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A temperatures variation favor human-elephant conflict in Gabon's Lékédi National Park

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***Keywords*— Unavailability of Moabi tree fruit, temperatures, elephant movement, Lékédi National Park, human-elephant conflict.**

***Abstract*— The purpose of the study, conducted from August 8th to 12th, 2022, in Gabon's Lékédi National Park, was to assess elephant movement in relation to the availability of Moabi tree fruit. The goal was to understand the close connection between fluctuating temperatures and elephant movement toward human habitations. A questionnaire was utilized to gather insights from 53 individuals, primarily adults residing around Lékédi National Park. Statistical analysis of the collected data revealed a significant correlation between the percentage of individuals noticing changes in Moabi tree productivity and variations in mean annual temperature. The mean annual temperature had increased by +0.06°C over the two consecutive 5-year intervals between 2011 and 2020 (study period). The survey indicated that 56.6% of respondents perceived the Moabi fruit harvest as average in the last two years, and around 90% of people had witnessed their own or a relative's field being devastated by elephants during the same period. Notably, 96.23% of respondents believed that present-day elephants are getting closer to human dwellings, compared to 3.77% who thought they were moving farther away. The lack of available Moabi fruit would encourage elephants to venture into secondary forests, thereby escalating the risk of human-elephant conflict.*

I. INTRODUCTION

Interest in comprehending temperature and rainfall variations in Africa arises from their impact on fauna, flora, and human life, often leading to human-elephant conflicts [1,2]. Climate change-related phenomena such as drought, flooding, and desert encroachment pose serious threats to elephant populations in certain Central African regions [3]. A study conducted in Côte d'Ivoire's Sikensi Park revealed that elephants are increasingly entering human settlements, damaging crops, food supplies, and water sources [4]. Research has indicated that most elephants in Cameroon's Mbam and Djerem National Park prefer settling in young colonial forests [5]. In Burkina Faso, over 80% of the population considers elephants insignificant due to their significant crop damage, as they're consistently seeking food to meet their high dietary requirements. They reportedly consume around 450 kg of food daily [7]. Forest elephants primarily feed on fruit [3], as well as grass [2].

Similarly, human-elephant conflicts exist in Gabon, as evidenced by a tragic incident in September 2021 that claimed a truck driver's life in Mouila, southeast Gabon [8]. Damage to human crops is also noticeable. A study in the

Massaha village in Makokou, northeast Gabon, demonstrated that 77% of surveyed families had encountered fields ravaged by elephants [9]. Residents near Gabon's Lékédi National Park report elephants damaging fields and water sources, while also encroaching closer to human habitats [10]. However, the impact of temperature and rainfall changes on human-elephant conflict acceleration remains underexplored [1,11]. This study aims to depict temperature changes in Lékédi National Park and highlight fluctuations in Moabi fruit availability during the same period. Moabi fruit constitutes 80% of elephants' preferred food and is a crucial part of their diet. Additionally, the study aims to observe elephant migratory behavior toward human settlements.

This study holds particular significance, as it deepens the understanding of temperature variation's impact on human-elephant conflict acceleration within the Lékédi National Park Reserve. Temperature fluctuations can alter plant and fruit availability for elephants. Furthermore, this study serves as a wake-up call, emphasizing the urgent need for increased attention to climate variations by populations and governments, given their potentially irreversible consequences on people's daily lives.

II. STUDY AREA

The present study was conducted in eastern Gabon (Figure 1) and focused on the Sébé-Brikolo department, with Okondja as its chief town. The population primarily comprises indigenous groups, particularly the Obambas. Other groups, such as the Bakaningui and Tékés, are also present but in smaller numbers. The area has low overall population density, approximately 1.1 inhabitants per square kilometer. The Lékédi climate experiences four seasons, including two rainy and two dry seasons, with an average annual temperature of 25.1°C. The landscape predominantly features forests and a variety of animal species, including the protected and dominant elephant species. The vegetation is diverse, including the highly valued Nkumou, a main delicacy in Okondja.

The present study was carried out in eastern Gabon (Figure 1). The study area is located in the department of Sébé-Brikolo, whose chief town is Okondja. The population is predominantly made up of indigenous peoples, specifically the Obambas. In addition, there are a few Bakaningui, Tékés and other peoples. The area is sparsely populated overall, with a population density of around 1.1 inhabitants/km².km^2. The Lékédi climate has four seasons, including two rainy seasons and two dry seasons, with an average annual temperature of 25.1°C. The vegetation is largely made up of forests and animal species, including a protected and predominant species: the elephant. The vegetation abounds in a wide variety of species, including the highly prized Nkumou, one of Okondja's main delicacies.

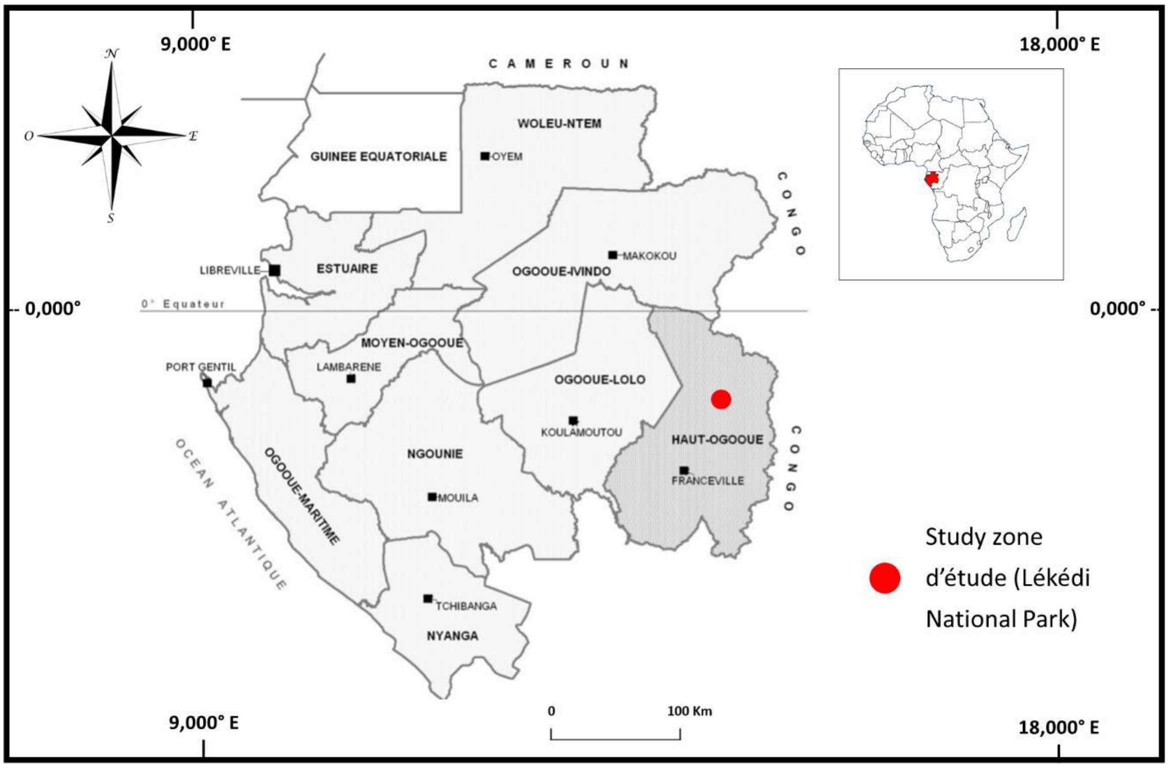


Fig.1: Location of the study area [source internet].

In this region, agriculture stands as the dominant activity, serving as the primary source of both food and income for the local population. A significant portion of the bananas exported to the provincial capital, Haut-Ogooué, Franceville, originates from this area. Additionally, Haut-Ogooué plays a crucial role in cassava cultivation [12]. Recognizing this potential, the United Nations Development Program launched the Art Gold program in 2007, aiming to foster the region's development [12]. Consequently, the Lékédi region serves as a vital link within the food supply chain for neighboring communities.

III. METHODOLOGY

The survey, combined with statistical analysis of data and the evaluation of temperature change between 2011 and 2020 in the study area, facilitated the examination of elephant movement concerning the availability of Moabi fruit. Information about the frequency of observing elephant droppings, elephants near or distant from houses, the preferred food of elephants, knowledge of the Moabi tree, and the percentage of people affected by elephant-induced field devastation was collected through a form modeled after the African Elephant Specialist Group's questionnaire [4]. A series of interviews was conducted with a group of 53 mainly adult participants, accounting for approximately half of the population residing near the Lékédi park. This approach was due to the low density of 1.1 inhabitants per square kilometer in an area of about 140 square kilometers. Only the interviewer had access to the questionnaire, and solely conducted interviews with local residents. Certain questions included a "miscellaneous" option to capture unexpected responses and gather comprehensive information.

For questions concerning elephant sightings near or far from human dwellings, the available response options were "none," "one," and "several." Questions related to incidents or accidents involving elephants, awareness of the Moabi tree, and the elephant's most preferred food had binary options "yes" or "no." For the preferred elephant food, the choices encompassed fruit, leaves, and an "other" category to account for unexpected responses. Based on the appearance of Moabi fruit, the available options were specific months of the year. Solutions to the human-elephant conflict were proposed as follows: cessation of hunting, population relocation, elephant eradication in the study area, and establishment of a more distant elephant reserve. Using Microsoft Excel 2021, an Excel spreadsheet containing all collected data was generated.

Once the Excel table was established, statistical analysis was conducted using our AdvDatAna (Advanced Data Analysis) toolbox, customized for database analysis. This toolbox facilitated descriptive statistical analysis of survey form data. All graphs, including the graph depicting temperature trends sourced from the National Climatic Data Centre (CNDC) database, were created using Microsoft Excel 2021. Accessing CNDC's online data requires utilizing FTP (File Transfer Protocol) software such as FileZilla Client. This database is one of the leading meteorological databases globally, incorporating data from the National Oceanic and Atmospheric Administration (NOAA) satellites and ground sensors. It differs from data obtained from the Climatic Research Unit (CRU), often utilized in various studies, which tends to be less precise due to reanalysis or simulated calculations. With ground-based data becoming scarcer [14], the Okondja station presented limited measurements possibly due to equipment issues. As a result, the Franceville-Mvengué station, located around 200 km from the study area, was selected for its comprehensive meteorological parameter measurements. Regrettably, temperature data from June 2021 to December 2021 were absent. Notably, initial temperatures in this database were presented in degrees Fahrenheit (°F). To calculate average temperatures (Tables 1a and 1b) in degrees Celsius (°C), initial temperatures were converted using the formula: $T(°C)=(T(°F)-32)/1.8$. Subsequently, various values were compared to ascertain the month with the highest or lowest mean annual temperature. The statistical series was divided into two equally sized sub-series (each containing five values). The mean annual temperature for each sub-series was determined separately, and the temperature difference between these two five-year periods was calculated, thus highlighting the temperature variance over these two periods.

Table 1a : Temperature trends from 2011 to 2021 (January to June) at the Franceville-Mvengué station [source: CNDC].

	Months (1/2)					
Year	January	February	March	April	May	June
2011	22,57778	24,20556	24,46112	23,56667	24,66667	23,40556
2012	23,83334	23,01112	25,01667	24,77778	23,51112	23,27778
2013	24,92778	25,43334	24,11667	24,88889	23,79445	22,85
2014	24,44445	24,18334	24,31667	24,55	23,4	23,29445
2015	23,92223	24,26112	23,79445	23,57223	23,4	22,77778
2016	24,44445	24,55556	24,74445	24,03334	24,08334	23,11112
2017	23,62223	23,90556	23,77778	23,85	23,27778	23,25556
2018	23,72223	24,02778	23,81667	23,63889	23,42223	23,03334
2019	24,22778	25,27778	25,66112	25,18334	24,49445	24,08889
2020	25,12223	24,42223	25,05	24,66667	23,99445	23,01667
2021	22,36112	24,52223	23,31112	23,66667	22,77778	

Table 1b : Temperature trends from 2011 to 2021 (July to December) at the Franceville-Mvengué station [source: CNDC].

	Months (2/2)					
Year	Jully	August	September	October	November	December
2011	24,17223	23,00556	24,01667	23,54445	23,12778	23,92223
2012	22,58889	21,78889	23,75556	23,18889	23,46112	23,41112
2013	22,57778	22,98889	24	23,67223	23,7	23,81667
2014	23,83334	22,59445	23,57223	23,61667	23,25556	23,29445
2015	22,86667	23,07778	23,61112	23,65556	23,47778	24,22778
2016	22,47223	23,22223	24,01667	23,45556	23,52223	24,24445
2017	22,34445	22,86667	24	23,42223	23,18334	23,52778
2018	22,34445	23,04445	23,79445	23,16667	23,22223	23,33334
2019	23,22223	23,05556	23,94445	23,00556	23,46667	23,72223
2020	22,97223	23,22223	24,18334	23,83334	23,16667	23,58334
2021						

Once the temperature table had been clearly highlighted using the two previous sub-tables (Tables 1a and 1b), a quarterly comparison followed, which involved averaging three consecutive months per year, then comparing the results of the various quarterly averages with each other. After the quarterly comparison, a half-yearly comparison was also carried out. This consisted in calculating the average temperature after six months, i.e. two half-years per year. This was followed by two seasonal comparisons (type 1 and 2). The type 1 seasonal comparison is based on the mean temperature determined over two seasons (dry and rainy). In concrete terms, this involved grouping temperatures by season, according to the corresponding month, and then establishing a comparison between the dry and rainy season averages. The Type 2 seasonal comparison follows the same principle as the first, i.e. to determine the average temperature per season, this time carried out over the four seasons, i.e. two dry seasons (long and short) and two rainy seasons (long and short). We then compare the averages obtained for each season and year.

Finally, we determined the correlation between the percentage of people observing changes in Moabi fruit harvesting and average annual temperatures. By calculating the correlation coefficient, we were able to highlight the degree of relationship between the two variables.

The main stages of the methodology followed are listed in the flow chart in figure 2, and the mathematical background is developed in the appendix.

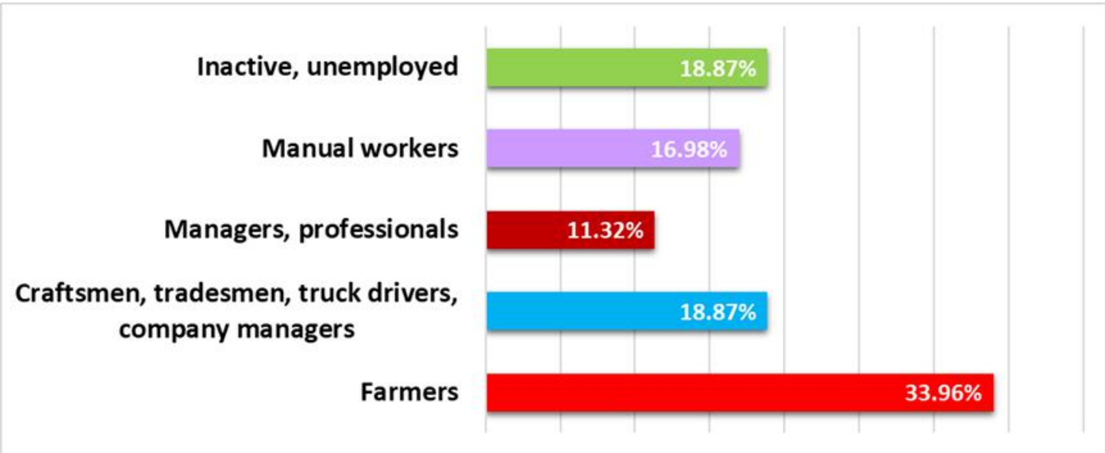
1	***Bibliographic research***	☐ Knowledge of the Moabi tree ■ Impact of climate change on biodiversity
2	***Form creation***	☐ Observing the african elephant specialist group form ■ Defining the questions on my form
3	***Choice of data collection site***	☐ Importance of the site for local populations ■ Recurrent observation of human-elephant Conflict
4	***Material and type of population to be interviewed***	☐ Material : Survey form ■ Target population: adults and young people
5	***Collecting data***	☐ Filling in a form for each interviewee ■ Verification of all forms
6	***Data processing***	☐ Transcription of data into a Microsoft Excel 2021 file ■ Application of statistical processing with the AdvDatAna toolbox
7	***Results***	☐ Analysis and interpretation of results ■ Decision-making and recommendations

Fig.2: Steps in the methodology.

IV. RESULTS

The majority of respondents were farmers (33.96%), followed by craftsmen, shopkeepers, truck drivers and business owners (18.87%) and the economically inactive without stable employment (18.87%) (Figure 3a). The most represented age group is 30-39 (39.62%), followed by 20-29 (18.87%), 15-19 (15.09%), and 40-49 and 50-60 (13.21%) (Figure 3b).

a)



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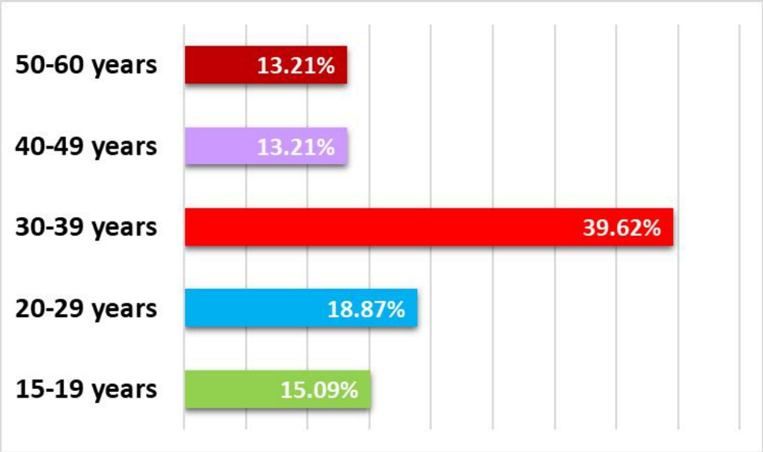
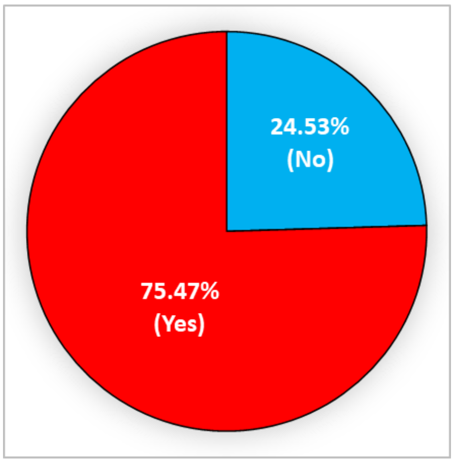


Fig.3 : Information on the survey population: a) socio-professional category, b) different age groups of respondents.

During the study period, no particular situations were observed or reported. However, more than 70% of those questioned had already had an accident with an elephant, or knew someone in their immediate environment who had had an accident with an elephant in the last 5 years. The proportion of such people is shown in Figure 4a. When asked how many piles of elephant dung they see per week in their plantation, 50.94% of people claim to encounter several per week in their field, 18.87% encounter at least one pile of elephant dung, and 30.19% see no elephant waste at all (Figure 4b). In terms of knowledge of the Moabi tree, 90.57% of those questioned were familiar with it, compared with 9.43% for whom it was unknown (Figure 4c). With regard to the food that elephants are fond of, over 60% of respondents felt that they feed mainly on fruit, as opposed to 32.08% who thought they preferred leaves. 1.89% gave a combined answer, i.e. they thought the elephant ate leaves and bark or fruit and bark, while 1.89% gave no opinion (Figure 4d). Concerning the month of greatest production of the Moabi tree, 50.94% of respondents felt that Moabi fruit is produced abundantly in May each year, compared with 18.87% who thought it was in April, 15.09% in March and 1.89% in the remaining months (Figure 4e).

a)



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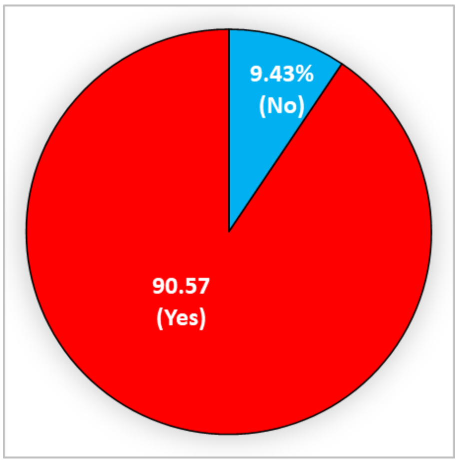

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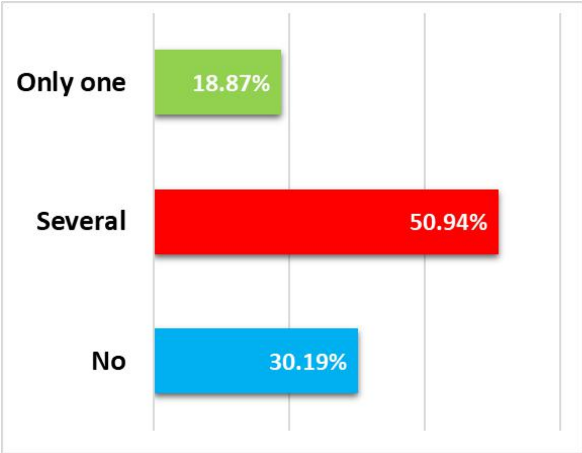

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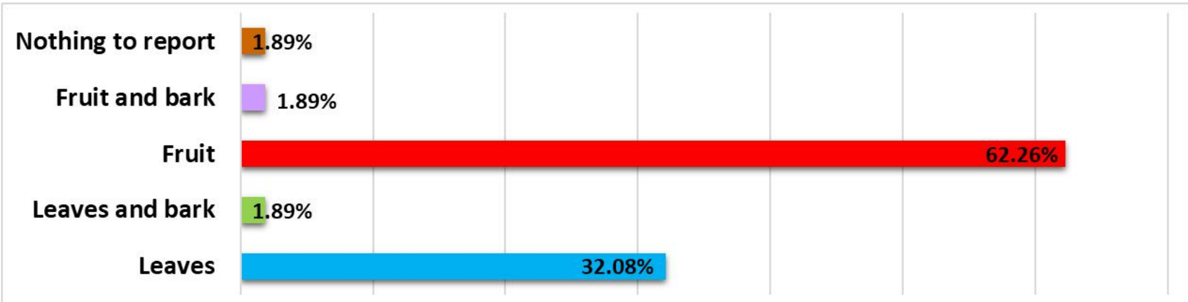

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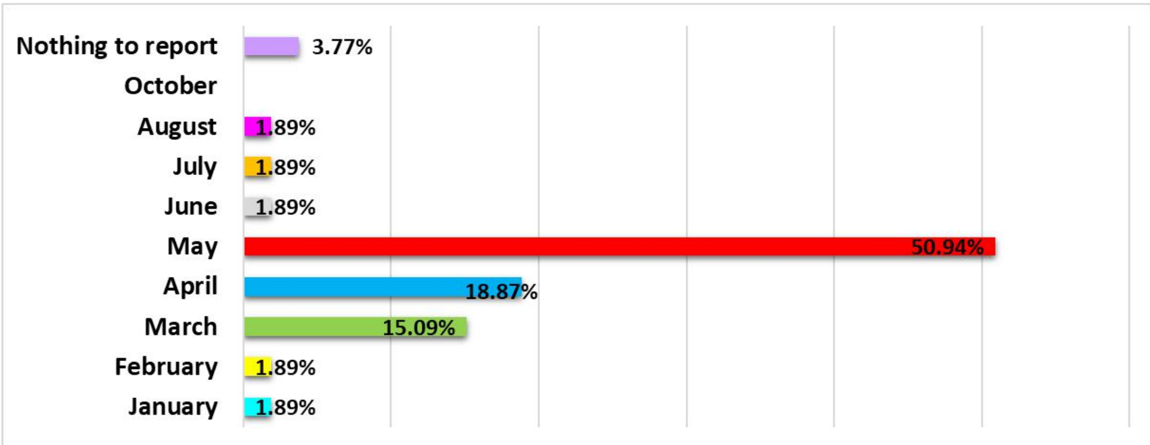


Fig.4: Practical information on elephants and villagers' knowledge of the Moabi tree: a) percentage of people with or without an elephant accident in the last five years, b) proportion of people seeing at least one pile of elephant dung per week in the field, c) proportion of people with or without knowledge of the Moabi tree, d) elephant's favorite food, e) months of abundant Moabi tree fruit productivity.

With regard to the quality of the harvest over the last five years, 56.6% of those questioned felt that the harvest had been average. 35.85% said it had been poor, and the remainder were undecided (Figure 5a). Speaking of the year in which changes occurred in Moabi tree production, 69.81% felt that the Moabi fruit harvest fell in 2021, 16.98% that it fell in 2020, 1.89% that it fell considerably in 2019, and the remaining percentage was unable to give an answer (Figure 5b). Answering the question "Do you think the elephant is closer to human habitation or further away?", 96.23% of respondents gave a favorable answer, compared with 3.77% who answered unfavorably (Figure 5c).

The percentage of people who observed changes in the harvesting of Moabi fruit was strongly correlated with the average annual temperatures of the years under consideration (Figure 5d), with a correlation coefficient of $r = -0{,}99$. This strong negative correlation translates into a decrease in average temperatures over said years, while the percentage of observations increases (Figure 5d).

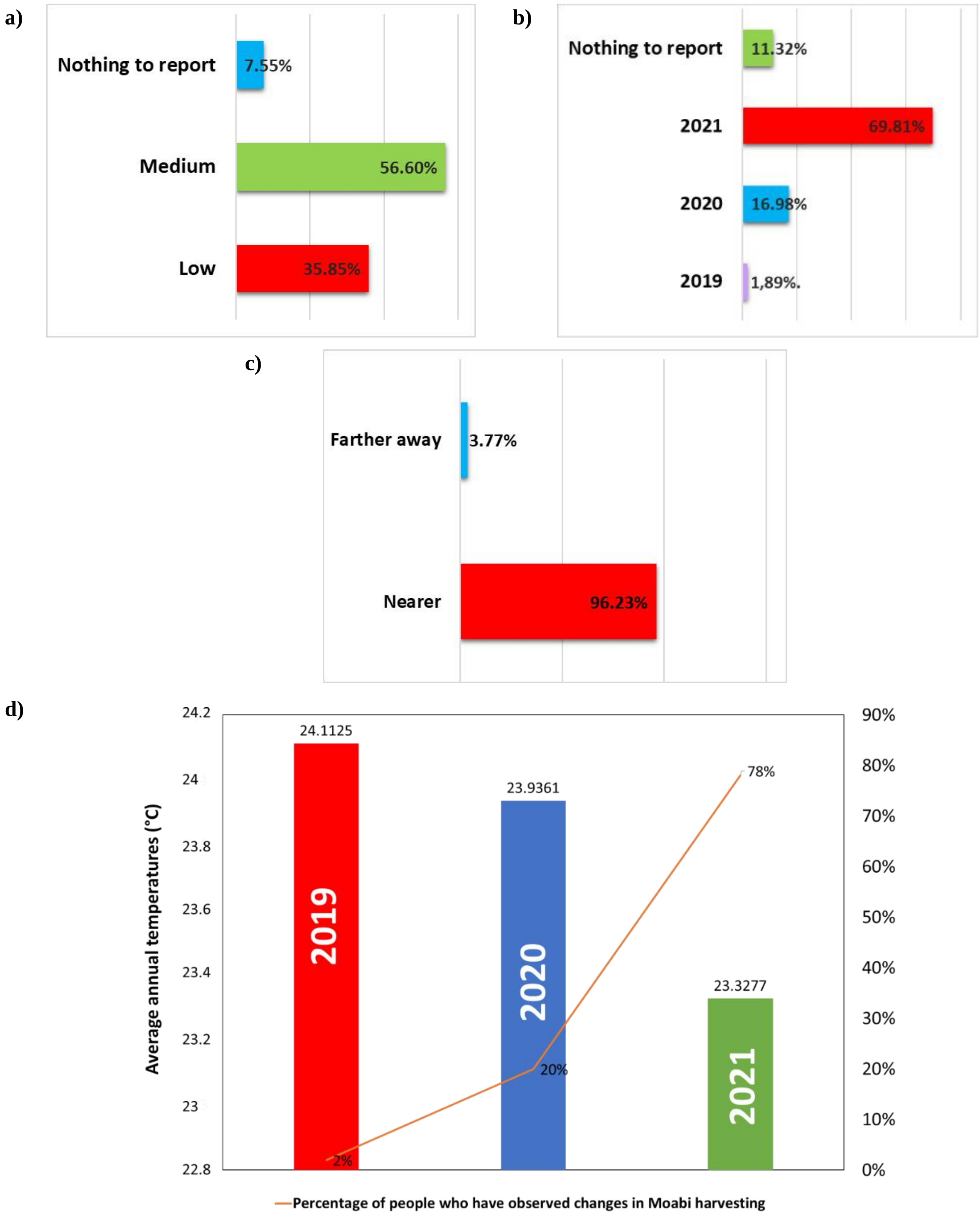
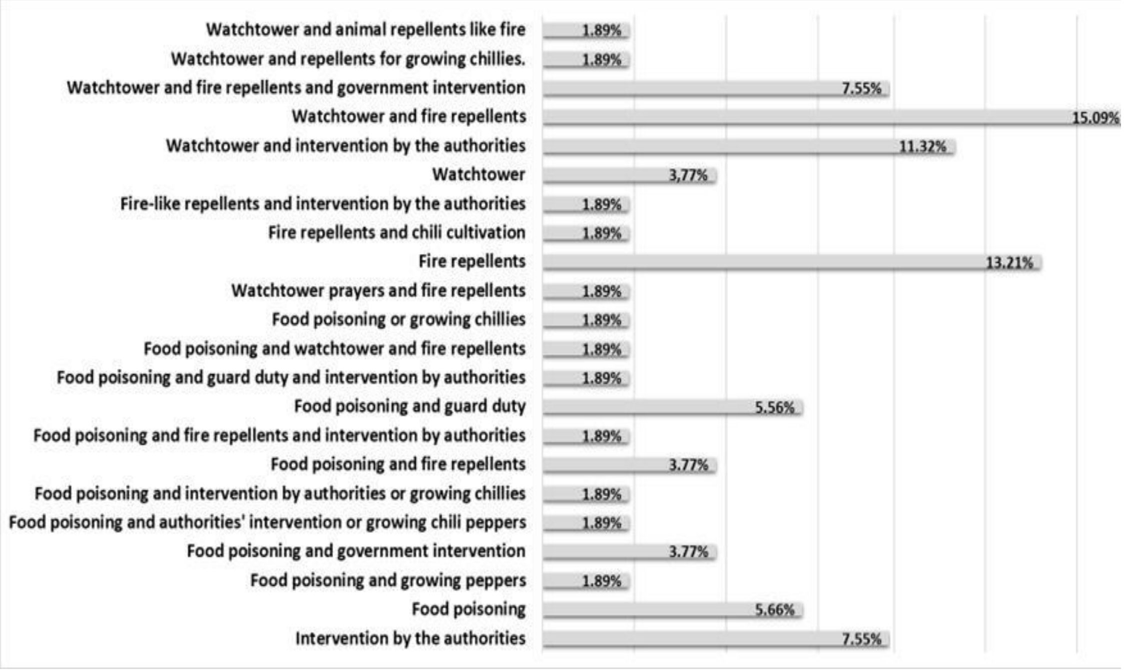


Fig.5 : Quality of Moabi fruit harvest in recent years and proximity of elephant to human dwellings: a) proportion of Moabi fruit harvest in recent years, b) year of low Moabi tree productivity according to villagers, c) position of elephant in relation to human dwellings, d) correlation between temperatures and percentage of people observing changes in Moabi fruit harvest.

On the subject of crop fields devastated by elephants, almost 90% of those questioned had already suffered damage, and 10% had experienced no elephant-related damage.

People use a variety of techniques to protect their fields and crops. The majority (15.09%) use the duo of "watchtowers and repellents such as fire" (Figure 6a). According to them, this duo has borne fruit, even though it requires considerable physical effort and sacrifice, such as chopping wood at every vigil to make fire. This activity also results in a significant reduction in the wake-keepers' sleep time. In order to avoid the long-term damage caused by elephants, people believe it would be advisable to consider the following options: 67.93% of those questioned were convinced that the best solution would be to create a fenced reserve for elephants, 7.55% opted to give up hunting and create a reserve for elephants at the same time. The remaining 26.41% fell into the other categories shown in figure 6b.

a)



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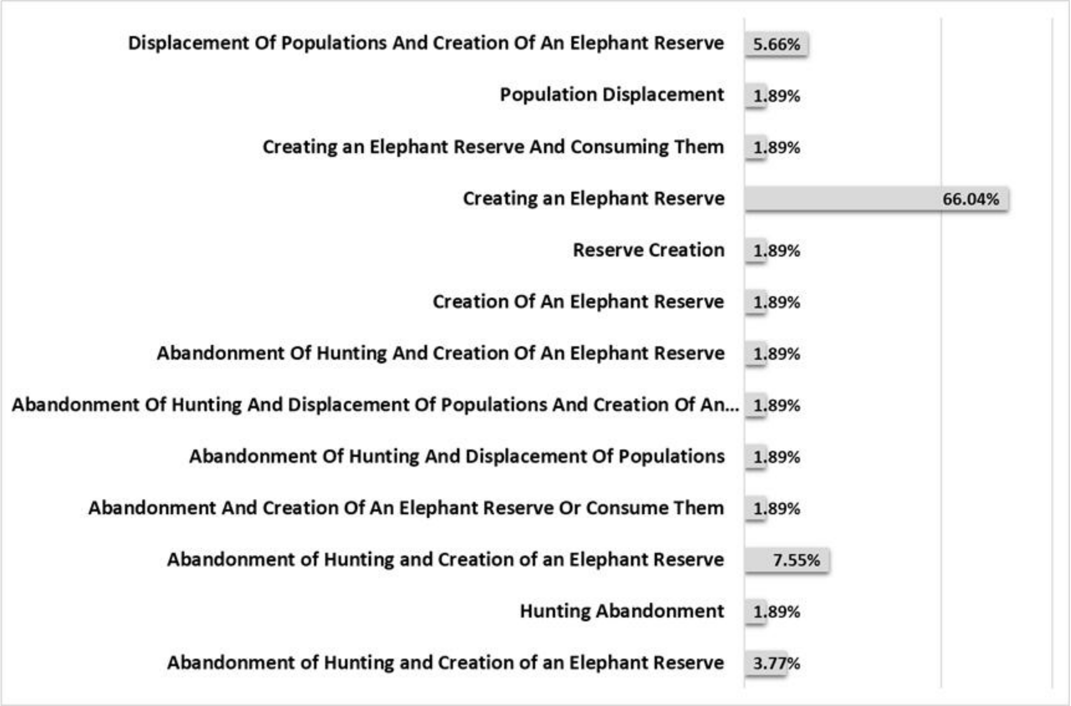


Fig.6 : Proposed solutions to human-elephant conflict: a) various elephant deterrence techniques, b) solutions proposed by villagers to curb human-elephant conflict.

The study of temperatures was the second major part of our work. This was divided into three sub-steps. Firstly, the evolutionary curve of mean annual temperatures (Figure 7) revealed that these oscillated between 23.3°C and 24.2°C over the 2011-2021 period.

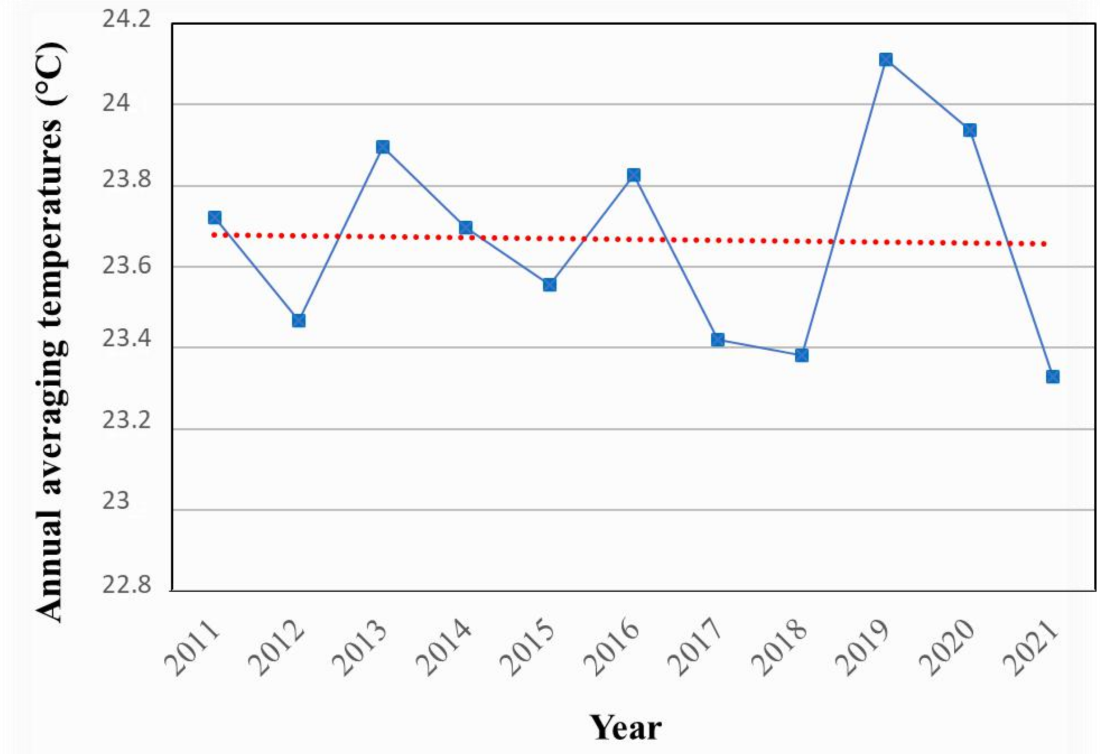
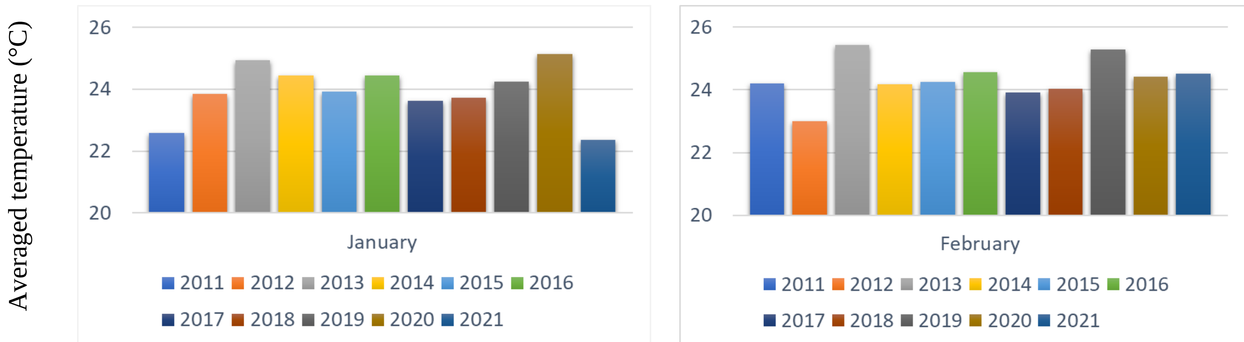


Fig.7: Trends in mean annual temperatures over the period 2011-2021

The monthly histograms of mean temperatures over the 2011-2021 period (Figures 8a and 8b) show that August 2012 was the month with the lowest mean temperature (T= 21.8°C), while February 2013 was the month with the highest mean temperature (T= 25.4°C). The mean annual temperature rose by +0.06°C between the two 5-year periods in Lékédi National Park.



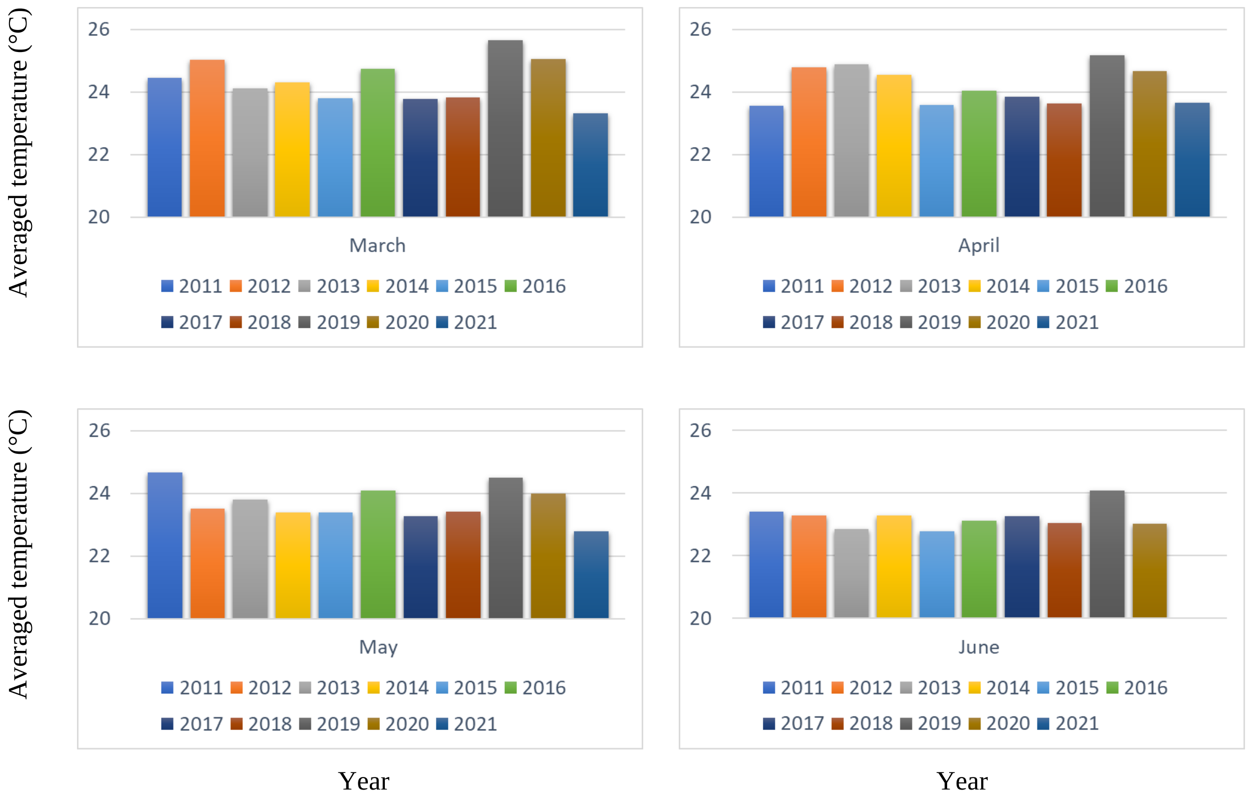
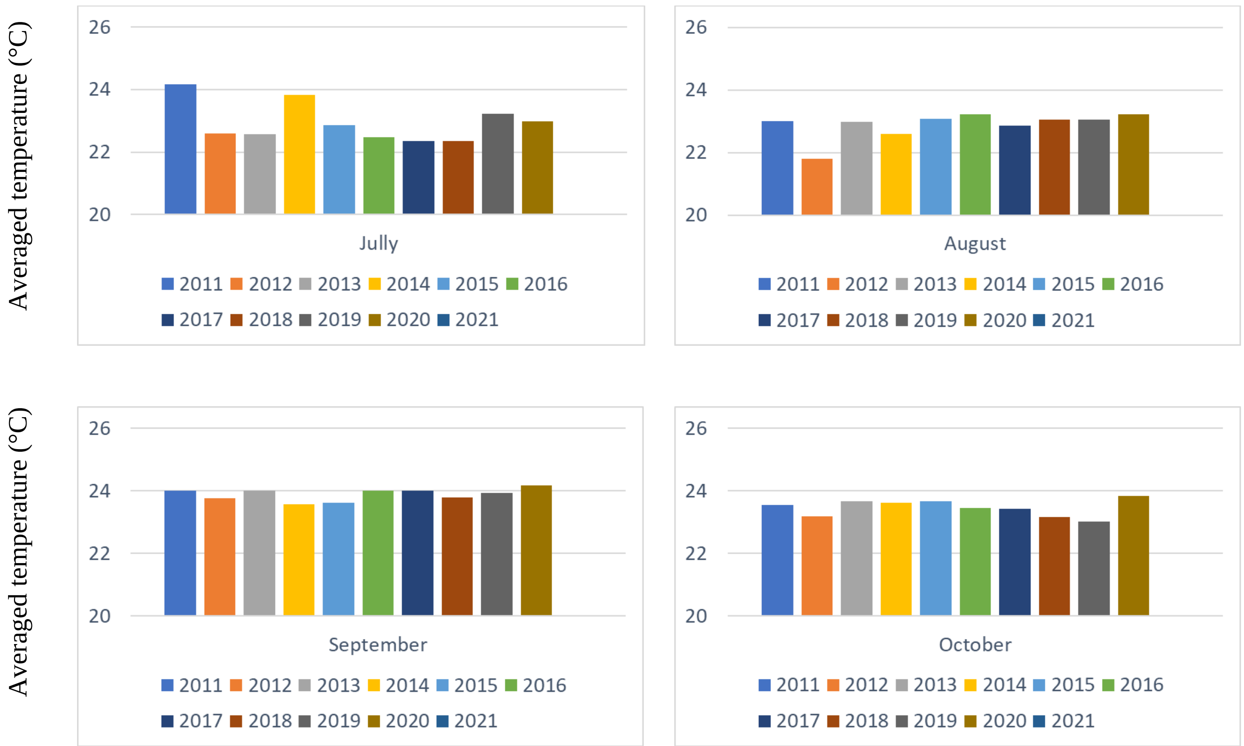


Fig.8a: Average monthly temperatures measured at the Franceville-Mvengué station from 2011 to 2021 (January to June) [source: CNDC].



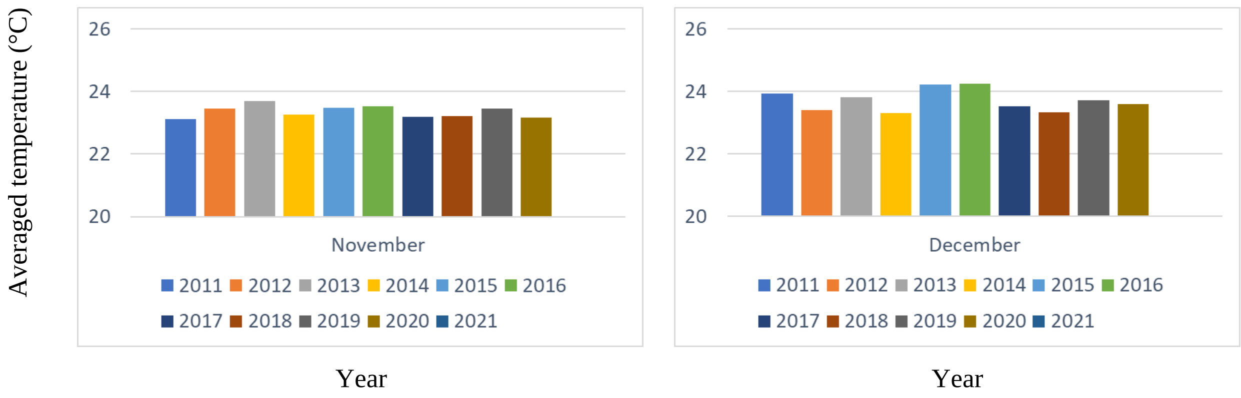


Fig.8b: Average monthly temperatures at the Franceville-Mvengué station, over the period 2011 to 2021 (July to December) [source: CNDC].

Lastly, the comparisons of quarterly and half-yearly averages may not be very indicative, but they do reveal that the first quarter and the first half-year of 2019 were the hottest (Figure 9a and Figure 9b).

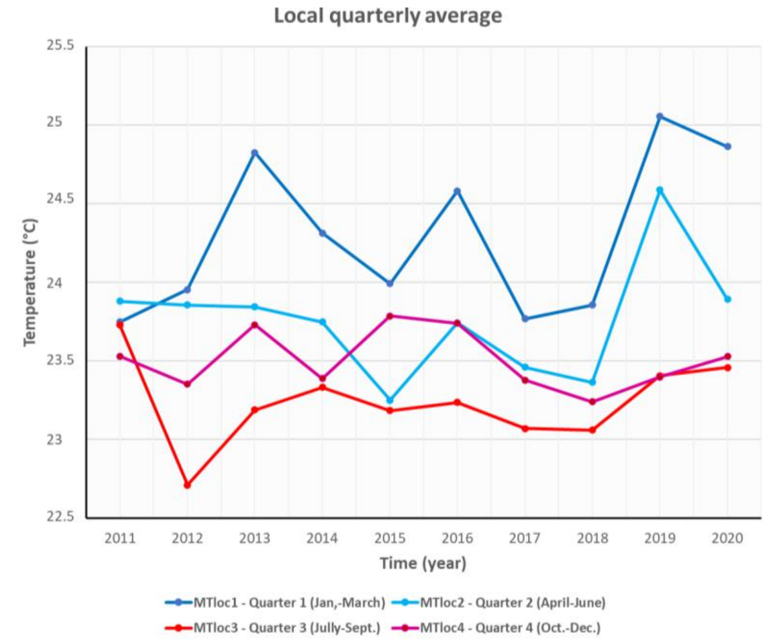
The Type 1 seasonal comparison yielded two significant findings. Firstly, in 2019, both the dry and rainy seasons were the warmest, with temperatures of 23.94°C and 24.29°C, respectively. However, we also note a slight increase in temperature during the rainy season compared to that in the dry season (Figure 9c). This minor temperature increase ranges from [0.26% to 4.20%] (Table 2a). However, this increase was observed in all years except 2014, when the temperature during the rainy season slightly decreased by 0.30% compared to that in the dry season (Table 2a).

The Type 2 seasonal comparison revealed that the short rainy season of 2019 was the warmest (25.11°C) among the three other seasons. Nevertheless, it's important to note that in any given year, all the major dry seasons have lower temperatures than their minor counterparts. From the long dry season to the short dry season, we observe a slight temperature increase. The percentage increase in temperature generally falls within the range of [0.17%; 8.42%] (Figure 9d, Table 2b).

From one year to the next, the average temperature sometimes decreases (as in 2011 and 2012, for example) and sometimes increases (as in 2018 and 2019) (Table 3).

Additionally, the highest rate of temperature increase was recorded in 2019 (3.13%), as shown in Table 3.

a)



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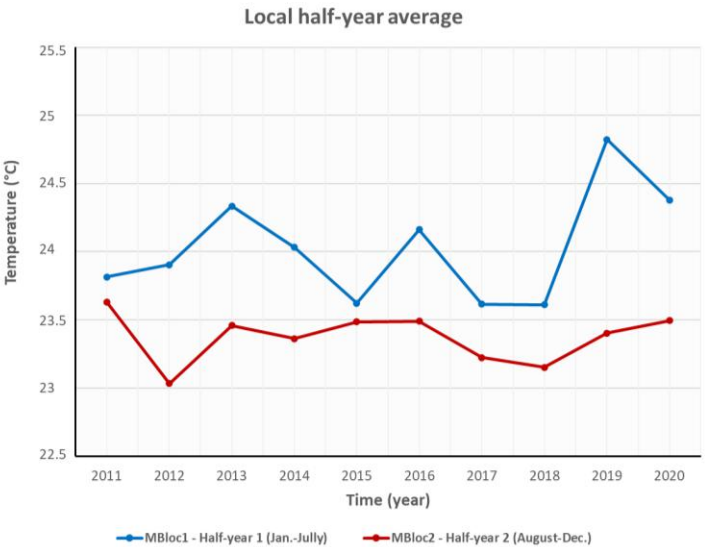

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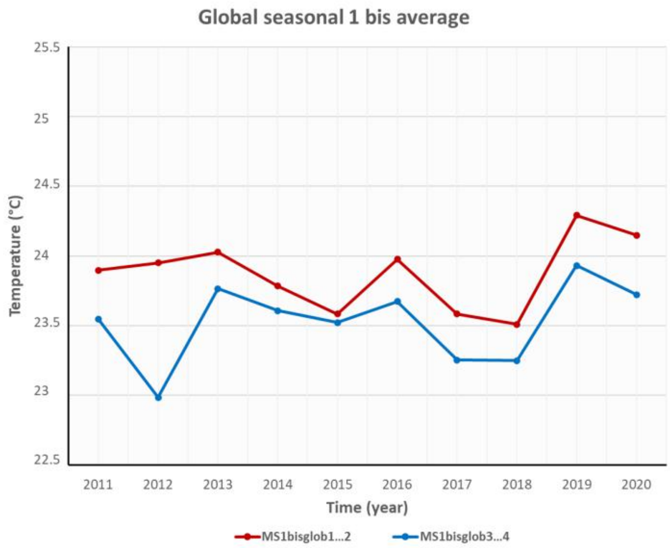

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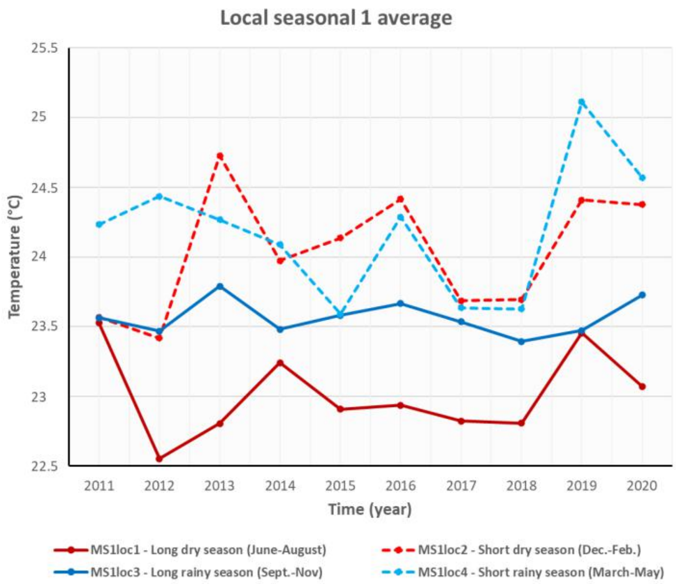

Fig.9 : The different temperature comparisons: a) quarterly comparison, b) half-yearly comparison, c) global seasonal comparison 1, d) local seasonal comparison 2

Table 2a : Temperature trends in the dry and rainy seasons from 2011 to 2021 at the Franceville-Mvengué station [source: CNDC].

Year	Temperature en °C (dry season)	Temperature en °C (rainy season)	Percentage increase
2011	23.54814	23.89723	1.48%
2012	22.98518	23.95185	4.2%
2013	23.76574	24.0287	1.1%
2014	23.8574	23.78518	-0.3%
2015	23.52223	23.58518	0.26%
2016	23.675	23.97592	1.27%
2017	23.2537	23.58518	1.42%
2018	23.25092	23.51018	1.11%
2019	23.9324	24.29259	1.5%
2020	23.72314	24.14907	1.79%

Table 2b : Temperature trends during the long and short dry seasons from 2011 to 2021 at the Franceville-Mvengué station [source: CNDC].

Year	Temperature en °C (long dry season)	Temperature en °C (short dry season)	Percentage increase
2011	23.52778	23.56851	0.17%
2012	22.55185	23.41851	3.84%
2013	22.80556	24.72592	8.42%
2014	23.24074	23.97407	3.15%
2015	22.9074	24.13703	5.36%
2016	22.93518	24.41481	6.45%
2017	22.82223	23.68518	3.78%
2018	22.8074	23.85556	4.59%
2019	23.45556	24.40925	4.06%
2020	23.07037	24.37592	5.65%

Table 3 : Rate of temperature increase between two consecutive years in the 2011-2020 study period, at Franceville-Mvengué station [source: CNDC].

Year	Average annual temperatures	Rate of increase between two successive years
2011	23.72269	0,00%
2012	23.4685233333333	-1.071%
2013	23.897225	1.82%
2014	23.6963008333333	-0.84%
2015	23.5537083333333	-0.6%
2016	23.8254691666667	1.15%
2017	23.4194483333333	-1.7%
2018	23.3805608333333	-0.16%
2019	24.112505	3.13%
2020	23.9361166666667	-0.73%

V. DISCUSSION

A survey carried out in Lékédi National Park suggests that elephants have a strong preference for fruit. More than 60% of those questioned said they were fond of fruit such as the Moabi tree, which grows predominantly in the park. The survey also revealed that elephants are now closer to human settlements; 96.23% of respondents supported this assertion. Elephants are a real danger to humans. In fact, over 70% of those questioned said they had already had an accident with an elephant. The survival of the people living near the Lékédi park is threatened, as most of them depend on agriculture. The destruction of plantations by elephants means the disappearance of people's main sources of subsistence. The average annual temperature rose by +0.06°C between the two 5-year periods in Lékédi National Park during the decade between 2011 and 2020. A slight warming of the Lékédi park is noticeable. Indeed, we noted an increase ranging from 0.26% to 4.20% in temperature in the rainy season compared with the dry season. This conclusion is reinforced by the 0.17% to 8.42% rise in temperature in the short dry season compared with the long dry season. There is a close link between the availability of Moabi fruit and elephant migration to human settlements, with a strong negative correlation ($r = -0{,}99$).

This survey of the indigenous populations of the Lékédi region revealed that over 70% of respondents had already experienced at least one unfortunate event involving elephants. In cases where respondents were not directly involved, it was a close relative who was. At the same time, around 90% of respondents claimed to have had at least one crop field devastated by elephants. Elephants have enormous nutritional needs [15]. Deprived of the fruit of the Moabi tree, which they love and are the main disseminators [16], elephants migrate to secondary forests. These forests, to which elephants migrate, are generally areas cultivated by local populations. This migration of elephants in search of food could explain the high percentage of people who have had an incident with an elephant. This finding is in line with Aimeric Ferlay's [9] work in three villages in the Makokou region, which showed that almost 77% of families surveyed had experienced at least one field ravaged by elephants.

During the survey, we noted that the majority of people (90.57%) interviewed were familiar with the Moabi fruit, suggesting that it is or was prevalent in the study area. The Moabi tree is said to play many roles in people's daily lives, with its numerous curative, culinary and other properties [1]. The Moabi tree therefore remains of vital importance to the people of this region. This is confirmed by the International Union for Conservation of Nature (IUCN), which has added the Moabi to its list of vulnerable species [15].

According to the testimonies of the people questioned, 62.26% believe that the forest elephant has a food preference for fruit; 32.08% believe that it prefers leaves and 1.89% think that it consumes leaves and bark, fruit and bark and the remaining 1.89% did not give an opinion, probably due to a lack of knowledge of the elephant's diet. These observations suggest that the elephant feeds mainly on fruit rather than leaves or bark. This is in line with the work of Bush [16]. The latter showed that a drop in fruiting led to an 11% reduction in the body condition of forest elephants, suggesting a dependence on fruit.

We found that over half (50.94%) of those surveyed felt that the Moabi tree produced more in May, while 18.87% chose April, 15.09% March and 1.89% the rest of the months. These results suggest that the margin in terms of fruiting months for the Moabi tree lies in the March-May range. The March-May range corresponds to the short rainy season, during which Gabon's climate generally alternates between mild hot spells and mild cold spells [17], resulting in an almost permanent minimum temperature during this period. This may be in line with the work of Bush, who argues that certain tree species require a minimum temperature to trigger flowering [16]. However, the 1.89% of people who opted for the rest of the months are not necessarily making a mistake. This is undoubtedly due to a disruption in the reproductive calendar of certain tree species during these months. This disruption would be due to climate change, as suggested by a study carried out in Uganda in 2018 [18]. It claimed that the modification of certain climatic signals had favored changes in the reproductive cycle of certain trees.

The elephant now seems to be closer to human habitation than to its natural environment, the forest. The data suggest that 96.23% of those surveyed claim that the elephant is closer to them than it used to be. Similarly, 69.81% of the sample claimed to find at least one pile of elephant dung per week in their field, compared with 30.19% who found no piles of elephant dung, probably due to the irregular use of their fields, as some of them had already suffered the devastating effects of elephant passage. All these observations confirm the hypothesis that the elephant is closer to the population these days. Certainly, this could be due to the absence of a food that elephants are fond of, the fruit of the Moabi tree, as emphasized by Nanfack [5] and Guibinga [6]. However, this could be the result of the gradual degradation of the elephant's ecosystem with the rise of manganese mining by Gabon Mining in the Okondja locality. This seems to accord with a recent survey by Afrobarometer [19], in which they suggest that Gabonese people blame logging and mining for exacerbating human-wildlife conflict. These results are in line with the survey conducted by the Wildlife Conservation Society (WCS) and the Agence Nationale des Parcs Nationaux (ANPN), which implied that the elephant population had increased from 7330 individuals in 2014 to around 95,000 elephants in Gabon by 2021 [8], thus proving the overpopulation of this species in the Gabonese forest. These results are confirmed by recent unfortunate events in the town of Mouila (southern Gabon), where an elephant killed a bus driver on the main road where buses and trucks travel [8]. On January 26 and 27, 2023, a man and a woman were mauled by elephants in the villages of Ilahounene and Iyoko Ngota respectively. Both are located in the Ogooué

Ivindo region (south-east Gabon) [20]. These recent tragedies clearly demonstrate that elephants are deserting their natural habitat to move into areas previously occupied and frequented by humans.

The absence of the Moabi fruit, which elephants love, is thought to have driven them to the local crop fields. This assertion is supported by the work of Bush. This work argues that the fruiting of trees in natural forests has fallen dramatically over the last thirty years, encouraging elephants to move out of the forest [16].

To deal with this animal threat, the majority of respondents (15.09%) use the "watchtower and fire repellent" duo to keep elephants away from their crop fields. This technique is said to play a positive role in keeping elephants away from homes. However, its implementation requires considerable effort, i.e. huge amounts of wood to be cut for the fire, which would accelerate the desertification process in the area [21]. Burning wood increases the release of carbon dioxide (CO_2) into the atmosphere, contributing to global warming [11]. In the long term, it is also said to cause sleep disturbance for the guards, who have to keep vigil over and over again. While some opted for intervention by the authorities (7.55%), others believed in the use of food poisons (5.66%), which would not be good practice as the elephant is on the IUCN Red List of Vulnerable Species and is therefore a fully protected species [22]. On the other hand, a section of the population has opted to grow large quantities of chilli trees around the crop fields. This would make sense, as elephants might be disturbed by the pungent smell of chillies. Planting chilli trees around crop fields would be a viable avenue to explore in Lékédi National Park. It could be of dual importance: to protect the crops, and to help increase people's incomes after exporting and selling the chillies to major markets. All these techniques do not seem to be fully supported by the work of Ouattara [4], who considers their effectiveness to be temporary. In fact, these studies show that elephants become accustomed to traditional human techniques over time, and their response to the signals emitted by humans diminishes considerably over the long term.

In an attempt to eradicate the human-elephant conflict caused by the absence of Moabi fruit in Lékédi National Park, some 67.93% of people felt that it would be a good idea to create a fenced reserve to contain the elephants. Some even suggested that it should be electrified, which would be a continuation of the electric fencing program that has already proved successful in various protected areas in Gabon [23] and northern Congo [22]. However, their implementation would pose a serious dilemma in terms of high installation costs. We might also ask what would be the long-term impact of electric discharges on the pachyderms? Would they lead to infertility? Despite the growing interest in this approach, a long-term study of pachyderm fertility would be welcome. A small percentage (1.89%) opt for abandoning hunting and suggest population relocation. However, this would further increase the vulnerability of populations that depend mainly on forest resources [24]. This solution would also increase the poverty of the Lékédi population, most of whom live off agriculture. This observation is partly endorsed by Thomas Breur [7], who considers that while abandoning hunting and the rural exodus may appear to be a legitimate resolution to spare people the worst, it would nonetheless have serious consequences for family food supplies. Hill's work in 2018 [25] highlighted the fact that farmers are rarely compensated in the event of forced rural exodus, thus demonstrating the limits of the proposed solution of population displacement.

The average annual temperature in Lékédi Park has risen by +0.06°C between two 5-year periods, leading to a considerable drop in the Moabi fruit harvest, as suggested by more than half of the natives in 2021. Indeed, 69.81% believe that it was in 2021 that the Moabi fruit harvest dropped considerably, and 16.98% think it was in 2020.These observations underline the significant changes that began in the tenth year of the study period. These results are in line with those of Bush [1], who showed a rise in daily minimum temperature of +0.25°C per decade in Lopé. In addition, the temperature in the rainy season was higher than in the dry season, and the temperature in the short dry season was 0.17% to 8.42% higher than in the long dry season. These different temperature variations would influence the productivity rate of the Moabi tree. All these factors would explain the decline in Moabi tree productivity, since based on the experience of the local population, the tree produces better during the short rainy season. This hypothesis is confirmed by the Intergovernmental Panel on Climate Change (IPCC) [26], which states that rising temperatures and the occurrence of more frequent and prolonged extreme events are affecting the biosphere at several levels (species distribution, phenology, ecosystem structure).

There is a strong negative correlation ($r = -0{,}99$) between mean annual temperatures and the percentage of people observing changes in Moabi fruit harvesting. The increase in one variable (average temperature) would favor a decrease in the reproduction of Moabi fruit, thus explaining the drop in the harvest of this fruit observed by people from the year 2019 onwards. 2019 also recorded the highest rate of increase between two consecutive years. This rise in temperature may be man-made, with manganese extraction in the Okondja region by Nouvelle Gabon

Mining (NGM) beginning in earnest in 2019. This assertion is supported by the IPCC, whose latest report states that global warming is unprecedented and caused by human activities [20]. There is a close link between climate signals (temperature and precipitation) and plant production. Nevertheless, we deplore the absence of precipitation data. The non-exploration of rainfall data is due to their relative unavailability due to the small number of rain gauge stations in Central Africa [27]. Changes in these climatic variables would therefore have an impact on the reproductive cycle of certain trees [7]. This supports the idea that an increase of one hundredth of a degree Celsius in mean annual temperature influences the reproductive process of Moabi. This correlation has also been proven by Bush [16], whose work in the Lopé reserve revealed the existence of a minimum temperature for triggering flowering in certain trees.

VI. CONCLUSION

The inhabitants of Lékédi National Park are under serious threat from the movement of elephants. Elephants migrate towards human settlements in search of food. Their movement is correlated with the availability of Moabi fruit in their natural habitat. Moabi fruit is highly prized by pachyderms, and its harvest has declined considerably in recent years. Statistical analysis of the data collected during the survey suggests that elephants are moving closer and closer to human habitations, and that an increase in mean annual temperature (+0.06°C) between two 5-year periods would favour a decrease in Moabi fruit reproduction. Higher temperatures during the rainy season and the short dry season, compared with the long dry season, are indeed reasons for the drop in Moabi fruit production. The results of this study therefore allow us to assert that a change in temperature in the Lékédi National Park leads to a scarcity of Moabi fruit, which in turn drives elephants towards people's crop fields. This study has also enabled us to sound the alarm once again, urging the authorities to focus more on this little-studied area, which is nevertheless a strong link in the supply of foodstuffs such as bananas, a foodstuff much appreciated by the populations of the surrounding localities. The Gabonese government has decided to release 4 billion FCFA in May 2023 to compensate populations suffering the effects of the human-elephant conflict. This palliative solution is not sustainable in the long term, as the populations concerned are numerous. Concrete solutions are therefore urgently needed.

The current study can therefore be strengthened by applying it to other national parks. It would also be advisable to carry out a survey of victims of human-elephant conflict living outside national parks. In addition to these studies, a real awareness campaign on the elephant's major role in ecosystem conservation should be carried out among the local population. The absence of temperature data for the rest of the months in 2021 is an obstacle to our study. On the one hand, it would be necessary to acquire all temperature data, preferably even daily data, for all the years from 2011 to 2022, and on the other hand, to take an interest in the quality of rainfall in Lékédi. This acquisition could be carried out using machine learning tools. All this would enable experimental studies to be reinforced, as has been the case in the Lopé reserve by numerous researchers.

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Appendices

Mathematical background

The various average calculations in this article are based on this mathematical background.

In the following, M_i^k will be the variable denoting average temperatures for month no.i of the year k.

Overall annual average

The average temperatures obtained, for the year 2011 only, will be noted $MA_{glob}^{k=2011}$ and calculated as :

$$MA_{glob}^{k=2011} = \text{mean}\Big(\sum_{i=1\ldots12} M_i^k\Big) \ .$$

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$$MA_{glob}^{k=2011\ldots2020} = \left[MA_{glob}^{k=2011},\ \ MA_{glob}^{k=2012}\ \ ,\ \ldots\ \ , MA_{glob}^{k=2019}\ \ ,\ MA_{glob}^{k=2020}\right];$$

Local half-year average

The average local temperatures obtained during semesters 1 and 2, for 2011 only, will be respectively $MB_{loc1}^{k=2011}$ and $MB_{loc2}^{k=2011}$ and calculated as follows :

$MB_{loc1}^{k=2011} = \frac{\sum_{i=1...6} M_i^k}{6}$, $MB_{loc2}^{k=2011} = \frac{\sum_{i=7...12} M_i^k}{6}$.

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$MB_{glob1}^{k=2011...2020} = [MB_{loc1}^{k=2011}, \ MB_{loc1}^{k=2012} \ , \ ... \ , MB_{loc1}^{k=2019} \ , \ MB_{loc1}^{k=2020}]$;

$MB_{glob2}^{k=2011...2020} = [MB_{loc2}^{k=2011}, \ MB_{loc2}^{k=2012} \ , \ ... \ , MB_{loc2}^{k=2019} \ , \ MB_{loc2}^{k=2020}]$;

Overall half-year average

The average local temperatures obtained, for the year 2011 only, will be noted $MB_{glob1...2}^{k=2011}$ and calculated as follows :

$MB_{glob1...2}^{k=2011} = \text{mean}(MB_{loc1}^{k=2011} \ , \ MB_{loc2}^{k=2011})$

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$MB_{glob1...2}^{k=2011...2020} = [MB_{glob1...2}^{k=2011} \ , \ MB_{glob1...2}^{k=2012} \ , \ ... \ , \ MB_{glob1...2}^{k=2019} \ , \ MB_{glob1...2}^{k=2020}]$

Local quarterly average

The average local temperatures obtained during quarters 1, 2, 3 and 4, for the year 2011 only, will be respectively noted as $MT_{loc1}^{k=2011}$, $MT_{loc2}^{k=2011}$, $MT_{loc3}^{k=2011}$, $MT_{loc4}^{k=2011}$ and calculated as :

$MT_{loc1}^{k=2011} = \frac{\sum_{i=1...3} M_i^k}{3}$, $MT_{loc2}^{k=2011} = \frac{\sum_{i=4...6} M_i^k}{3}$, $MT_{loc3}^{k=2011} = \frac{\sum_{i=7...9} M_i^k}{3}$,

$MT_{loc4}^{k=2011} = \frac{\sum_{i=10...12} M_i^k}{3}$,

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$MT_{loc1}^{k=2011...2020} = [MT_{loc1}^{k=2011}, \ MT_{loc1}^{k=2012} \ , \ ... \ , MT_{loc1}^{k=2019} \ , \ MT_{loc1}^{k=2020}]$;

$MT_{loc2}^{k=2011...2020} = [MT_{loc2}^{k=2011}, \ MT_{loc2}^{k=2012} \ , \ ... \ , MT_{loc2}^{k=2019} \ , \ MT_{loc2}^{k=2020}]$;

$MT_{loc3}^{k=2011...2020} = [MT_{loc3}^{k=2011}, \ MT_{loc3}^{k=2012} \ , \ ... \ , MT_{loc3}^{k=2019} \ , \ MT_{glob3}^{k=2020}]$;

$MT_{loc4}^{k=2011...2020} = [MT_{loc4}^{k=2011}, \ MT_{loc4}^{k=2012} \ , \ ... \ , MT_{loc4}^{k=2019} \ , \ MT_{loc4}^{k=2020}]$.

Overall quarterly average

The average local temperatures obtained, for 2011 only, will be noted $MT_{glob1...4}^{k=2011}$ and calculated as follows :

$MT_{glob1...4}^{k=2011} = \text{mean}(MT_{loc1}^{k=2011} \ , MT_{loc2}^{k=2011} \ , MT_{loc3}^{k=2011} \ , MT_{loc4}^{k=2011})$,

The vector corresponding to the period from 2011 to 2020 will have the expression :

$MT_{glob1....4}^{k=2011...2020} = [MT_{glob1...4}^{k=2011} \ , \ MT_{glob1...4}^{k=2012} \ , \ ... \ , \ MT_{glob1...4}^{k=2019} \ , \ MT_{glob1...4}^{k=2020}]$

Seasonal average 1 local

The average local temperatures obtained during the long dry season, the short dry season, the long rainy season and the short rainy season, for 2011 only, will be respectively noted as $MS1_{loc1}^{k=2011}$, $MS1_{loc2}^{k=2011}$, $MS1_{loc3}^{k=2011}$, $MS1_{loc4}^{k=2011}$ and calculated as :

$MS1_{loc1}^{k=2011} = \frac{\sum_{i=6...8} M_i^k}{3}$, $MS1_{loc2}^{k=2011} = \frac{\sum_{i=12,1,2} M_i^k}{3}$, $MS1_{loc3}^{k=2011} = \frac{\sum_{i=9...11} M_i^k}{3}$,

$MS1_{loc4}^{k=2011} = \frac{\sum_{i=3...4} M_i^k}{3}$

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$MS1_{loc1}^{k=2011...2020} = [MS1_{loc1}^{k=2011}, \ MS1_{loc1}^{k=2012} \ , \ ... \ , MS1_{loc1}^{k=2019} \ , MS1_{loc1}^{k=2020}]$;

$MS1_{loc2}^{k=2011...2020} = [MS1_{loc2}^{k=2011}, \ MS1_{loc2}^{k=2012} \ , \ ... \ , MS1_{loc2}^{k=2019} \ , MS1_{loc2}^{k=2020}]$;

$MS1_{loc3}^{k=2011...2020} = [MS1_{loc3}^{k=2011}, \ MS1_{loc3}^{k=2012} \ , \ ... \ , MS1_{loc3}^{k=2019} \ , MS1_{loc3}^{k=2020}]$;

$MS1_{loc3}^{k=2011...2020} = [MS1_{loc4}^{k=2011}, \ MS1_{loc4}^{k=2012} \ , \ ... \ , MS1_{loc4}^{k=2019} \ , MS1_{loc4}^{k=2020}]$;

Seasonal average 1 overall

The average of local mean temperatures obtained during the long dry season, short dry season, long rainy season and short rainy season, for the year 2011 only, will be noted $MS1_{glob1...4}^{k=2011}$ and calculated as :

$$MS1_{glob1...4}^{k=2011} = \text{mean}\left(MS1_{loc1}^{k=2011}\ ,MS1_{loc2}^{k=2011}\ ,MS1_{loc3}^{k=2011}\ ,MS1_{loc4}^{k=2011}\right),$$

The vector corresponding to the period from 2011 to 2020 will have the expression :

$$MS1_{glob1...4}^{k=2011...2020} = \left[MS1_{glob1...4}^{k=2011}\ ,\ MS1_{glob1...4}^{k=2012}\ ,\ ...\ ,MS1_{glob1...4}^{k=2019}\ ,\ MS1_{glob1...4}^{k=2020}\right]$$

Seasonal average 1 bis overall

The average of local mean temperatures obtained during the long dry season, short dry season, long rainy season and short rainy season, for the year 2011 only, will be noted. $MS1bis_{glob1...2}^{k=2011}$. Similarly, the average of local mean temperatures obtained during the long dry season, short dry season, long rainy season and short rainy season, for 2011 only, will be noted. $MS1bis_{glob3...4}^{k=2011}$. These 2 variables will be calculated as :

$$MS1bis_{glob1...2}^{k=2011} = \text{mean}(MS1_{loc1}^{k=2011}\ ,MS1_{loc2}^{k=2011}),$$

$$MS1bis_{glob3...4}^{k=2011} = \text{mean}(MS1_{loc3}^{k=2011}\ ,MS1_{loc4}^{k=2011}).$$

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$$MS1bis_{glob1...2}^{k=2011...2020} = \left[MS1bis_{glob1...2}^{k=2011}\ ,\ MS1bis_{glob1...2}^{k=2012}\ ,\ ...\ ,MS1bis_{glob1...2}^{k=2019}\ ,\ MS1bis_{glob1...2}^{k=2020}\right]$$

$$MS1bis_{glob3...4}^{k=2011...2020} = \left[MS1bis_{glob3...4}^{k=2011}\ ,\ MS1bis_{glob3...4}^{k=2012}\ ,\ ...\ ,MS1bis_{glob3...4}^{k=2019}\ ,\ MS1bis_{glob3...4}^{k=2020}\right]$$

Seasonal average 2 local

The average local temperatures obtained during the dry and rainy seasons, for the year 2011 only, are respectively noted as $MS2_{glob1}^{k=2011}$and $MS2_{glob2}^{k=2011}$and calculated as :

$$MS2_{loc1}^{k=2011} = \frac{\sum_{i=9...11} M_i^k + \sum_{i=3...5} M_i^k}{6}\ ,\ MS2_{loc2}^{k=2011} = \frac{\sum_{i=6...8} M_i^k + \sum_{i=12,1,2} M_i^k}{6}.$$

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$$MS2_{loc1}^{k=2011...2020} = \left[MS2_{loc1}^{k=2011},\ MS2_{loc1}^{k=2012}\ ,\ ...\ ,MS2_{loc1}^{k=2019}\ ,MS2_{loc1}^{k=2020}\right];$$

$$MS2_{loc2}^{k=2011...2020} = \left[MS2_{loc2}^{k=2011},\ MS2_{loc2}^{k=2012}\ ,\ ...\ ,MS2_{loc2}^{k=2019}\ ,MS2_{loc2}^{k=2020}\right];$$

Seasonal average 2 overall

The average of local mean temperatures obtained during the dry and rainy seasons, for the year 2011 only, will be noted $MS2_{loc1...2}^{k=2011}$ and calculated as follows :

$$MS2_{glob1...2}^{k=2011} = \text{mean}(MS2_{loc1}^{k=2011}\ ,MS2_{loc2}^{k=2011})$$

The vectors corresponding to the period from 2011 to 2020 will be expressed as :

$$MS2_{glob1...2}^{k=2011...2020} = \left[MS2_{glob1...2}^{k=2011}\ ,\ MS2_{glob1...2}^{k=2012}\ ,\ ...\ ,MS2_{glob1...2}^{k=2019}\ ,\ MS2_{glob1...2}^{k=2020}\right]$$