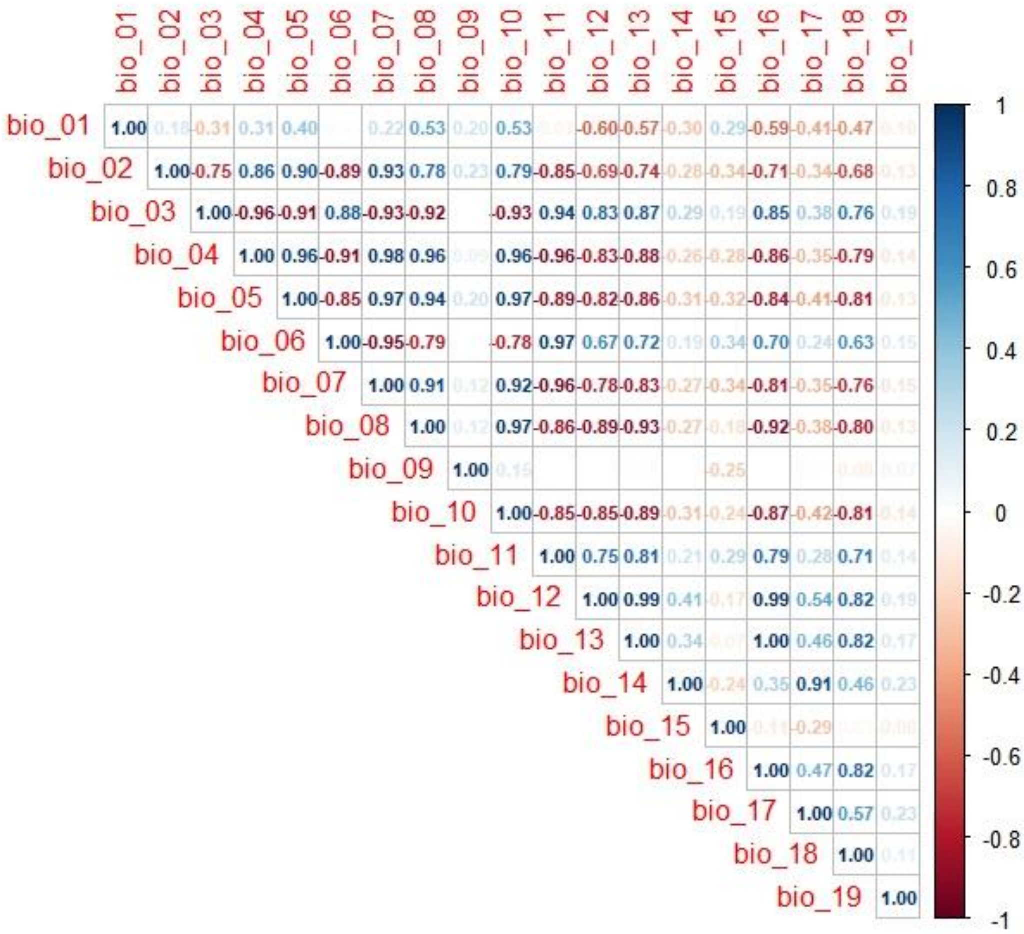
APPENDIX D: FIGURE OF SENSITIVITY VS. SPECIFICITY FOR THE THREE SPECIES







APPENDIX E: Figure of Omission and predicted area for the three species



APPENDIX F: TEST FOR MATRIX OF CORRELATION

GCM	Code	Suitable habitants(%)	Unsuitable habitants (%
BC_BCC-CSM1-1			
Horizon 2050 and 2070			
	bc26Det_50	47.45	55.55
	bc85Det_50	19.18	80.82
	bc26Det_70	31.3	68.7
	bc85Det_70	0.18	99.82
	bc26Park_50	66.16	33.83
	bc85Park_50	68.86	31.14
	bc26Park_70	67.73	32.27
	bc85Park_70	66.03	33.97
	bc26Vit_50	57.53	42.47
	bc85Vit_50	57.33	42.67
	bc26Vit_70	45.41	54.59
	bc85Vit_70	44.15	55.13%
HD_HadGEM2-AO			
Horizon 2050 and 2070			
	hd26Det_50	48.4	51.6
	hd85Det_50	49.82	51.18
	hd26Det_70	13.26	86.74
	hd85Det_70	0	100
	hd26Park_50	87.13	14.87
	hd85Park_50	93.43	6.57
	hd26Park_70	43.8	56.2
	hd85Park_70	86.75	13.25
	hd26Vit_50	61.42	38.58
	hd85Vit_50	46.87	53.13
	hd26Vit_70	43.74	56.26
	hd85Vit_70	22.08	77.92
Note:			
GCM: Globale Climate M	bc=BC_BCC-CSM1-	hd=HD_HadGEM2-AO	Det:Detarium microcar
Park:Parkia biglobosa	Vit:Vitellaria paradoxa		

APPENDIX G:ENVIRONMENTAL HABITAT SUITABILITY UNSUITABILITY FOR THE THREE SPECIES UNDER THE TWO HORIZONS AND TWO MODELS.

Variables contribution for *Detarium microcarpum*

Variable	Percent contribution
bio_12	79.9
bio_17	5.2
bio_15	3.8
bio_03	3.6
bio_10	3.3
bio_02	1.3
bio_05	1.2
bio_07	1.2
bio_06	0.4
bio_08	0.2

Variables contribution for *Parkia biglobosa*

Variable	Percent contribution
bio_12	44.4
bio_08	21
bio_10	12.2
bio_15	8.6
bio_05	6
bio_02	2.1
bio_07	1.8
bio_06	1.4
bio_17	1.2
bio_03	1.1

Variable	Percent contribution
bio_05	44
bio_12	21
bio_15	11.7
bio_07	6.4
bio_08	5.9
bio_03	5.9
bio_06	3
bio_02	1.2
bio_17	0.9
bio_10	0

Variables Contribution for Vitellaria paradoxa

APPENDIX H: VARIABLES CONTRIBUTION FOR THE THREE SPECIE