

Czech University of Life Sciences
Faculty of Environmental Sciences
Department of Ecology



Česká zemědělská
univerzita v Praze

Detection of Vocalizations of Different Mammal
Species on Forest Clearings in The Congo

Bachelor Thesis

Supervisor: Mgr. Tomáš Jůnek, Ph.D.

Author: Ema Cehelská

2024

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

BACHELOR THESIS ASSIGNMENT

Ema Cehelská

Applied Ecology

Thesis title

Detection of vocalizations of different mammal species on forest clearings in the Congo

Objectives of thesis

The goal of the thesis is to use the methods of passive acoustic monitoring to detect acoustically active and conservation significant species of mammals, to evaluate the quantity and quality of the acoustic recordings using current technology (and to evaluate against other study methods) and to learn how to use specialized analytical software. The thesis also includes literary research about the methods of direct and indirect study of mammals in the tropical rainforest area.

Methodology

Bioacoustic research is currently gaining in importance for its potential of long-term autonomous detection of animal species in visually challenging and difficult-to-traverse environment. Scientists are already able to differentiate between e.g. bird species based on their vocalizations and confirm their occupancy. This thesis will focus on the detection of mammal vocalizations, especially arboreal primates, which are present on the project site in the rainforests of the Republic of Congo. Mammal vocal expressions are an understudied topic and can directly indicate conservation priorities in the areas with the occurrence of globally threatened species. The student will work with specialized software, which offers the possibility of machine learning, and will also analyze audio records with emphasis on spatio-temporal distribution of species along with camera-trapping photographs taken in the same study sites.

The proposed extent of the thesis

60 pages

Keywords

bioacoustics, monitoring, biodiversity

Recommended information sources

- Buxton R. T., Lendrum P. E., Crooks K. R., Wittemyer G., 2018: Pairing camera traps and acoustic recorders to monitor the ecological impact of human disturbance. *Global Ecology and conservation* 16: e00493.
- Heinicke S., Kalan A. K., Wagner O. J. J., Mundry R., Lukashevich H. and Kühl H. S. 2015: Assessing the performance of a semi-automated acoustic monitoring system for primates. *Methods in Ecology and Evolution* 6: 753-763.
- Marler P., 1972: Vocalizations of East African Monkeys II: Black and White Colobus. *Behaviour* 42 (3-4): 175-197.
- Sugai L.S.M., Silva T.S.F., Ribeiro Jr J.W., Llusia D., 2019: Terrestrial passive acoustic monitoring: review and perspectives. *BioScience* 69 (1): 15-25.
- Wrege P. H., Rowland E. D., Keen S., Shiu Y., 2017: Acoustic monitoring for conservation in tropical forests: examples from forest elephants. *Methods in Ecology and Evolution* 8 (10): 1292–1301.
- Zwerts J. A., Stephenson P. J., Maisels F., Rowcliffe M., Astaras C., Jansen P. A., van der Waarde J., Sterck L. E. H. M., Verweij P. A., Bruce T., Brittain S., van Kuijk M., 2021: Methods for wildlife monitoring in tropical forests: Comparing human observations, camera traps, and passive acoustic sensors. *Conservation Science and Practice* 3 (12): e568.
-

Expected date of thesis defence

2023/24 SS – FES

The Bachelor Thesis Supervisor

Mgr. Tomáš Jůnek, Ph.D.

Supervising department

Department of Ecology

Electronic approval: 4. 3. 2024

prof. Mgr. Bohumil Mandák, Ph.D.

Head of department

Electronic approval: 18. 3. 2024

prof. RNDr. Michael Komárek, Ph.D.

Dean

Prague on 18. 03. 2024

Author's Statement

I hereby declare that I have independently elaborated the bachelor/final thesis with the topic of: Detection of Vocalizations of Different Mammal Species on Forest Clearings in The Congo and that I have cited all of the information sources that I used in the thesis as listed at the end of the thesis in the list of used information sources.

I am aware that my bachelor/final thesis is subject to Act No. 121/2000 Coll., on copyright, on rights related to copyright and on amendments of certain acts, as amended by later regulations, particularly the provisions of Section 35(3) of the act on the use of the thesis.

I am aware that by submitting the bachelor/final thesis I agree with its publication under Act No. 111/1998 Coll., on universities and on the change and amendments of certain acts, as amended, regardless of the result of its defence. With my own signature,

I also declare that the electronic version is identical to the printed version and the data stated in the thesis has been processed in relation to the GDPR.

In Prague 25.3.2024

.....

Abstract

This thesis focuses on using acoustic recording devices to survey vocally active mammal species on four different forest clearings rich in minerals, so called *bais*, in the Messok-Dja wildlife conservation area located in the Republic of Congo. One AudioMoth recording device was placed on each of the four clearings during springtime for the duration of approximately 30 days. One additional recording session on the Dibo bai took place in autumn.

The obtained audio files were sorted and labelled manually. This process found 5 instances of gunfire and 366 instances of vocal activity of animals. The vocalizations came from 4 species of mammals: mantled guerezas (*Colobus guereza*), chimpanzees (*Pan troglodytes*), western lowland gorillas (*Gorilla gorilla*), and African forest elephants (*Loxodonta africana*). The obtained data was used to create graphs comparing diel activity patterns of observed mammals. Additional data from a camera trap study concurrently conducted at the Dibo bai was used for comparison of activity patterns.

The results of this thesis can serve as a reference for future acoustic monitoring projects in Messok-Dja. The recorded vocalizations can also be used as training data for potential automation of the identification process.

Keywords:

Bioacoustics, monitoring, biodiversity

Abstrakt

Tato práce se zaměřuje na využití akustických nahrávacích zařízení k průzkumu vokálně aktivních druhů savců na čtyřech různých lesních mýtinách bohatých na minerální látky, takzvaných *bai*, v chráněné oblasti Messok-Dja nacházející se v Konžské republice. Na každou ze čtyř mýtin bylo během jara umístěno jedno nahrávací zařízení AudioMoth po dobu přibližně 30 dnů. Jedno další nahrávání na salině Dibo proběhlo také na podzim.

Získané nahrávky byly rozříděny a označeny ručně. Tímto způsobem bylo nalezeno 5 případů střelby a 366 případů zvukové aktivity zvířat. Vokalizace pocházely od 4 druhů savců: guerézy pláštíkové (*Colobus guereza*), šimpanze (*Pan troglodytes*), gorily nížinné (*Gorilla gorilla*) a slona pralesního (*Loxodonta africana*). Získaná data byla použita k vytvoření grafů porovnávajících vzorce denní aktivity pozorovaných savců. Pro srovnání vzorců aktivity byla použita další data ze studií fotopastí současně provedených na salině Dibo.

Výsledky této práce mohou sloužit jako reference pro budoucí projekty akustického monitoringu v Messok-Dja. Zaznamenané vokalizace mohou být také použity jako tréninková data pro případnou automatizaci procesu identifikace.

Klíčová slova:

Bioakustika, monitoring, biodiverzita

Contents:

1. Introduction	1
2. Objectives of the thesis	3
3. Literary research	4
3.1 Passive acoustic monitoring (PAM).....	4
3.1.1 PAM and recording devices	4
3.1.2 PAM and analysis tools	5
3.1.3 The potential of PAM.....	7
3.1.4 Comparison with other methods	8
3.1.4.1 PAM vs. transect studies	8
3.1.4.2 PAM vs. camera trapping.....	9
3.2 Mammals in the bais.....	9
3.2.1 “Bais” and their use by wildlife.....	9
3.2.2 Interspecific interactions.....	11
3.2.3 Vocalizations of the mammals	12
3.2.3.1 Mantled guereza vocalizations	12
3.2.3.2 Chimpanzee vocalizations.....	13
3.2.3.3 Western lowland gorilla vocalizations.....	14
3.2.3.4 African forest elephant vocalizations	15
4. Methodology	16
4.1 Study area	16
4.2 Data collection.....	19
4.3 Classification of vocalizations.....	20
4.4 Data analysis.....	21
5. Results	23
5.1 Sampling effort and summary.....	23

5.2 Vocalization of detected species.....	23
5.3 Diel activity pattern of vocalization	28
5.4 PAM and camera trapping.....	30
6. Discussion.....	33
7. Conclusion.....	38
8. Bibliography	40
9. List of figures	51

1. Introduction

The forests in the Congo Basin form the world's second most expansive tropical forest, which is a home to a diverse range of mammals, including many threatened species of charismatic megafauna (Carvahlo-Resende & Gerandine-Meikengang 2023). Biodiversity in the region is currently being put at risk by habitat destruction due to deforestation (Shapiro et al. 2021) and by the increasing rates of poaching of elephants and apes, among others (UNDP 2018).

Mammals play a significant part in forming the tropical forest ecosystem. Their presence is often necessary for the propagation of many species of fruit-bearing trees (Blake et al. 2009, Gautier-Hion et al. 1985). Additionally, mammals like forest elephants (*Loxodonta cyclotis*), forest buffaloes (*Syncerus caffer nanus*), sitatungas (*Tragelaphus spekei*), and western lowland gorillas (*Gorilla gorilla*) are responsible for the creation and maintenance of clearings, also known as bais. These places usually contain mineral-rich clay, which is directly consumed by dominantly herbivorous species (e.g. forest elephants, mantled guerezas (*Colobus guereza*)) – this behavior is known as geophagy. After some time, a portion of the exposed soil is grown over by vegetation rich in sodium, which serves as an important source of nutrition for other species, e.g. gorillas. (Klaus & Schmid 1998, Klaus et al. 1998, Maisels & Breuer 2015).

Bais have been shown to be regularly visited by a variety of mammals, making them valuable sites for conducting surveys (Vanleeuwe et al. 1998, Gessner et al. 2014). Monitoring at bais has already helped advance the knowledge of behavior of some elusive or cryptic species. A study by Oates (1978), which explored the importance of swampy clearings to mantled guerezas in Uganda, uncovered that intergroup interactions at bais differ from those known from arboreal habitats. The observations of western lowland gorillas made on bais in the Republic of Congo helped provide a better understanding of the size and structure of their social groups (Parnell 2002). Important findings about forest elephant social behaviors, population structures and demographic changes over time also came from a long-term monitoring study made at Dzanga Bai in Central African Republic (Turkalo et al. 2013).

Passive acoustic monitoring (PAM) is a non-invasive surveying method which could prove useful especially for studies taking place in remote and difficult-to-access areas.

Acoustic surveys are already commonly used for studying bats, birds, and anurans. They are typically used to assess presence, observe behavior, or describe activity patterns (Sugai et al. 2019). Although the usage of PAM is not as advanced when it comes to terrestrial mammals, it can still be a valuable monitoring tool. A study taking place in Ghana confirmed PAM as a viable and effective method for establishing forest elephant occupancy across a vast area of tropical forest (Thompson et al. 2009). A different study conducted in Gabon and the Republic of Congo used data obtained through PAM to calculate population density of forest elephants. The same data also allowed researchers to describe forest elephant diel activity patterns, which were previously not well known (Wrege et al. 2017).

When it comes to primates, PAM has been used to describe vocal activity patterns of Black and Gold Howler Monkeys (*Alouatta caraya*) throughout the year (Pérez-Granados & Schuchmann 2021a). It was also used to describe home ranges and territory use of chimpanzee populations in two different habitats (Kalan et al. 2016). Another study in Tanzania used PAM to establish calling rates of local chimpanzee populations (Crunchant et al. 2021), while other studies were mostly concerned with creating automated detection systems for calls from a variety of species (Heinicke et al. 2015, Kalen et al. 2015).

Given the fact that clearings with clay deposits attract a variety of large mammals and other protected species to open areas, such sites are also likely to attract poachers. However, PAM can be used to identify and monitor illegal activity and the obtained data can aid law enforcement in developing strategies against it (Wrege et al. 2017). Conservation organizations already use acoustic sensors to detect gunshot sounds in some protected areas e.g. Elephant Listening Project in the Nouabalé-Ndoki National Park in the Republic of Congo (Swider et al. 2022), or the Panthera non-government organization in the Sierra Caral National Protected Area in Honduras (Alberts 2021, Ritts et al. 2024).

Overall, PAM has proven to be useful monitoring tool with a promising future in automated detection and classification, which could be used for large-scale monitoring projects and surveys in remote regions such as the Congo basin tropical forests (Sugai et al. 2019).

2. Objectives of the thesis

The detection of instances of vocal activity by mammals in the recordings obtained with the use of AudioMoth recording devices during a pilot passive acoustic monitoring project in the Messok-Dja wildlife conservation area.

The creation of literary research containing detailed information about passive acoustic monitoring and ways in which it can be used in monitoring, the temporal calling patterns of the species recorded, their usage of the baits and any interspecific relationships which might influence their behavior.

The summary of the audio data in a contingency table, the creation of a series of graphs comparing daily vocal activity patterns between species as well as comparison of data from photo traps at the same location.

3. Literary research

3.1 Passive acoustic monitoring (PAM)

Passive acoustic monitoring (PAM) is a non-invasive method for studying wildlife with the use of microphones or recording devices. Thanks to acoustic monitoring researchers are able to gain information about the presence or abundance of acoustically active species, typically birds (Perez-Granados & Schuchmann 2021b), cetaceans (Todd et al. 2020), and insects (Mankin et al. 2011). This method is particularly useful to survey cryptic species such as forest elephants (Wrege et al 2017) and frogs (Wood et al. 2023) or nocturnal species such as bats (Walters et al. 2012). PAM also has potential when it comes to studying primates (Heinicke et al. 2015, Kalan et al. 2015).

3.1.1 PAM and recording devices

Before the development of specialized recording devices, acoustic monitoring used to be done by readily available microphones (Harris 2006). These devices were either placed by themselves or in various arrays and grids depending on the goal of the study. Different models of microphones can however record different ranges of frequencies, which influences detectability of vocalizations or even completely inhibits detection of certain sounds. Nowadays, the usage of commercial recording devices is preferred. In studies where sounds outside human hearing range (infrasound sounds in the case of some larger mammal species and ultrasonic sounds in the case of bats) are being studied it is necessary to use specialized equipment to obtain recordings (Blumstein et al. 2011).

The choice of a recording device depends heavily on whether the study is conducted in terrestrial or aquatic environments. Another important factor to consider is the sampling rate of the device whose value should be at least twice as high as the maximum frequencies produced by the species being studied. Some of the available devices are specifically designed to detect ultrasonic signals e.g. Batlogger or Anabat Swift, different devices e.g. BAR-LT are able to record ultrasonic signals and signals within the human hearing range, while others offer the ability to record the full audio spectrum. The full spectrum recording devices such as AudioMoth or SongMeter offer

the possibility to extract the highest amount of data from the recording, however, full-spectrum recordings take up significantly more memory, which can be especially challenging for long-term monitoring studies in remote areas. To partially remedy this problem, some devices offer the ability to program the recording schedule to capture only the periods of highest activity or only a certain number of minutes per hour. (Browning et al. 2017).

The costs of devices are also a deciding factor when it comes to designing a monitoring system. The prices of recorders vary significantly as some of those in the high-cost category, e.g. Anabat Swift (Wildcare) are currently listed for sale at 1090 GBP (equivalent to 1271 EUR). On the other side of the spectrum are low-cost recording devices, such as AudioMoth (LABmaker), which can be obtained for 97 USD (equivalent to 89 EUR) (Starbuck et al. 2023).

3.1.2 PAM and analytical tools

Once collected, audio data is then analyzed with the option of visualizing it in the form of a spectrogram (Gibb et al. 2018). Manual audio analysis requires human researchers to observe the recordings and tag each vocalization individually. This method is the most labor and time intensive, yet still comprises 58% of acoustic monitoring studies published (Sugai et al. 2019).

To save time and human effort, some research utilizes automated tools which use several different techniques to identify animal vocalizations within the recordings. Identification is comprised of two steps: detection, where the sound is found in the recording, and classification, where the sound is sorted into a specific category. There are multiple methods for classification in use today (Gibb et al. 2018).

Supervised classification is performed by a pattern recognition algorithm, which is trained using preexisting recordings. It first detects clusters, then compares them with existing records of animal vocalizations and lastly classifies them into desired categories (Blumstein et al. 2011, Gibb et al. 2018, Ulloa et al. 2018). Currently there are commercially available software tools such as ARBIMON, Kaleidoscope Pro, and SoundScape, which allow the users to train the detection algorithm with their own data (Aide et al. 2013, Ross et al. 2018, Machal et al. 2022). Researchers can also build their own Convolutional Neural Network, a type of supervised classification

algorithm, which has been shown to be more accurate compared to commercial software tools (Gibb et al. 2018, Marchal et al. 2022).

Supervised classification is the most limited by the necessity for a high number of high-quality variable sample recordings for training the algorithm (Heinicke et al. 2015). Additionally, several automated detection algorithms which were developed as part of various studies have been reported to be less likely to properly classify signals similar to those of other species e.g. the clicks of the bats in the *Myotis* genus (Walters et al. 2012) or the alert barks of sika deer (Enari et al. 2019). Individually variable signals like chimpanzee pant hoots are also less likely to be identified and classified correctly, as are short low-intensity signals such as the calls of Western red colobus (*Procolobus badius*), which tended to be overlooked, leading to an increased number of false positives. In environments with high background noise levels such as tropical rainforests, there is tendency for a high proportion of false positive detections which leads to unnecessary additional data that needs to be stored and analyzed (Heinicke et al. 2015).

Unsupervised classification is an alternative method, which does not require preexisting training data. Instead, it groups signals into clusters based on mutual similarity (Blumstein et al. 2011). This can be performed either by using licensed software tools such as Kaleidoscope Pro, or by using freely available R packages such as Monitor R or Warble R (Guerrero et al. 2023).

While this method alleviates the need for large amounts of pre-labelled data, it does require a big enough dataset to be meaningfully effective (Stowell & Plumbley 2014). In instances when the sample size of a specific call type is too low, these systems tend to struggle with classifying it correctly. This increases the amount of audio which needs to be recorded in order to correctly classify rare and elusive species or species living in environments with high levels of background noise (Guerrero et al. 2023).

Semi-automated methods of analysis present a compromise between full automation and manual categorization. Automated tools are used first to detect and classify individual vocalizations. Afterwards, human experts verify these classifications (Sugai et al. 2019). This method ensures higher precision while also significantly reducing the time it takes to process whole recordings. Heinicke et al. (2015) reported that an

identification algorithm they developed reduced the amount of time necessary for classification and verification by 96.5% compared to manual classification.

3.1.3 The potential of PAM

Acoustic data can be used to study various aspects of the lives of animals. It can help us better understand communication in the wild and in some cases can be used for estimating population size or observing whether applied conservation strategies are successful (Wrege et al. 2017). Currently, these topics comprise only a small proportion of the studies using PAM. The majority of studies which use PAM are concerned with daily or seasonal activity patterns, habitat usage or they compare the method's effectiveness with other surveying methods (Sugai et al. 2019).

By using a grid of acoustic sensors, researchers can record the changes in size of different populations or identify areas which are important for these populations and therefore need to be conserved the most. With an array of sensors, it is possible to study the movements of entire groups of animals. However, even a single sensor can alert to unwanted human presence on location, monitor changes in activity over time or throughout seasons, and identify which locations serve as hotspots of activity (Wrege et al. 2017).

Instead of identifying every single vocalization, some research focuses on the overall complexity of the recorded soundscape (Deichmann et al. 2017, Sethi et al. 2020). Comparing soundscapes, biodiversity and activity of indicator species recorded over a period of time can potentially provide an accurate picture of changes on the level of entire ecosystems (Blumstein et al. 2011).

Automated real-time detection and alert systems such as the Guardian (Rainforest Connection ©2024) can also aide conservation of animals in areas with high rates of poaching or illegal logging. By recording audio signals in these areas and analyzing the spatial and temporal distribution of gunshot signals within them, law enforcement is able to gain valuable data about the activity of poachers and more effectively deploy anti-poaching patrol teams to mitigate the effects of illegal hunting on the animal populations (Astaras et al. 2017). An automated real-time detection system with the ability to alert the patrol teams almost immediately after detecting the gunshot signal also significantly improves the chances of patrol teams actually getting to the

perpetrators in time. The further improvement and increased use of such systems would make the law enforcement system in vast areas of remote forest much more effective against illegal activity (Wrege et al. 2017).

3.1.4 Comparison with other monitoring methods

3.1.4.1 PAM vs. transect studies

Traditionally, the most common field monitoring techniques for large mammals actively involved human researchers performing transect studies and reconnaissance walks. This method required researchers to either count the amounts of individual animals spotted or, in the cases of more elusive species, record the signs of activity such as chimpanzee or gorilla nests, footprints, or elephant dung (Plumptre 2000, Sanz et al. 2007). Unlike automated methods, transect studies require specialists to be present on-site to collect the data which increases the costs associated with labor, transportation and resources needed to sustain teams of up to 14 researchers for the duration of the data collection (Zwerts et al. 2021). Human presence might also influence the behavior of the studied species leading to less accurate data due to the elusiveness of the animals (Marini et al. 2009).

On the other hand, initial costs of equipment for either camera traps or recording devices are much higher than initial costs associated with transect studies which require minimal specialized equipment. The possibility of technical failure of special equipment, especially in hard-to-access remote areas, or theft of these devices in areas more accessible by passers-by are some additional factors associated with higher costs of studies which also need to be considered (Zwerts et al. 2021). PAM can be used in combination with transect studies especially in instances where the detection and classification algorithms need further development to reach desired accuracy. By planning the transect studies with occupancy data obtained through PAM, resources can be better allocated to studying or patrolling only the relevant areas (Kalan et al. 2015).

3.1.4.2 PAM vs. camera trapping

Camera trapping refers to a method of monitoring wildlife when a camera with an infrared sensor is used to capture an image, a sequence of images, or video after being triggered (Rovero & Zimmermann 2016). Camera traps are generally less effective compared to acoustic sensors when it comes to monitoring arboreal species (Wrege et al. 2017). Given the fact that a camera lens has a predefined view angle, infrared sensor sensitivity does not usually exceed 20 meters, and image or video resolution is restricted both by camera sensor and memory card capacity, a range of detection of camera traps deployed in the specific study area is limited. Especially for species with loud calls, including many species of primates, a single acoustic recorder covers a much larger area for monitoring compared to camera traps. PAM also may provide additional data about the specific type of vocalization used which can be helpful when studying the behavior of a certain species (Enari et al. 2019, Wrege et al. 2017).

On the other hand, acoustic monitoring is limited only to vocally active species and in many cases does not allow for the study of population structure. Utilizing a combination of both methods could help more effectively monitor wildlife diversity and behavior, assess the effects of human activity on different species, and help better understand interspecific interactions (Buxton et al. 2018).

3.2 Vocally active mammals in the Congo basin rainforest

3.2.1 “Bais” and their use by wildlife

“Bai” is a word used by the indigenous Baka populations living in Central Africa to refer to natural clearings, also known as salines. They are usually connected to a water source and can be found in the middle of forests or savannas. Their size can vary between a couple meters to over a kilometer from one end to another. Various species of animals use these bais as a source of vegetation rich in sodium and proteins such as sedges (*Cyperaceae*) or grasses (*Graminae*). In particularly water-rich bais, highly nutritious swamp vegetation is also present. It is possible to differentiate between bais frequented mainly by forest elephants, which are usually next to rivers and tend to have more exposed soil, and bais preferred by gorillas which are usually further away

from major rivers with little to no exposed soil and higher diversity of herbs (Maisels & Breuer 2015, Vanleeuwe 1998).

Forest elephants often dig holes and caves in the bais and nearby riverbeds, exposing the soil rich in minerals such as sodium, potassium, calcium, and magnesium. They then consume the soil to supplement some nutrients, but also allow other geophagous species to take advantage of the exposed dirt (Klaus et al. 1998).

For Western lowland gorillas bais represent an important source of herbaceous vegetation rich in sodium (Magliocca & Gautier-Hion 2002, Vanleeuwe et al. 1998). One visit of the bai lasts for an average of 1 hour and 18 minutes and while they mostly enter and exit in groups, solitary visits are also not particularly rare (Magliocca et al. 1999; Parnell 2002). A study by Magliocca and Gauthier-Hion (2002) observed gorillas for a whole year and found that high visitation rates were disrupted only during a drought period in January and February which affected the availability of the vegetation and forced the gorillas to look for an alternative food source. Overall, the studied gorillas only spent about 1% of their waking hours per month in the bais. Once there, they spent about 72% of the time feeding on herbaceous plants. The rest of the time was devoted to moving around, visually surveying the area and miscellaneous behaviors. The least amount of time (0.5%) was devoted to socializing.

Chimpanzees also appear on bais (Gessner et al. 2014) although the purpose of their visits is not clearly described in literature. Some articles claim that chimpanzees do not visit forest clearings for the purpose of feeding (Breuer et al. 2021), however, in a study taking place in the Odzala-Kokoua National Park, chimpanzee groups have been observed feeding on algae found in a temporary flood pool in one of the bais (Devos et al. 2002, Tomáš Jůnek & Stanislav Lhota, 2024, pers. comm.).

Mantled guerezas are an arboreal species spending most of their lives, up to 97%, in the canopy of trees in various forest ecosystems ranging from dry forests alongside rivers to rainforest habitats (Oates 1977). They are primarily folivorous with up to 94% of their diet consisting of leaves (Harris & Chapman 2007). However, they also commonly enrich their diet with fruit, flowers, and seeds (Plumptre 2007). Mantled guerezas have been observed regularly travelling to bais to feed on water plants as well as consume exposed mineral-rich clay (Oates 1978, Vanleeuwe et al. 1998, Tomáš Jůnek & Stanislav Lhota, 2024, pers. comm.). Gessner et al. (2014) also

captured guerezas on camera traps searching for food inside the bais. They observed that these visits occurred exclusively during the daytime. A study by Oates (1978) also found that the normally territorial guerezas were often sharing the bai and feeding alongside members of multiple other troupes without any antagonistic interactions.

3.2.1 Interspecific interactions

Chimpanzees are mainly frugivorous and supplement their diet with plants and insects, but they are also known to hunt, kill and consume other mammals (Tutin & Fernandez 1993). The hunting takes place mostly during the dry season when fruit is the most abundant and when they have sufficient energy to engage in the pursuit of the prey animals (Klein et al. 2021). While their primary prey preference is the red colobus monkey (*Procolobus spp.*), mantled guerezas are also commonly hunted by them (Buigr et al. 2021, Watts & Mittani 2015, Tomáš Jůnek & Stanislav Lhota, 2024, pers. comm.). In the Kyambura Gorge in Uganda, the mere presence and activity of chimpanzees had a significant effect on the mantled guereza populations. The areas populated by chimpanzees were much less densely populated by guerezas and their group size was also smaller compared to areas outside of the chimpanzee range (Krüger et al. 1998).

Chimpanzees and gorillas across Central Africa live sympatrically and their diet contains many of the same species of herbs and trees, however, gorillas mainly rely on vegetative foods while chimpanzees mostly consume fruit. Another significant difference is that gorillas do not hunt and consume mammalian prey (Head et al. 2011; Tutin & Fernandez 1993). Most observed interactions between gorillas and chimpanzees have been peaceful, however, there have been recorded instances when adult chimpanzee males initiated group attacks and eventually killed two gorilla infants. In both situations the chimpanzees vastly outnumbered the gorillas present. In one of the cases, the body was consumed. The researchers offered two possible explanations: chimpanzees hunting infant gorillas as prey or the killing being the result of interspecific competition for food (Southern et al. 2019).

Surveys of multiple forests across Central Africa have confirmed that Western lowland gorillas and mantled guerezas occupy and utilize the same sites, but not much else is

known about their interspecific interactions (Mitani 1990, Tomáš Jůnek & Stanislav Lhota, 2024, pers. comm.).

African forest elephants play a significant role in forming the structure of the forest ecosystem and therefore indirectly influence the species which reside within it. Whether it is by dispersing the seeds of a large amount of fruiting trees (Blake et al. 2009) or disturbing the soil in the clearings and thus prohibiting the growth of trees in the bais (Klaus et al. 1998).

While forest elephants feed on many of the same species of fruiting trees as western lowland gorillas, the evidence from observations of both species suggests that they prefer to avoid one another. When groups of gorillas are approached by elephants, silverbacks perform various intimidating signals in so-called displays. On one recorded occasion (Tutin et al. 1995), the presence of elephants caused a gorilla group to abandon their nests during the night and relocate.

3.2.3 Vocalizations of selected mammals

3.2.3.1 Mantled guereza vocalizations

Mantled guerezas are known to produce five types of vocal expressions. The most characteristic and the most common one is the ‘roar’ sequence which is exclusively produced by the males leading the troop. As a distinct low-frequency sound it can be distinguished from distances as far as 1.6 km. It begins with the ‘snort’ vocalization which then revolves into on average 15 distinct compound pulses making up individual roars. These pulses are then repeated in series. Each roar has the strongest acoustic energy concentrated around 600 Hz and 1200 Hz and lasts for about 0.7 seconds. The roaring sequences are produced in various lengths and with differing numbers of pulses with some individual variation (Marler 1969).

Some research has been able to identify the differences in numbers of roars and pulses as a response to different predators threatening the mantled guerezas. The roaring sequences given as an alert about the presence of a leopard were shorter and consisted of fewer individual phrases compared to when the guerezas were alerting to the presence of a crowned eagle (Schel et al. 2010). There also appear to be slight differences in the roaring sequences serving as predator alerts and roaring sequences produced during the so-called morning choruses.

The morning choruses are a form of collective inter-group vocal communication occurring usually around 2 hours before sunrise (Schel & Zuberbühler 2012) They are initiated by one male leader of a group performing his roaring sequence and continue by other male leaders of a separate groups in turn responding with their own roaring sequences (Marler 1972). Harris (2006) has hypothesized that these choruses serve to signify the ability of the leading male to defend his group and resources to the other leaders. Another possible explanation is that the morning chorus roars are a territorial signal used to maintain spatial distances between individual groups (Marler 1969).

The three other types of vocalizations seem to be produced only by females or juveniles. The purrs are produced to coordinate movement while both caws and screams are produced in distressing situations. None of these sounds seem to be particularly common nor acoustically distinct (Marler 1972).

3.2.3.2 Chimpanzee vocalizations

Chimpanzees also regularly utilize vocal signals to communicate within their social group. There seems to be little consensus when it comes to classifying the overall vocal repertoire. While van Lawick-Goodall (1986) named as many as 32 call categories based on context and sound structure, another study described 15 pure sounds used to create 88 different sound combinations (Crockford & Boesch 2005). The simplest classification system named 7 vocalization groups with various subcategories dependent on the context: pants, hoos, grunts, barks, screams, roars, and whimpers (Crockford 2019).

One of the most characteristic forms of long-range signal for chimpanzees is the pant-hoot. This type of vocalization is used as a response to another chimpanzee's call in the distance, during inter-group meetings, or it is a signal given when a chimpanzee approaches a group. Other individuals often respond by vocalizing their own pant-hoot (van Lawick-Goodall 1968). A single pant-hoot usually lasts for 7—11 seconds and can be comprised of four distinct phrases, although not all of them are present during every single pant-hoot emittance. It begins with a series of drawn out lower-pitched calls with highest energy levels in the 300-500 Hz range. Then it continues building up in volume with a varying number of individual calls in the 200-500 Hz range. The climax is the loudest part of the calls with most energy between 1000 and 1600 Hz

(Arcadi 1996, Marler & Hobbet 1975). This portion of the pant-hoot appears to have the most variety between chimpanzees, allowing for distinction of different individuals (Mitani & Nishida 1993; Mitani et al. 1996). However, it appears to be exclusively produced by male chimpanzees. The pant-hoot finally concludes with the let-down which is in many aspects similar to the first part of the call (Arcadi 1996, Marler & Hobbet 1975).

3.2.3.3 Western lowland gorilla vocalizations

Western lowland gorillas tend to be more vocally active than chimpanzees although their calls tend to be overwhelmingly used for short-range signaling (Mitani 1996). The silverback male leaders of the pack are the ones who vocalize the most often and who utilize the highest number of vocalization types. The purpose of sound signals for Western lowland gorillas seems to be mostly communication between members of the same group over distances of several hundred meters (Harcourt et al. 1993). Gorillas' vocal repertoire has been shown to contain up to 17 different types of sound signals. Those exclusively produced by silverback males are utilized mainly while defending the group from outside threats and include vocalizations such as cough barks, roars, whinnies, sex-whinnies, and hoots in combination with chest beating. Adult and juvenile females are the only ones to produce scream vocalizations (Salmi et al. 2013). Series of hoots without the chest beating elements are produced by gorillas regardless of their sex or age during travel, foraging and while resting. Their purpose is mainly to maintain contact between members of a single group (Watts 1991). The vast majority of signals used by gorillas are various forms of grunts and grumbles which differ depending on specific context. For example, both males and females utilize the cough or cough grunt vocalization exclusively during aggressive encounters. Its acoustic energy ranges from around 100 Hz to approximately 1500 Hz and lasts less than 1 second (Salmi et al. 2013).

3.2.3.4 African forest elephant vocalizations

African forest elephants are able to communicate over large distances even in dense forest environments by producing near-infrasound signals called rumbles. Some studies claim that they carry over distances as far as 10 km under ideal conditions (Garstang 2004) while other observations claim that elephants are able to recognize these rumbles from maximum distances of 2.5 km (McComb 2002). Their primary purpose is coordinating movement between individuals. While there appears to be slight variation between calls produced in the forests and in baobabs, a single rumble lasts on average 2.98 seconds and is comprised of two main formants. The lower one has the average center frequency of 46 Hz while the center frequency of the second formant is usually around 154 Hz with a peak around 200 Hz (Hedwig et al. 2019).

Another common and characteristic vocal signal is the high-frequency trumpet sound associated with states of high excitement or distress (Witzany 2013). A single trumpet is usually about a second long with some lasting up to 3 seconds. Acoustic energy of trumpets is usually concentrated at frequencies from 428 Hz to 856 Hz with a possible peak of 8000 Hz (Berg 1983). By changing the length of the trumpet, overall intensity of the signal, or bodily posture, elephants can create a wide variety of types of trumpets. Additionally, forest elephants' vocal repertoire includes signals such as the roar, snort, rev, croak, cry, husky-cry, bark, and grunt vocalizations (Poole 2011).

4. Methodology

4.1 Study area

The data collection took place on four bays: Messok, Dibo, Golom and Ecobai, located in the Messok-Dja area in the north of the Republic of Congo. This area, which spans 144 000 ha of rainforest, is situated in the Trinational-Dja-Odzala-Minkebe (TRIDOM) area spanning across Gabon, Republic of Congo, and Cameroon.

While Messok-Dja is currently not a formally protected area, it has been excluded from logging concessions to serve as a wildlife conservation area and is located to the south of the Nki National Park in Cameroon and to the north of the Odzala-Kokoua National Park in the Congo. Its strategic position as a potential bio corridor was part of the reason why the United Nations Development Programme (UNDP) drafted a plan for TRIDOM II whose aims were, among others, to turn Messok-Dja into a national park to help conserve the natural conditions and prevent biodiversity loss in the region.

Poaching was identified as one of the major contributors to the loss of wildlife biodiversity in the region. With an increased accessibility of automatic firearms, poachers began targeting larger mammals such as forest elephants and gorillas along with an increase in the hunting of more traditional targets such as duikers, porcupines, and monkeys, causing noticeable declines in population.

Habitat degradation was identified as another major threat to biodiversity in the region. This is done mainly by the establishment of oil palm plantations fragments the land and shrinks the habitats of many large mammals for whom the conditions of the oil palm monocultures are inhospitable. Another significant threat to the rainforest habitat comes from unsuitable logging practices and overexploitation of the land (UNDP ©2018).

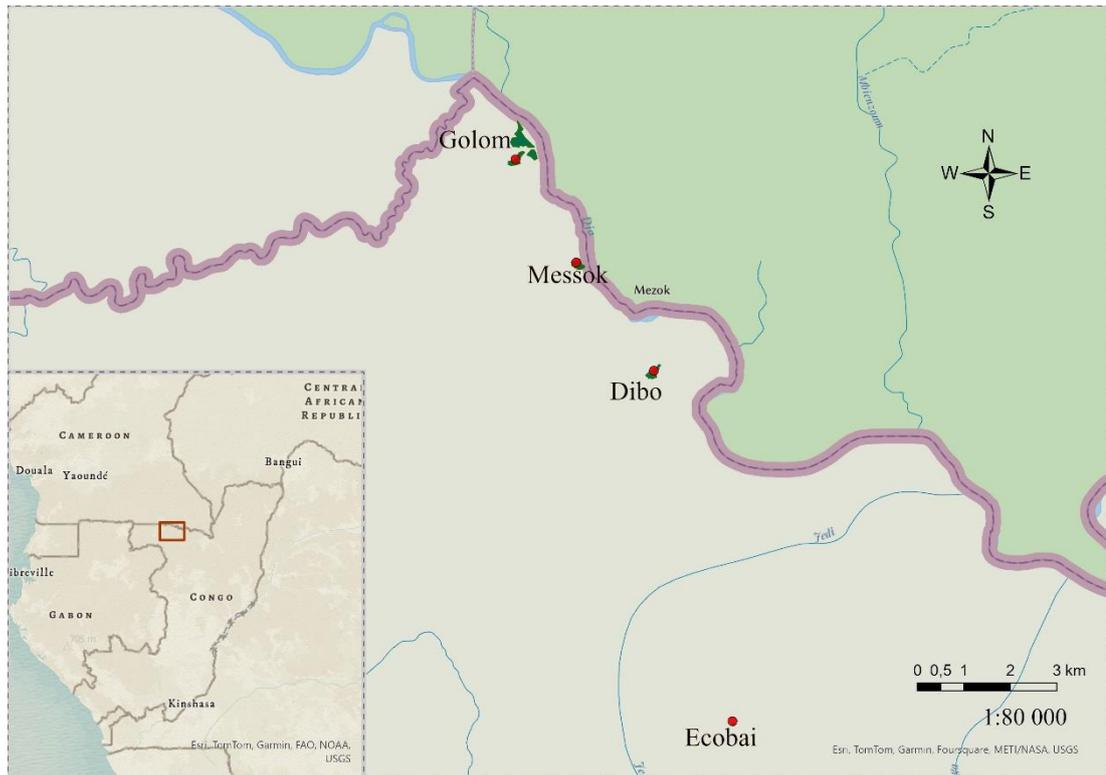


Figure 1: The location of the bays in Messok-Dja which were monitored during the study (Created in ArcGIS Pro).

The Golom bay complex is the largest of the studied areas and comprises of three clearings in close proximity which are separated by a strip of rainforest. All three of the clearings are irregularly shaped and amount to a total area of 163 172 m². Its surface is covered dominantly with grassy savanna with visibility across the majority of its area. It is also at the highest elevation of roughly 375 m above sea level. The respective lengths of the individual clearings are: 675 m, 435 m, and 228m, and their widths are: 518 m, 190 m, and 189 m. The edges of the bays are approximately 200 m away from the Dja river which also forms the border between the Republic of Congo and Cameroon. Golom is also the most distant from human settlements as it is 29 km north-west of the nearest village of Kinshasa.

The Messok bay is the third largest of the salines, taking up 34 410 m². It is located between the Dibo and Golom bays, the distance between them being 2 670 m and 2 370 m respectively. Its surface is covered mostly by grassy savanna. Visibility is good across its whole area. It is the bay which is the closest to the river Dja, being only 68 m away. It has an overall symmetrical shape with rough edges spiking out into the

rainforest. The clearing is 150 m wide with an elevation of 362 m above sea level. It is 26 km away from Kinshasa village.

The Dibo bai is set more deeply in the rainforest as it is 1035 m away from the river. It is 380 m long and 230 m wide with an area of 45 379 m² and an elevation of 373 meters above sea level. It is marshy with remnants of trees and bushes and good visibility across one half of its surface. The clearing has a rough triangular shape with a patch of forest dividing the saline at the widest point. The closest human settlement to the Dibo bai is Kinshasa village, which is 24 km away.

Ecobai is the most remote of the clearings as it is 7 700 m away from Dibo. It is also the bai furthest away from the Dja river, roughly 6 650 m, and it is the smallest of the bais with an area equal to 1886 m². It is covered with a mixture of grass, bushes, and flowering plants of the *Zingiberaceae* family. Visibility is good across the majority of its area. The bai is the closest to human settlements, being 17.5 km away from Ngbala village and 27.5 km away from Kinshasa village. In total it is 55 m long and 31 m wide with an elevation of 410 m above sea level (Fig.1).

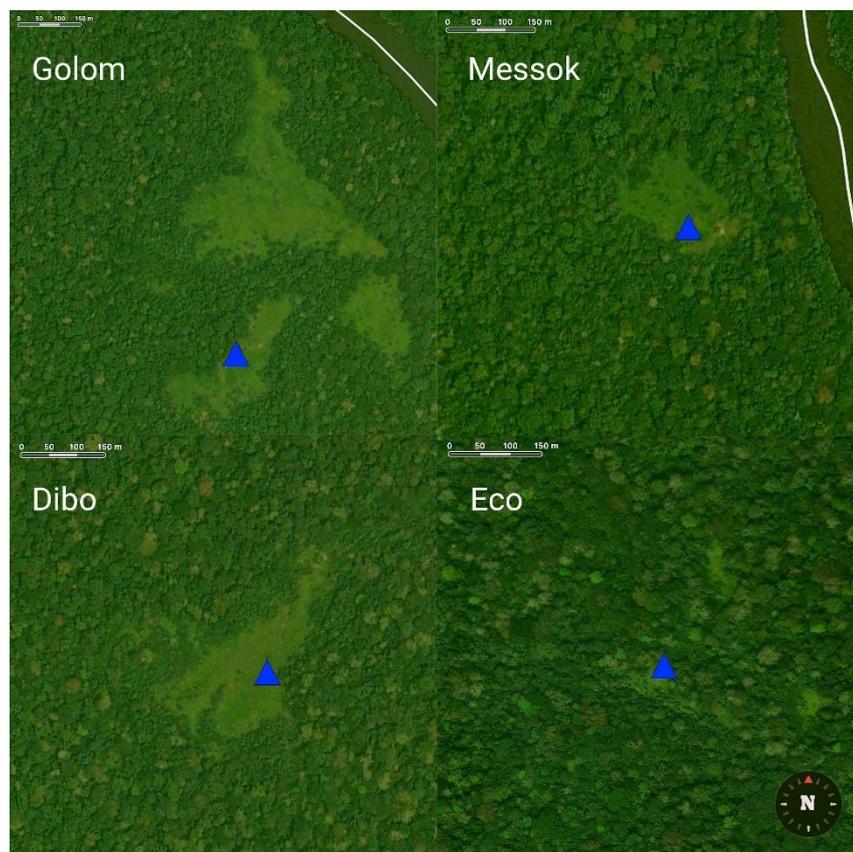


Figure 2.: Aerial images of the bais in Messok-Dja, blue triangle represents the placement of the recording device.

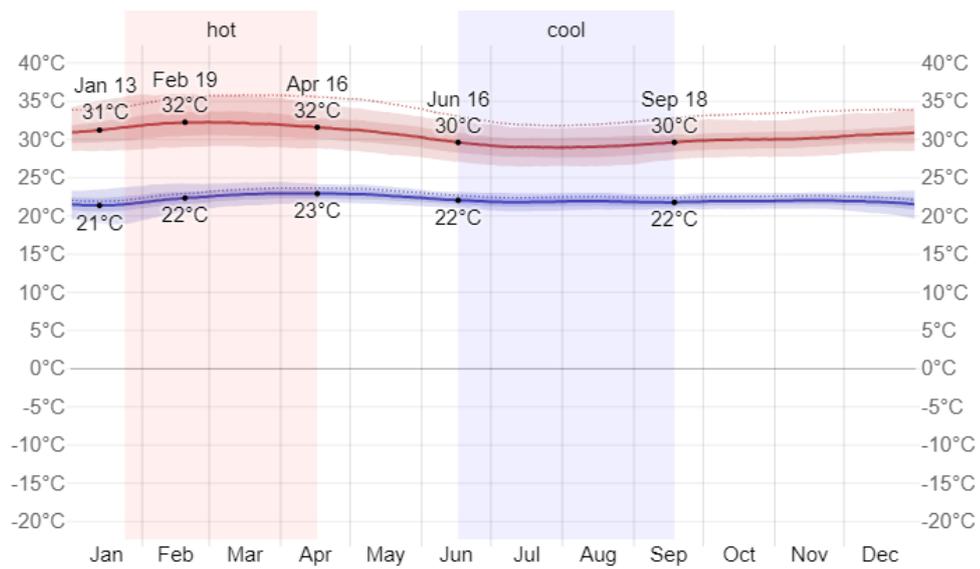


Figure 3: Average highest and lowest daily temperatures in Ouesso, Republic of Congo (Cedar Lake Ventures, Inc. © 2024).

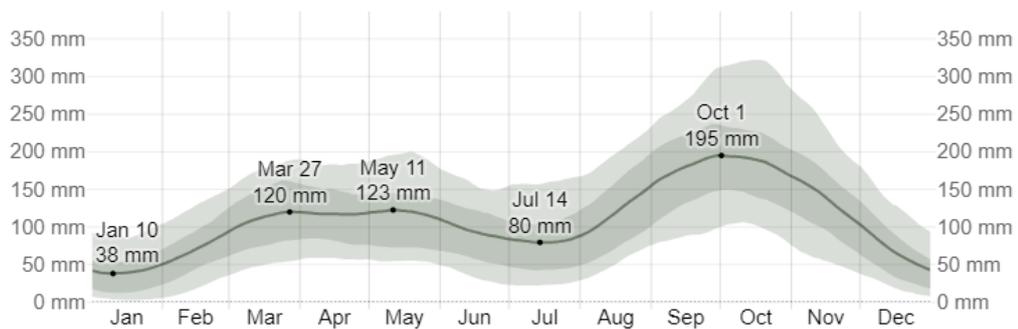


Figure 4: Average monthly rainfall in Ouesso, Republic of Congo (Cedar Lake Ventures, Inc. © 2024).

Data from the nearest meteorological station at Ouesso show that the spring recording period at Messok-Dja coincided with a period of the highest annual average temperatures and moderate rainfall, while the autumn recordings occurred during a colder period with a considerably higher rainfall (Fig. 3, Fig.4).

4.2 Data collection

One AudioMoth (Version 1.2.0.) recording device was used for each of the studied bais. Recording devices were placed by the thesis supervisor or an assistant in the height of 2-5m on branches of trees as close to the center of the bai and with as little surrounding vegetation as possible. This was done with the intention of avoiding

additional background noise. Wherever possible, the trees chosen for placing the recording devices were non-fruiting ones as to not attract primates (Fig.2).

Recording devices were set to record and pause in alternating 15-minute segments for the duration of the whole day, i.e. each hour only the 0:00-0:15 and 0:30-0:45 segments were recorded. The sampling rate was set to the lowest available 8 kHz to allow for the detection of low frequency elephant calls. The collected data was stored on SD cards in a .wav format.

Recording devices were left running until the AA lithium battery ran out. The total number of hours recorded thus varied between study sites: for Messok (AM1) recording took place between 28.02.2022 at 15:30 and 23.03.2022 at 15:30; for Dibo (AM2) recording took place between 28.02.2022 at 10:41 and 23.03.2022 at 03:00; for Ecobai (AM3) recording took place between 27.02.2022 at 10:22 and 23.03.2022 at 23:30; for Golom (AM4) recording took place between 27.02.2022 at 10:00 and 28.03.2022 at 11:00; and lastly for Dibo (AM5) in the autumn period recording took place between 24.08.2022 at 17:30 and 14.09.2022 at 16:30.

In total, twenty-three camera traps were deployed across the Dibo bai as well as in its vicinity to monitor various species at every potential source of minerals found (Fig.5). Spromise Tetrao S308 camera traps were used. These were equipped with a 940nm infrared flash which was triggered by passing animals or humans. Camera traps were operating for the duration of 24 hours a day with minimal delay between two shutter releases and in a 3-image multishot mode.

4.3 Classification of vocalizations

All recordings were reviewed manually. The Raven Lite (version 2.0.5) software was used to first generate and display the spectrograms and waveforms of each audio file. Segments of each recording that were identified as mammal vocalizations or gunshot sounds were then annotated with the name of the animal or as a gunshot.

Due to the lack of identification manuals containing a systematic overview of mammal vocal expressions, various studies classifying and describing the vocalizations were used as a reference instead. For gorillas, the classification and description of 17 various signals by Salmi et. al. (2013) was used as a reference; for mantled guerezas it was the

descriptions, spectrograms and classification categories provided by Mitani (1972); the spectrograms, descriptions and vocal categories from the study conducted by Crockford and Boesch (2005) served as a reference for identifying chimpanzee vocal expressions; and the descriptions and spectrograms by Poole (2011) served as a reference for forest elephant vocalizations.

In the case that one audio file contained multiple occurrences of the same type of vocal expression only those with a period of silence between sound emissions no longer than five seconds were considered as one vocalization.

4.4 Data analysis

Due to differing numbers of recorded hours between devices, we decided to weight the results with the sampling effort to generate a metric we called the Acoustic Index. To obtain the indices, each total number of calls or gunshots was divided by the number of hours recorded by the device and multiplied by 100, similarly to the Relative Abundance Index metric used for camera trapping reports (O'Brien 2011).

Due to insufficient data, the only comparison of daily activity patterns between different bays was done for Dibo (spring 2022) and Messok where mantled guereza daily call patterns were analyzed. The Dibo bay was the only study site with audio recordings from both spring and autumn 2022. Again, due to insufficient data for other species, only mantled guereza vocalizations were compared between seasons.

Dibo was also a site of a camera trapping experiment which overlapped with the time of AudioMoth placement on the site (Jůnek & Lhota 2024). Only those camera trapping records, separated by 1 hour to ensure independence of detection events, which were obtained during the same period as the audio recordings were then used for further analysis. The daily vocal activity patterns of mantled guerezas, chimpanzees, and western lowland gorillas in the Dibo bay (spring) were compared with sightings of these species on camera traps throughout the day.

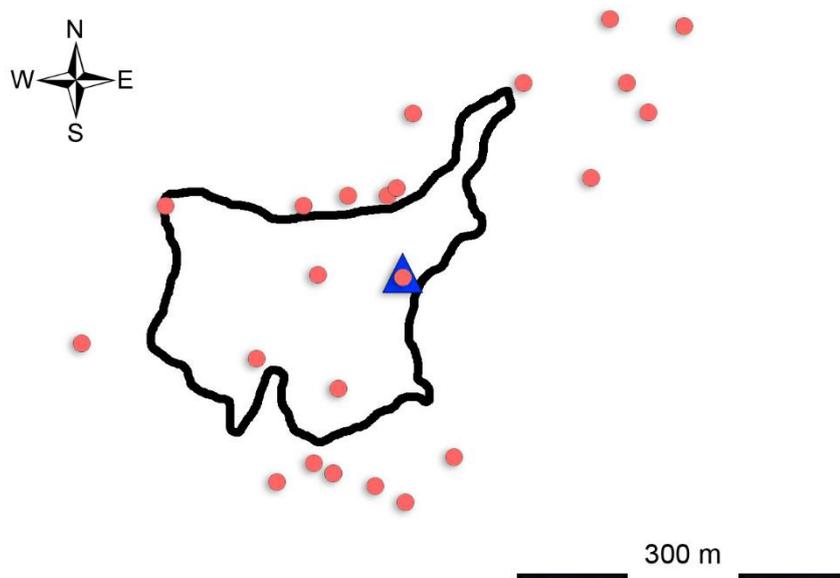


Figure 5: Scheme of camera trap placement (red dots) on and around the Dibo bai. The blue triangle represents the placement of the AudioMoth (Jůnek & Lhota 2024).

The graphs comparing the daily activity patterns were created in the R Statistical Software version 4.2.2 (R Core Team 2022) using the overlap package version 0.3.9 (Meredith et al. 2024). Overlap coefficient and standard error was calculated for each of the pairs.

5. Results

5.1. Sampling effort and summary

Altogether we have accumulated 1442 hours of acoustic recordings with 276 hours recorded at the Messok bai; 272 hours were recorded at the Dibo bai in the spring period; 282 hours were recorded at Ecobai; 348.5 hours were recorded at the Golom bays; and 263.5 hours were recorded at the Dibo bai in the autumn period.

Four mammal species as well as gunshot sounds were identified throughout the whole recording period (Table 1). Detected number of vocalizing species different among bays, three species of primates were recorded on Dibo and Ecobai, two primate species on Messok and none on Golom bays, where, on the contrary, we only detected forest elephants.

Table 1: Acoustic Indices of particular species with the total number of vocalizations in each category in brackets. Instances of gunshot sounds given in total numbers.

Species	Recording device					Grand Total
	AM1 Messok	AM2 Dibo	AM3 Ecobai	AM4 Golom	AM5 Dibo	
<i>Loxodonta africana</i>	-	-	-	2,01 (7)	-	2,01 (7)
<i>Gorilla gorilla</i>	-	10,29 (28)	0,71 (2)	-	2,28 (6)	13,28 (36)
<i>Colobus guereza</i>	42,39 (117)	31,99 (87)	4,26 (12)	-	16,70 (44)	95,33 (260)
<i>Pan troglodytes</i>	3,26 (9)	8,09 (22)	4,96 (14)	-	6,83 (18)	23,14 (63)
Grand Total	45,65 (126)	50,37 (137)	9,93 (28)	2,01 (7)	25,81 (68)	133,76 (366)
<i>Gunshot</i>	-	1	1	-	3	5

The overall highest number of calls came from the Dibo bai with 50.37 calls per 100 hours coming from all mammals except the forest elephant. On the contrary, on Golom bays we have detected only seven instances of forest elephant vocalizations.

5.2 Vocalization of detected species

Overall, mantled guereza was the most vocal species of mammal recorded. Their vocalizations were heard on all study sites except on the Golom bai. However, over 78% of their calls were observed on just two of the study sites: the Messok bai and the Dibo bai in spring. Out of all known types of calls, we were only able to identify the roar call in all of 260 recorded instances of vocalizing. A typical roar had its frequency concentrated in two bands with the highest concentrations of acoustic

energy at around 700 Hz and 1200 Hz. One roar lasted for approximately 0.3 seconds (Fig. 6).

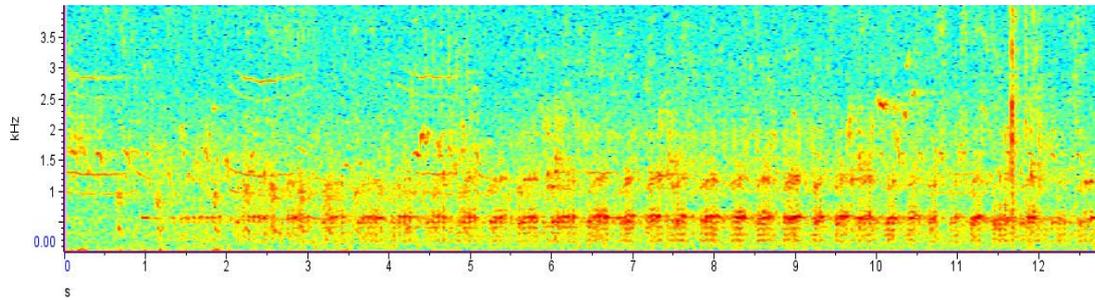


Figure 6: Spectrogram of a mantled guereza roaring sequence detected in recordings from Messok-Dja

The observed vocal expressions of the second most vocally active animal, chimpanzees came from all study sites except the Golom bai. The vocalizations were more evenly distributed among the study sites, however the recordings from the Dibo bai both in spring and in autumn contained 63% of calls. We were able to identify 2 types of known chimpanzee calls. Out of 63 total calls, 45 calls were pant-hoots, and 18 calls were screams.

A typical pant-hoot sequence lasted for about 15 seconds. It consisted of multiple phases with frequencies ranging from 300 Hz to 4000 Hz (Fig. 7).

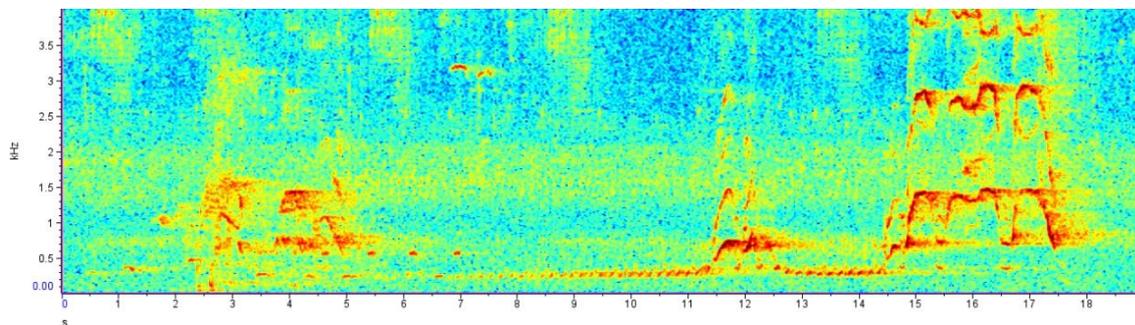


Figure 7: Spectrogram of a chimpanzee pant-hoot vocalization detected in recordings from Messok-Dja.

A typical scream vocalization was similar to the most intense part of the pant-hoot sequence, also reaching 4000 Hz. A single scream call lasted for approximately 1 second (Fig. 8).

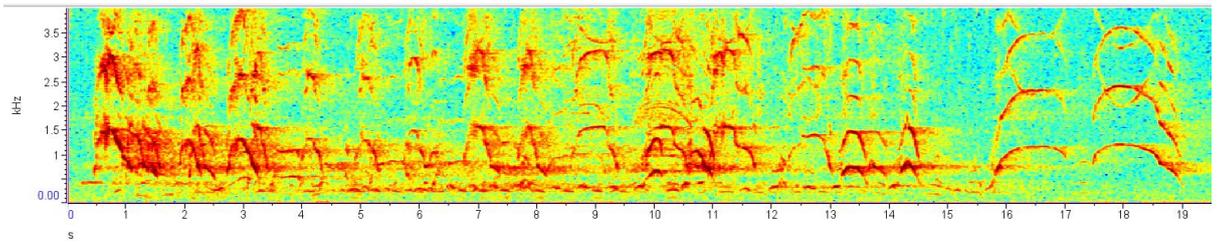


Figure 8: Spectrogram of a chimpanzee scream vocalization detected in the recordings from Messok-Dja.

Western lowland gorilla vocal expressions were observed on only three out of the five study sites. Over 77% of all gorilla calls came solely from the Dibo bai in the spring period. The second highest number of calls was also heard from Dibo in the autumn period. We were able to identify 2 types of known gorilla calls. Out of 36 total calls, 32 were cough grunts and 3 were single calls and 1 instance of hoot series vocalizations was recorded.

Cough grunt vocalizations recorded in gorillas reached frequencies around 1500 Hz and lasted for approximately 0.2 seconds (Fig. 9).

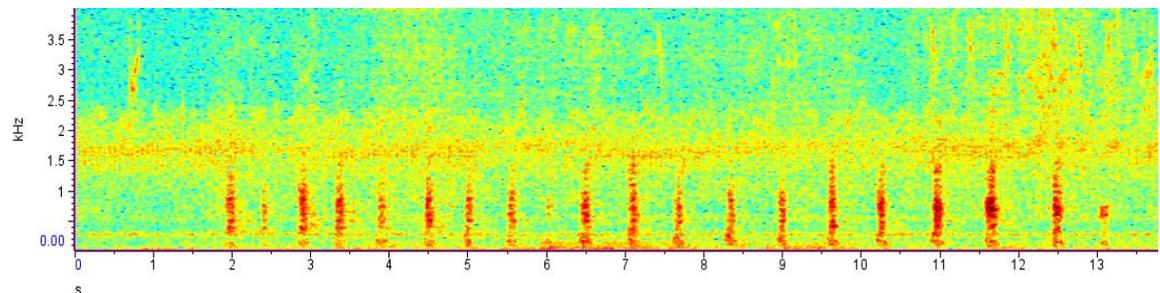


Figure 9: Spectrogram of repeated gorilla cough grunts detected in the recordings from Messok-Dja.

The single calls also reached frequencies around 1500 Hz and lasted for around 0.3 seconds (Fig. 10).

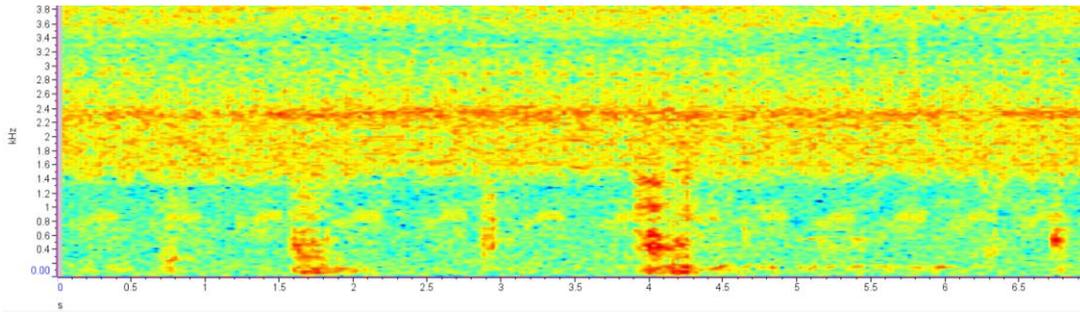


Figure 10: Spectrogram of repeated gorilla single calls detected in the recordings from Messok-Dja.

A typical hoot series was made up of individual calls lasting for around 0.1 seconds, with most acoustic energy concentrated in two bands: at around 300 Hz and in the 600-1000 Hz range (Fig. 11).

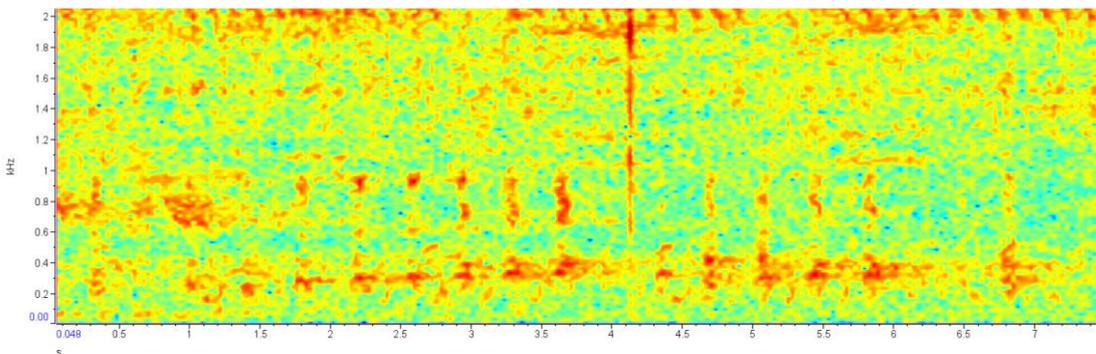


Figure 11: Spectrogram of a hoot series vocalization detected in the recordings from Messok-Dja.

African forest elephant vocalizations were observed solely on the Golom bai. We were able to 2 types of known elephant calls. Out of 7 total calls, 3 were rumbles and 4 were trumpets.

A typical rumble lasted for approximately 3.5 seconds, with most energy in the 110-160 Hz (Fig. 12).

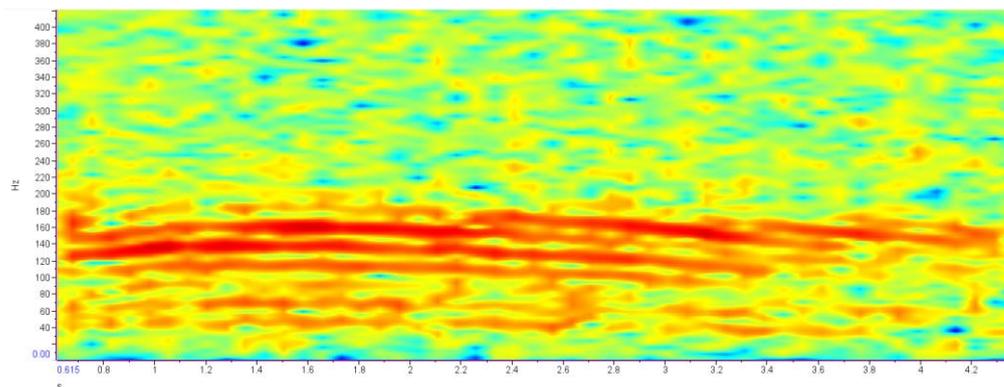


Figure 12: Spectrogram of an elephant rumble detected in the recordings from Messok-Dja.

A single trumpet lasted for approximately 2 seconds. It reached frequencies of 4000 Hz, with the majority of the acoustic energy in the 1500-3000 Hz range (Fig. 13).

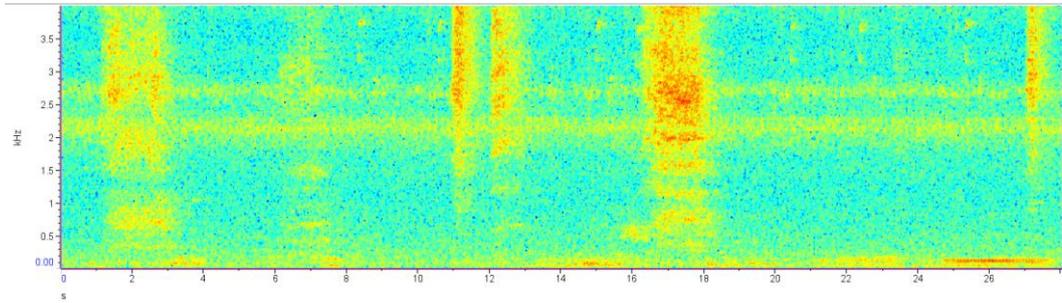


Figure 13: Spectrogram of multiple elephant trumpet vocalizations detected in the recordings from Messok-Dja.

Gunshot sounds were heard on the recordings from 3 out of the 5 study sites. The Dibo bai in autumn was the only one of the sites where gunshot sounds were recorded more than once.

A typically prominent sound of gunfire reached initial frequencies of 4000 Hz and the subsequent echo then continued to gradually decrease in intensity for approximately 2.5 seconds (Fig. 14).

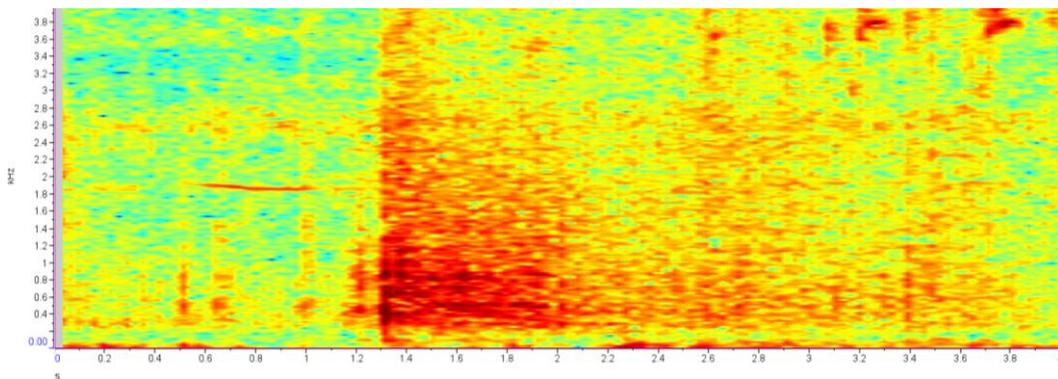


Figure 14: Spectrogram of a gunshot sound detected in the recordings from Messok-Dja.

5.3 Diel activity pattern of vocalization

Mantled guereza groups on the Dibo bai were heard vocalizing mainly during the night and early morning with a peak in activity at around 6:00 (Fig. 15).

The daily activity patterns of guerezas at Dibo and calling patterns of guerezas at Messok had the highest overlap out of all the comparison (Table 2). The main difference is that on Messok there were two peaks in vocal activity: the first one at around 20:00 and the second, slightly larger one, around 4:00. (Fig. 15).

During the autumn, the mantled guerezas on the Dibo bai were the most vocally active during the second half of the night, similarly to spring. However, in contrast to spring, they displayed a noticeable peak in vocal activity between 12:00 and 15:00 as well as during morning hours. The main peak in autumn occurred at around 2:00 (Fig. 16).

The chimpanzees at the Dibo bai had their most significant peak of vocal activity at around 0:00 which coincided with the period of high calling rates of the mantled guerezas on the same location, their second activity peak at around 13:00 happened at a time when no mantled guereza vocalizations were recorded (Fig. 17). This pair had the lowest overlap out of the three comparisons of vocal activity.

Table 2: Overlap and standard error values calculations for each of the compared pairs.

Comparison subjects	Overlap	Standard error
Guereza Dibo vs Guereza Messok	0,7241	0,014
Guereza Dibo Spring vs Guereza Dibo Autumn	0,6414	0,045
Guereza Dibo Sping vs Chimpanzee Dibo Spring	0,5551	0,016

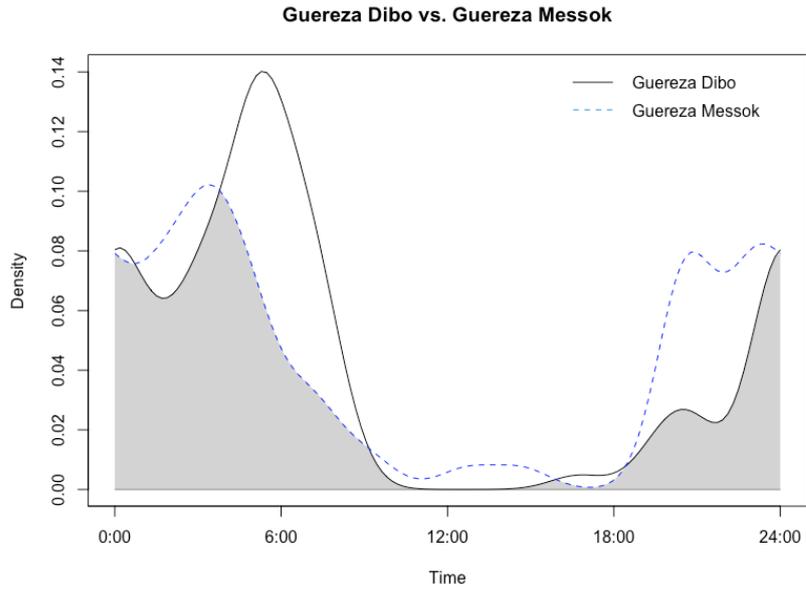


Figure 15: Comparison of daily vocal activity patterns of mantled guerezas between the Dibo bai in spring (n = 87) and the Messok bai (n = 117).

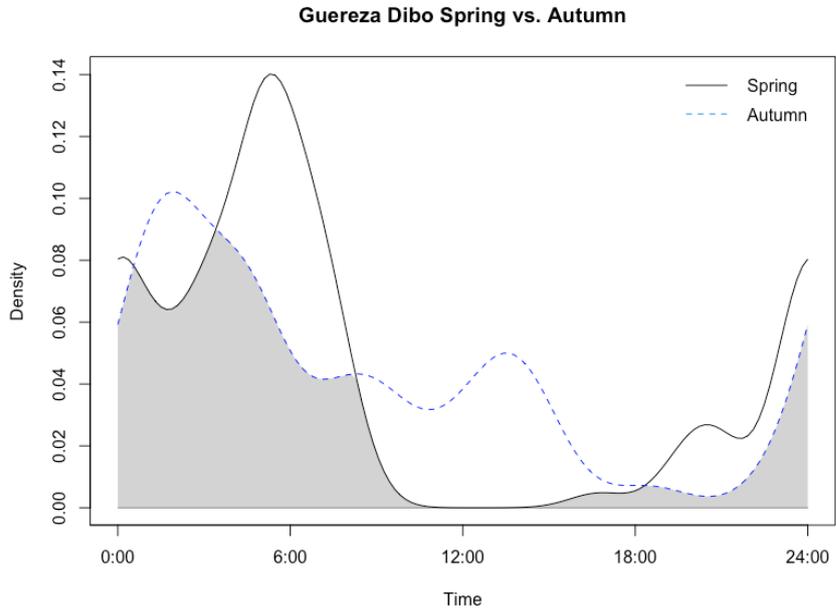


Figure 16: Comparison of mantled guereza daily vocal activity patterns at the Dibo bai between the spring (n = 87) and the autumn period (n = 44).

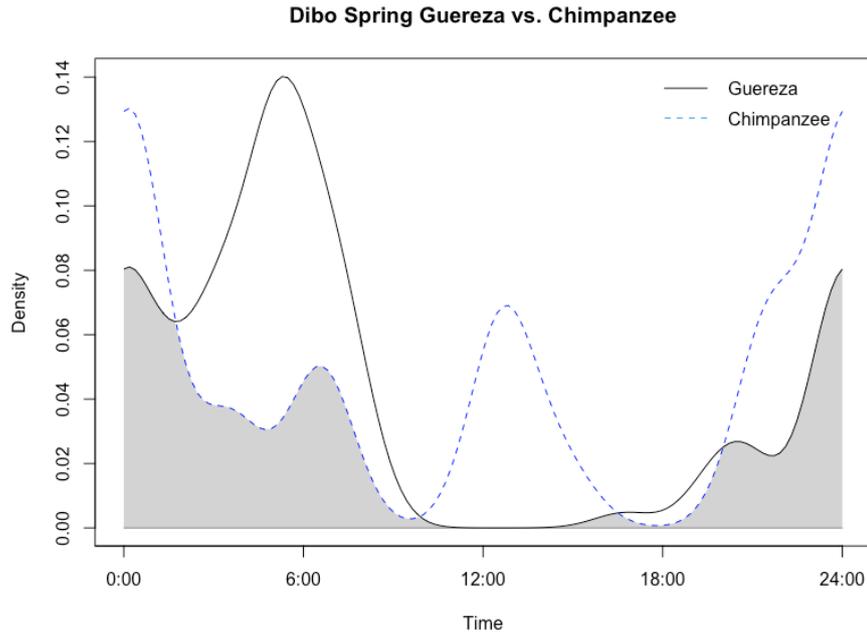


Figure 17: Daily vocal activity patterns of chimpanzees (n = 22) and mantled guerezas (n = 87) on the Dibo bai in spring.

5.4 PAM and camera trapping

The comparison of mantled guereza presence on the Dibo bai throughout the day from camera trapping with the records of their daily calling patterns had the lowest overlap of all the comparisons (Table 4). All the guereza captures by cameras occurred between 8:00 and 19:00 with two noticeable peaks at 11:00 and 15:00, which is a time period when they were not vocally active at all (Fig. 18).

The vocal activity of chimpanzees had the highest overlap out of all the comparisons with camera sightings. Both vocal activity and camera trap sightings had two distinct peaks: the vocal expressions were the most abundant at around 20:00 and 1:00 while the camera sightings peaked slightly at around 9:00 and then peaked more significantly at 15:00 (Fig. 19).

Gorillas were the species captured the camera traps the highest number of times in both seasons (Table 3) They were observed the most often at around 8:00. The second highest number of sightings happened between 13:00 and 14:00 which coincided with

the second highest peak in their vocal activity. However, most gorilla calls occurred during the nighttime when no camera trap sightings were recorded (Fig. 20).

Table 3: Total numbers of independent events of detections of particular species captured by camera traps on the Dibo bai.

Species	Spring	Autumn	Total
<i>Gorilla gorilla</i>	54	66	120
<i>Colobus guereza</i>	31	16	47
<i>Pan troglodytes</i>	27	35	62
Total	112	117	229

Table 4: Overlap and standard error calculations for each of the compared pairs.

Comparison subjects	Overlap	Standard error
Guereza Dibo Spring photo vs audio	0,02	0,03
Chimpanzee Dibo Spring photo vs audio	0,3542	0,01
Gorilla Dibo Spring photo vs audio	0,0919	0,03

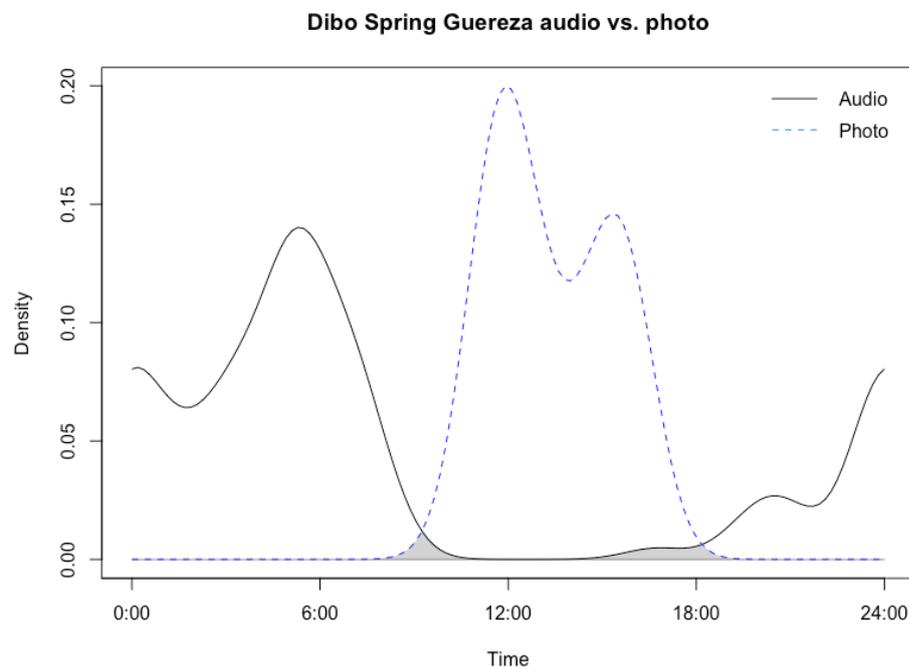


Figure 18: Daily vocal patterns of Mantled guerezas (n = 87) and sightings by camera traps (n = 31) during the spring at the Dibo bai.

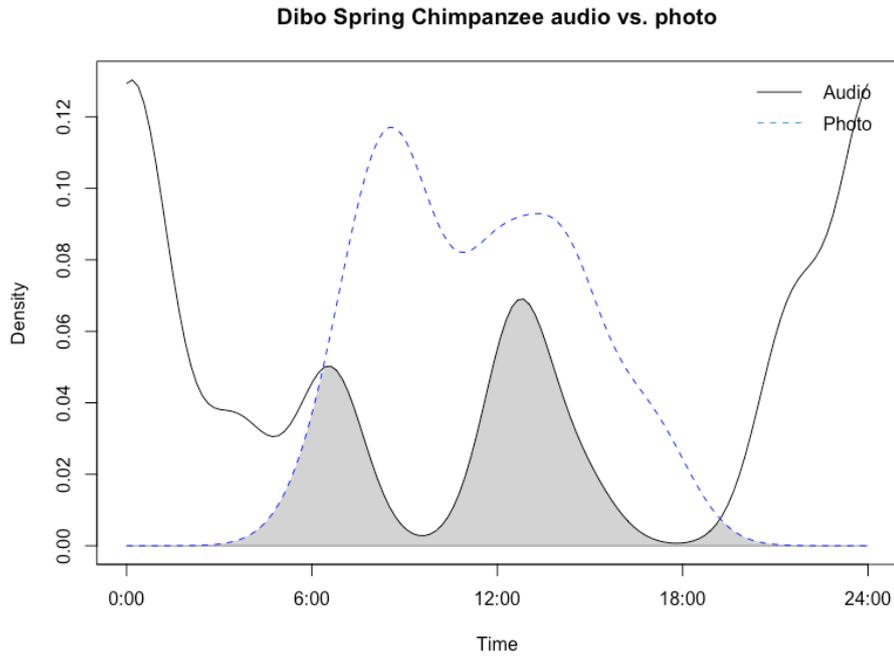


Figure 19: Daily vocal patterns of chimpanzees (n = 22) and sightings by camera traps (n = 27) during the spring at the Dibo bai.

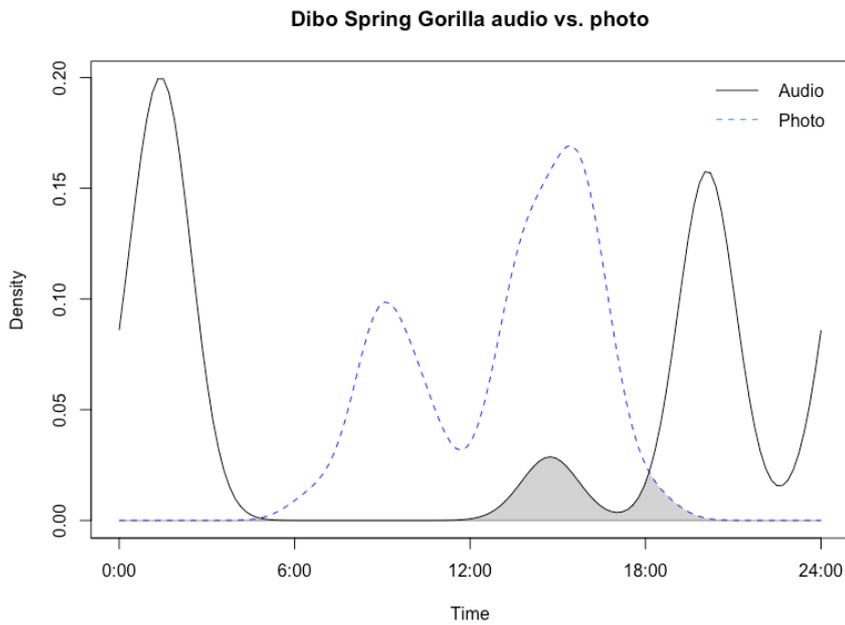


Figure 20: Daily vocal patterns of western lowland gorillas (n = 28) and sightings by camera traps (n = 54) during the spring at the Dibo bai.

6. Discussion

This thesis focuses on vocally active mammals known to utilize bais in Messok-Dja and their diel vocal activity patterns. The species identified in the recordings from the four study sites are consistent with surveys of other bais throughout Central Africa (Vanleeuwe et al. 1998, Gessner et al. 2014). However, the numbers of vocalizations recorded differed between sites, which might be a result of a variety of factors such as environment, location, and the presence of other species.

Mantled guerezas were by far the most vocally active species in Messok-Dja. The high number of recorded instances of vocalizing is likely due to their regular morning choruses, since the peaks of vocal activity on both Dibo and Messok occurred at the times when these choruses typically happen (Schel & Zuberbühler 2012). The vocal activity recorded throughout the night is also consistent with findings made by Marler (1969).

The comparison of vocal activity of guerezas in spring and autumn at the Dibo bai has shown a considerable overlap of 66% between the seasons. The number of instances when guerezas vocalized was, however, considerably lower during the autumn period. There was less vocal activity during the expected dawn chorusing hours, however, their vocal activity during the day was noticeably higher with a peak at around 13:30. One possible explanation for this is the influence of the weather. Schel and Zuberbühler (2012) established that guerezas do not engage in morning chorusing behavior after cold and rainy nights. While no meteorological measurements were conducted on the location, the data from Ouessou shows that the August-September period is on average colder and experiences more precipitation compared to the spring recording period. However, this only explains the lower rates of dawn chorusing, not the overall change in the calling pattern.

The increase in guereza vocal activity during daytime hours in the autumn period might at least partially be explained by the presence of predators. Guerezas only visit bais during the day, which is also when they are the most visible and therefore vulnerable to predation (Gessner et al. 2014). The environment of the bai is much more exposed compared to the canopy of the trees where they spend the majority of their time. This means that they do not need to rely on vocal signals to communicate on bais. Producing the signals would also potentially unnecessarily alert predators to their

presence. However, when they register that a predator is nearby, they warn the other members of their group using the roaring vocal signal (Schel et al. 2010). This possible explanation is also supported by the higher number of sightings of chimpanzees during the autumn period, as chimpanzees are known to pose a predation threat to guerezas (Buigr et al. 2021, Watts & Mittani 2015).

The diel pattern of chimpanzee vocal activity closely matched the observations of calling habits made by Zamma (2014). This study also found that while they are not usually physically active after dusk, they are known to regularly vocalize throughout the whole night due to a variety of reasons such as predator alerts or maintaining contact with others, which is consistent with the high number of calls depicted at night on Dibo. It was expected that chimpanzee presence might affect the behavior of the guerezas, as we reported the higher vocal activity of guerezas in autumn when chimpanzees were detected more often compared to spring. Especially considering that higher densities of chimpanzee groups have been shown to negatively correlate with the presence and population density of guereza groups (Krüger et al. 1998). Given the considerable overlap between diel activity, consistency with typical calling patterns of both species, as well as similarities between calling behavior at Dibo and Messok, where a lower number of chimpanzee vocalizations were recorded, it appears that chimpanzee vocal activity does not seem to influence guereza diel calling patterns. However, it is still possible that the guereza troupes avoided the location when chimpanzees were present, considering that guerezas are known to change their nesting location almost daily (Von Hippel 1998).

In the case of gorillas, a lack of acoustic data or the low numbers of recorded vocalizations do not automatically mean the lack of their presence on the bais. Western lowland gorillas seem to communicate mainly using quieter, short-range signals, which are more difficult to record compared to long-range signals (Mitani 1996). The fact that they only dedicate a minimum of their time at bais to social activity might also explain the low numbers of recordings (Magliocca & Gauthier-Hion 2002).

The data from camera traps at the Dibo bai confirmed the presence of the primate species recorded through PAM. The difference in the number of sightings of mantled guerezas between seasons is consistent with the acoustic data and might be explained by the changes in available food sources, as both the number of vocalizations and the number of detections by camera traps resulted in a roughly 50% decrease from spring

to autumn unlike in the case of chimpanzees and gorillas where no such relation is apparent. A study by Plumptre (2006) observed the seasonal changes in diets of mantled guerezas and found that during February and March (corresponding to the spring recording period at Dibo) they consume a much higher proportion of leafy greens compared to August and September (corresponding to the autumn recording period at Dibo) when they substitute the greens for various fruits. This suggests that in this period the time they might have spent searching for edible plants at the clearings is dedicated to searching for fruit-bearing trees in the forest, lowering the number of sightings at the bais.

The minimal overlap between the data from camera traps and the vocal recordings in the case of mantled guerezas might also be caused by the avoidance of predators. As previously mentioned, guerezas only appear on bais during the daytime (Gessner et al. 2014). While they are there, they might want to avoid producing unnecessary noise, making it unlikely to detect their presence on the saline with an acoustic recording device. Once they return to the arboreal environment with dense vegetation, vocal communication is not only safer, but possibly necessary to coordinate between groups (Marler 1972).

The overlap of acoustic and camera trap data for chimpanzees was more pronounced at 35%. Given that chimpanzees communicate using many intense long-distance signals, their calls are more likely to be recorded even from a distance (Mitani & Nishida 1993). Chimpanzees are known to retrieve back to the locations on the edges of the forest around dusk to build nests in the trees where they spend the night, which explains the absence of sightings at bais throughout the night (van Lawick-Goodall 1968). At same time, the proximity of their nests to the bais allows for the detection of their vocal signals even during nighttime.

The overlap between acoustic data and data from camera traps in the case of western lowland gorillas was minimal. This species is known to come to bais to look for food throughout the day and to retrieve back to the forest in the evenings to find their preferred spots and construct a nest (Tutin et al. 1995). Though gorillas do not devote much time to social activity while on bais, it is known that in the forest they use vocal signals and chest beating to communicate with members of their group which is consistent with the high rates of vocal signaling after dusk (Remis 1993).

While the presence of forest elephants as well as their usage of bais has been documented across Central Africa (Fishlock & Lee 2013, Goldenberg et al. 2021), this acoustic survey in Messok-Dja recorded forest elephant vocal activity only on the Golom bai in low numbers. The location of most of the bais in close proximity to the river more closely resembles the description of bais frequented by elephants, suggesting that their presence should be expected in the area (Maisels & Breuer 2015). Jůnek & Lhota (2024, pers. comm.) report from Golom bai at least four large elephant boulevards and four frequently used mineral licks, which were 10 times larger than any others known in Messok-Dja. Elephant dung in all the varying stages of decomposition (from fresh to rotten) found by the mineral licks also indicated the constant presence of elephants. Hence, it was expected that elephants would be detected in audio recordings mainly on Golom.

It is possible that the lack of other recorded mammals on Golom is due to the placement of the AudioMoth device in the center of one of the smaller sections of the bai complex and close to a mineral lick frequently used by elephants. Golom is by far the largest of the clearings and it is the only one which is divided into multiple sections. Therefore, it is possible that, given that the AudioMoth recording device was placed on a bush only 1 m above the ground, the sound from the smaller sections was being muffled by the surrounding vegetation and insect sounds, and the vocal activity of mammals was not recorded properly. Given the size of the Golom complex and its open savanna-like character, many animals might prefer to feed on the edges of the bais instead of venturing into the center, where they can be more exposed to predators. Therefore, it is preferable that more acoustic sensors are used to monitor the Golom bais, which would help capture the vocalizations of mammals such as mantled guerezas who are known to frequently visit this location (Tomáš Jůnek & Stanislav Lhota, 2024, pers.comm.).

Aside from Golom, a comparatively low number of vocalizations was also recorded at Ecobai. It is likely that due to its isolated location, small size, and therefore a lower amount of vegetation available for consumption, it is not an attractive enough site for the primates and elephants. Out of all the studied sites, Ecobai is also the closest to humans, being 17.5 kilometers away from the Ngbala village. The proximity to human settlements has been shown to be a factor in the abundance of monkeys and apes in areas of Central Africa where the locals regularly hunt for sustenance (Koerner et al.

2017). Population densities for primates tend to increase with distance further from villages while the locations near the village have the lowest densities. Therefore, the proximity to the Ngbala village might also play a role in the low number of vocalizations recorded.

While the findings of the monitoring at Messok-Dja, which have been reported to WWF and currently in the stage of a manuscript (Jůnek & Lhota 2024), suggest the link between weather, seasonal fruit availability, interspecific interactions, as well as the character of the bai to play a role in the presence and vocal activity of the mammals, it is important to point out that these results only summarize a month-long recording period, which is not sufficient to provide conclusive results. More data from the sites gathered over a longer period of time is necessary in order to better understand how these factors influence the studied mammals, as well as to provide a more accurate description of their diel activity patterns and ways in which they change throughout the year. To prolong the recording period, future plans of the project include the placement of multiple devices, which would alternate in recording, in order to bypass the limitations of the battery life.

7. Conclusion

This thesis has provided a review of passive acoustic monitoring and its current usage including the identification and analysis methods, recording devices, and automated analytical tools. It has also described the specific habitat of bais (forest clearings rich in minerals), which is utilized by a wide variety of species. Further, it has focused on four vocally active species of mammals: mantled guerezas, chimpanzees, gorillas, and forest elephants, who are known to visit the bais in the Congo Basin, including our study site called Messok-Dja located in the republic of Congo. This thesis presents the first passive acoustic monitoring data ever for this site. This thesis has also described the way in which the named species utilize the bais, their interspecific interactions, as well as the vocal expressions they use to communicate.

A manual analysis of the recorded audio obtained from five recording sessions by AudioMoth recording devices conducted in Messok-Dja proved both the presence of the four mammal species in the monitored area and the suitability of the equipment used. Additionally, five instances of gunfire also confirmed the existence of illegal hunting activity in the area.

The graphs representing diel vocal activity patterns of the primate species showed that a significant portion of vocal activity for these species occurs throughout the night, which was also confirmed by the fewest instances of sightings on camera traps in the same period. This suggests that both methods should be used in unison to gain information about the behavioral patterns of these species.

This thesis has proven that the PAM is especially suitable for studying vocalizations of mantled guerezas. Since they are mostly arboreal and reside in the canopy of the trees, studying them using camera traps or personally observing them is challenging. Their morning choruses convey information about numbers of groups present, and therefore can be used to obtain information about population size. The consistency between the number of camera trap sightings and the number of vocalizations recorded further proves the viability of PAM as a monitoring tool for mantled guerezas.

Diel activity patterns of mantled guerezas were found to differ only slightly between sites, and in different seasons. Given the existence of these variations, a monitoring project comparing more locations could show whether these variations are in any way

related to environmental factors or to the presence of predators such as chimpanzees whose increased appearance at the bais led to an increase in guereza vocalizations during the day. A documentation of vocal behavior throughout the whole year would also provide important information about the way mantled guereza presence and vocal activity changes with the seasons.

The findings from bais with less vocal activity recorded can also be helpful for adjusting future monitoring. The data from Ecobai shows that the studied species are less likely to utilize smaller, more isolated bais, while the case of Golom has shown that too low of a placement of a recording device is likely to hinder its ability to properly capture mammal vocalizations due to high levels of ambient noise.

In order to track changes and seasonality of mammals on these bais, the study duration would have to be at least as long as the camera trap study, which is going to produce large amounts of acoustic data. Therefore, serious consideration should be given to automating the detection and identification part of the analysis with the use of a variety of existing methods. This has been shown to significantly reduce the time and labor required for processing the data, and therefore could have a considerable impact on the efficiency of further monitoring and analyses.

8. Bibliography

Scientific publications:

Aide T.M., Corrada-Bravo C., Campos-Cerqueira M., Milan C., Vega G., Alvarez, R., 2013: Real-time bioacoustics monitoring and automated species identification. PeerJ 1: e103.

Arcadi A.C., 1996: Phrase structure of wild chimpanzee pant hoots: patterns of production and interpopulation variability. *American Journal of Primatology* 39: 159-178.

Astaras C., Linder J., Wrege P., Orume R., Macdonald D., 2017: Passive acoustic monitoring as a law enforcement tool for Afrotropical rainforests. *Frontiers in Ecology and the Environment* 15 (5): 233–234.

Berg J.K., 1983: Vocalizations and associated behaviors of the African elephant (*Loxodonta africana*) in captivity. *Zeitschrift für Tierpsychologie* 63 (1): 63-79.

Blake S., Deem S.L., Mossimbo E., Maisels F., Walsh, P., 2009: Forest elephants: tree planters of the Congo. *Biotropica* 41 (4): 459-468.

Blumstein D.T., Mennill D.J., Clemins P., Girod L., Yao K., Patricelli G., Deppe J.L., Krakauer A.H., Clark C., Cortopassi K.A., Hanser S.F., 2011: Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. *Journal of Applied Ecology* 48 (3): 758-767.

Breuer T., Breuer-Ndoundou Hockemba M., Strindberg S., 2021: Factors influencing density and distribution of great ape nests in the absence of human activities. *International Journal of Primatology* 42 (4): 640-665.

Browning E., Gibb R., Glover-Kapfer P., Jones K.E., 2017: Passive acoustic monitoring in ecology and conservation. WWF-UK, Woking, 76 pp.

- Bugir C.K., Butynski T.M., Hayward M.W., 2021: Prey preferences of the chimpanzee (*Pan troglodytes*). *Ecology and Evolution* 11 (12): 7138-7146.
- Buxton R. T., Lendrum P. E., Crooks K. R., Wittemyer G., 2018: Pairing camera traps and acoustic recorders to monitor the ecological impact of human disturbance. *Global Ecology and conservation* 16: e00493.
- Carvalho Resende T., Geradine Meikengang A., 2023: Regional cooperation for the conservation of biodiversity in the Congo Basin forests: Feedback on actions carried out in the TRIODOM-TNS landscapes. In: Houehounha D., Moukala E. (eds.): *Managing Transnational UNESCO World Heritage Sites in Africa*. Springer Nature, Cham: 135-146.
- Crockford C., Boesch C., 2005: Call combinations in wild chimpanzees. *Behaviour* 142 (4): 397-421.
- Crockford C., 2019: Why does the chimpanzee vocal repertoire remain poorly understood? and what can be done about it. In: Boesch C., Wittig R. (eds.): *The chimpanzees of the Taï forest: 40 years of research*. Cambridge University Press, Cambridge: 394-409.
- Crunchant A.S., Stewart F.A., Piel, A.K., 2021: Vocal communication in wild chimpanzees: a call rate study. *PeerJ* 9: e12326.
- Deichmann J.L., Hernández-Serna A., Campos-Cerqueira M., Aide T.M., 2017: Soundscape analysis and acoustic monitoring document impacts of natural gas exploration on biodiversity in a tropical forest. *Ecological Indicators* 74: 39-48.
- Devos C., Gatti S., Levréo F., 2002: <Note> New record of algae feeding and scooping by *Pan t. troglodytes* at Lokoué Bai in Odzala National Park, Republic of Congo. *Pan Africa News* 9 (2): 19-21.

Enari H., Enari H.S., Okuda K., Maruyama T., Okuda K.N., 2019: An evaluation of the efficiency of passive acoustic monitoring in detecting deer and primates in comparison with camera traps. *Ecological Indicators* 98: 753-762.

Fishlock V., Lee P.C., 2013: Forest elephants: fission–fusion and social arenas. *Animal Behaviour* 85 (2): 357-363.

Garstang M., 2004: Long-distance, low-frequency elephant communication. *Journal of Comparative Physiology A* 190: 791-805.

Gautier-Hion A., Duplantier J.M., Quris R., Feer F., Sourd C., Decoux J.P., Dubost G., Emmons L., Erard C., Hecketsweiler P., Mounrazi A., 1985: Fruit characters as a basis of fruit choice and seed dispersal in a tropical forest vertebrate community. *Oecologia* 65: 324-337.

Gessner J., Buchwald R., Wittemyer G., 2014: Assessing species occurrence and species-specific use patterns of baies (forest clearings) in Central Africa with camera traps. *African Journal of Ecology* 52 (1): 59-68.

Goldenberg S.Z., Turkalo A.K., Wrege P.H., Hedwig D., Wittemyer, G., 2021: Entry and aggregation at a Central African bai reveal social patterns in the elusive forest elephant *Loxodonta cyclotis*. *Animal Behaviour* 171: 77-85.

Gibb R., Browning E., Glover-Kapfer P., Jones K. E., 2019: Emerging opportunities and challenges for passive acoustics in ecological assessment and monitoring. *Methods in Ecology and Evolution* 10 (2): 169-185.

Guerrero M.J., Bedoya C.L., López J.D., Daza J.M., Isaza, C., 2023: Acoustic animal identification using unsupervised learning. *Methods in Ecology and Evolution* 14 (3): 1500-1514.

Harcourt A.H., Stewart K.J., Hauser M., 1993. Functions of wild gorilla 'close' calls. I. Repertoire, context, and interspecific comparison. *Behaviour* 124 (1-2): 89-122.

Harris T. R., 2006: Within- and Among-Male Variation in Roaring by Black and White Colobus Monkeys (*Colobus Guereza*): What Does It Reveal about Function?. Behaviour 143 (2): 197–218.

Harris T.R., Chapman C.A., 2007: Variation in diet and ranging of black and white colobus monkeys in Kibale National Park, Uganda. Primates 48: 208-221.

Head J.S., Boesch C., Makaga L., Robbins M.M., 2011: Sympatric chimpanzees (*Pan troglodytes troglodytes*) and gorillas (*Gorilla gorilla gorilla*) in Loango National Park, Gabon: dietary composition, seasonality, and intersite comparisons. International Journal of Primatology 32: 755-775.

Hedwig D., Verahrami A.K., Wrege, P.H., 2019: Acoustic structure of forest elephant rumbles: a test of the ambiguity reduction hypothesis. Animal Cognition 22: 1115-1128.

Heinicke S., Kalan A.K., Wagner O.J.J., Mundry R., Lukashevich H., Kühl H.S., 2015: Assessing the performance of a semi-automated acoustic monitoring system for primates. Methods in Ecology and Evolution 6: 753-763.

Jůnek T., Lhota S., 2024: Wildlife monitoring in the Messok-Dja, Congo. [Manuscript in preparation].

Kalan A.K., Mundry R., Wagner O.J., Heinicke S., Boesch C., Kühl H.S., 2015: Towards the automated detection and occupancy estimation of primates using passive acoustic monitoring. Ecological Indicators 54: 217-226.

Kalan A.K., Piel A.K., Mundry R., Wittig R.M., Boesch C., Kühl, H.S., 2016: Passive acoustic monitoring reveals group ranging and territory use: a case study of wild chimpanzees (*Pan troglodytes*). Frontiers in Zoology 13 (1): 1-11.

Koerner S.E., Poulsen J.R., Blanchard E.J., Okouyi J., Clark C.J., 2017: Vertebrate community composition and diversity declines along a defaunation gradient radiating from rural villages in Gabon. Journal of Applied Ecology 54 (3): 805-814.

Klaus, G., Schmid, B., 1998: Geophagy at natural licks and mammal ecology: a review. *Mammalia*, 62 (4): 482-498

Klaus G., Klaus-Hügi C., Schmid B., 1998: Geophagy by large mammals at natural licks in the rain forest of the Dzanga National Park, Central African Republic. *Journal of Tropical Ecology* 14 (6): 829-839.

Klein H., Bocksberger G., Baas P., Bunel S., Théleste E., Pika S., Deschner T., 2021: Hunting of mammals by central chimpanzees (*Pan troglodytes troglodytes*) in the Loango National Park, Gabon. *Primates* 62: 267-278.

Krüger O., Affeldt E., Brackmann M., Milhahn K., 1998: Group Size and Composition of *Colobus guereza* in Kyambura Gorge, Southwest Uganda, in Relation to Chimpanzee Activity. *International Journal of Primatology* 19: 287–297.

Magliocca F., Querouil S., Gautier-Hion A., 1999: Population structure and group composition of western lowland gorillas in North-Western Republic of Congo. *American Journal of Primatology* 48: 1-14.

Magliocca F., Gautier-Hion A., 2002: Mineral content as a basis for food selection by western lowland gorillas in a forest clearing. *American Journal of Primatology* 57 (2): 67-77.

Maisels F., Breuer T., 2015: What is a bai?. In: Fishlock V., Breuer T. (eds.): *Studying Forest Elephants*. Neuer Sportverlag, Stuttgart: 13-14.

Mankin R.W., Hagstrum D.W., Smith M.T., Roda A.L., Kairo M.T., 2011: Perspective and promise: a century of insect acoustic detection and monitoring. *American Entomologist* 57 (1): 30-44.

Marchal J., Fabianek F., Aubry, Y., 2022: Software performance for the automated identification of bird vocalisations: the case of two closely related species. *Bioacoustics* 31 (4): 397-413.

- Marini F., Franzetti B., Calabrese A., Cappellini S., Focardi S., 2009; Response to human presence during nocturnal line transect surveys in fallow deer (*Dama dama*) and wild boar (*Sus scrofa*). *European Journal of Wildlife Research* 55: 107-115.
- Marler P., 1969: *Colobus guereza*: Territoriality and Group Composition. *Science* 163: 93-95.
- Marler P., 1972: Vocalizations of East African Monkeys II: Black and White *Colobus*. *Behaviour* 42 (3-4): 175-197.
- Marler P., Hobbett L., 1975: Individuality in a Long-Range Vocalization of Wild Chimpanzees. *Zeitschrift für Tierpsychologie* 38 (1): 97-109.
- Mitani M., 1990: A Note on the Present Situation of the Primate Fauna Found from South-eastern Cameroon to Northern Congo. *Primates* 31 (4): 625-634.
- Mitani J. C., Nishida T., 1993: Contexts and social correlates of long-distance calling by male chimpanzees. *Animal Behaviour* 45 (4): 735-746.
- Mitani J. C., Gros-Louis J., Macedonia J.M., 1996: Selection for acoustic individuality within the vocal repertoire of wild chimpanzees. *International Journal of Primatology* 17: 569–583.
- Mitani J. C., 1996: Comparative studies of African ape vocal behavior. In: McGrew W. C., Marchant L. F., Nishida T. (eds.): *Great Ape Societies*. Cambridge University Press, Cambridge: 241-254.
- O'Brien T., 2011: Abundance, Density and Relative Abundance: A Conceptual Framework. In: O'Connell A.F., Nichols J.D., Karanth K.U. (eds.): *Camera traps in animal ecology: methods and analyses*. Springer, New York: 71-96.
- Oates J. F., 1977: The guereza and man: how man has affected the distribution and abundance of *Colobus guereza* and other black colobus monkeys. In: H. S. H. Prince

Rainier of Monaco, Bourne G. H. (eds.): Primate Conservation. Academic Press, New York: 419-467.

Oates J. F., 1978: Water-plant and soil consumption by guereza monkeys (*Colobus guereza*): a relationship with minerals and toxins in the diet?. *Biotropica* 10 (4): 241-253.

Parnell R.J., 2002: Group size and structure in western lowland gorillas (*Gorilla gorilla gorilla*) at Mbeli Bai, Republic of Congo. *American Journal of Primatology* 56: 193-206.

Pérez-Granados, C., Schuchmann, K.L., 2021a. Passive acoustic monitoring of the diel and annual vocal behavior of the Black and Gold Howler Monkey. *American Journal of Primatology* 83 (3): e23241.

Pérez-Granados C., Schuchmann K.L., 2021b: Passive acoustic monitoring of Chaco Chachalaca (*Ortalis canicollis*) over a year: vocal activity pattern and monitoring recommendations. *Tropical Conservation Science* 14: 19400829211058295.

Plumptre A. J., 2000: Monitoring mammal populations with line transect techniques in African forests. *Journal of Applied Ecology* 37 (2): 356-368.

Plumptre A. J., 2006: The diets, preferences, and overlap of the primate community in the Budongo Forest Reserve, Uganda: effects of logging on primate diets. In: Newton-Fisher N. E., Notman H., Paterson J. D., Reynolds V. (eds.): *Primates of western Uganda*. Springer, New York: 345-371.

Poole J.H., 2011: Behavioral contexts of elephant acoustic communication. In: Moss C. J., Croze H., Phyllis C.L. (eds.): *The Amboseli elephants: a long-term perspective on a long-lived mammal*. The University of Chicago, Chicago: 125-161.

Remis M.J., 1993: Nesting behavior of lowland gorillas in the Dzanga-Sangha Reserve, Central African Republic: Implications for population estimates and understandings of group dynamics. *Tropics* 2 (4): 245-255.

- Ritts M., Simla, T., Gabrys, J., 2024: The environmentality of digital acoustic monitoring: Emerging formations of spatial power in forests. *Political Geography* 110: 103074.
- Ross S.R.J., Friedman N.R., Dudley K.L., Yoshimura M., Yoshida T., Economo E.P., 2018: Listening to ecosystems: data-rich acoustic monitoring through landscape-scale sensor networks. *Ecological Research* 33: 135-147.
- Rovero F., Zimmermann F., 2016: Camera trapping for wildlife research. Pelagic Publishing Ltd., Exeter, 11 pp.
- Salmi R., Hammerschmidt K., Doran-Sheehy D.M., 2013: Western Gorilla Vocal Repertoire and Contextual Use of Vocalizations. *Ethology* 119 (10): 831-847.
- Sanz C., Morgan D., Strindberg S., Onononga, J.R., 2007: Distinguishing between the nests of sympatric chimpanzees and gorillas. *Journal of Applied Ecology* 44 (2): 263-272.
- Sethi S.S., Jones N.S., Fulcher B.D., Picinali L., Clink D.J., Klinck H., Orme C.D.L., Wrege P.H., Ewers R.M., 2020: Characterizing soundscapes across diverse ecosystems using a universal acoustic feature set. *Proceedings of the National Academy of Sciences* 117 (29): 17 049-17 055.
- Schel A.M., Candiotti A., Zuberbühler K., 2010: Predator-detering alarm call sequences in Guereza colobus monkeys are meaningful to conspecifics. *Animal Behaviour* 80 (5): 799-808.
- Schel A.M., Zuberbühler K., 2012a: Dawn chorusing in guereza colobus monkeys. *Behavioral Ecology and Sociobiology* 66: 361–373.
- Southern L.M., Deschner T., Pika S., 2021: Lethal coalitionary attacks of chimpanzees (*Pan troglodytes troglodytes*) on gorillas (*Gorilla gorilla gorilla*) in the wild. *Scientific reports* 11 (1): 14673.

- Starbuck C.A., DeSchepper L.M., Hoggatt M.L., O’Keefe, J.M., 2023: Tradeoffs in sound quality and cost for passive acoustic devices. *Bioacoustics* 33 (1): 1-16.
- Stowell D., Plumbley M.D., 2014: Automatic large-scale classification of bird sounds is strongly improved by unsupervised feature learning. *PeerJ* 2: e488.
- Sugai L.S.M., Silva T.S.F., Ribeiro Jr J.W., Llusia D., 2019: Terrestrial passive acoustic monitoring: review and perspectives. *BioScience* 69 (1): 15-25.
- Swider C.R., Gemelli C.F., Wrege P.H., Parks S.E., 2022: Passive acoustic monitoring reveals behavioural response of African forest elephants to gunfire events. *African Journal of Ecology* 60 (4): 882-894.
- Thompson M.E., Schwager S.J., Payne, K.B., 2010: Heard but not seen: an acoustic survey of the African forest elephant population at Kakum Conservation Area, Ghana. *African Journal of Ecology* 48 (1): 224-231.
- Todd N.R., Cronin M., Luck C., Bennison A., Jessopp M., Kavanagh A.S., 2020: Using passive acoustic monitoring to investigate the occurrence of cetaceans in a protected marine area in northwest Ireland. *Estuarine, Coastal and Shelf Science* 232: 106 509.
- Turkalo A.K., Wrege P.H., Wittemyer, G., 2013: Long-term monitoring of Dzanga Bai forest elephants: forest clearing use patterns. *PloS one* 8 (12): e85154.
- Tutin C.E., Fernandez M., 1993: Composition of the diet of chimpanzees and comparisons with that of sympatric lowland gorillas in the Lopé Reserve, Gabon. *American journal of Primatology* 30 (3): 195-211.
- Tutin C.E., Parnell R.J., White L.J., Fernandez M., 1995. Nest building by lowland gorillas in the Lopé Reserve, Gabon: environmental influences and implications for censusing. *International Journal of Primatology* 16: 53-76.

UNDP, 2017: Integrated and Transboundary Conservation of Biodiversity in the Basins of the Republic of Congo. United Nations Development Programme, 76 pp., “unpublished”.

van Lawick-Goodall J., 1968: The Behaviour of Free-living Chimpanzees in the Gombe Stream Reserve. *Animal behaviour monographs* 1: 161-IN12,

Vanleeuwe H., Cajani S., Gautier-Hion A., 1998: Large mammals at forest clearings in the Odzala National Park, Congo. *Revue d'Ecologie, Terre et Vie* 53 (2): 171-180.

Von Hippel F.A., 1998: Use of sleeping trees by black and white colobus monkeys (*Colobus guereza*) in the Kakamega Forest, Kenya. *American Journal of Primatology* 45 (3): 281-290.

Walters C.L., Freeman R., Collen A., Dietz C., Brock Fenton M., Jones G., Obrist M.K., Puechmaille S. J., Sattler T., Siemers B.M., Parsons S., 2012: A continental-scale tool for acoustic identification of European bats. *Journal of Applied Ecology* 49 (5): 1064-1074.

Watts D. P., 1991: Mountain gorilla reproduction and sexual behavior. *American journal of Primatology* 24 (3-4): 211-225.

Watts D.P., Mitani J.C., 2015: Hunting and Prey Switching by Chimpanzees (*Pan troglodytes schweinfurthii*) at Ngogo. *International Journal of Primatology* 36: 728-748.

Witzany G., 2013: African and Asian Elephant Vocal Communication: A Cross-Species Comparison. In: Witzany G. (ed.) 2013: *Biocommunication of Animals*, Springer, Dodrecht, Netherlands, 21-39.

Wood C.M., Kahl S., Barnes S., Van Horne R., Brown C., 2023: Passive acoustic surveys and the BirdNET algorithm reveal detailed spatiotemporal variation in the vocal activity of two anurans. *Bioacoustics* 32 (5): 532-543.

Wrege P.H., Rowland E.D., Keen S., Shiu Y., 2017: Acoustic monitoring for conservation in tropical forests: examples from forest elephants. *Methods in Ecology and Evolution* 8 (10): 1292–1301.

Zamma K., 2014. What makes wild chimpanzees wake up at night?. *Primates* 55 (1): 51-57.

Zwerts J.A., Stephenson P.J., Maisels F., Rowcliffe M., Astaras C., Jansen P.A., van der Waarde J., Sterck L.E.H.M., Verweij P.A., Bruce T., Brittain S., van Kuijk M., 2021: Methods for wildlife monitoring in tropical forests: Comparing human observations, camera traps, and passive acoustic sensors. *Conservation Science and Practice* 3 (12): e568.

Internet sources:

Alberts E.C., 2021: Electronic ears listen to poachers in a key Central American jaguar habitat. (on-line) [cit. 2021.03.14], available at <https://news.mongabay.com/2021/02/electronic-ears-spy-on-poachers-in-a-key-central-american-jaguar-habitat/>.

Rainforest Connection, ©2024: Guardian Platform. (on-line) [cit. 2024.02.29], available at <https://rfcx.org/guardian>.

Other sources:

Meredith M., Ridout M., Campbell L.A., 2024: overlap: Estimates of Coefficient of Overlapping for Animal Activity Patterns. R package version 0.3.9, <https://CRAN.R-project.org/package=overlap>.

R Core Team, 2022: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

9. List of figures

Figure 1: The location of the bays in Messok-Dja which were monitored during the study (Created in ArcGIS Pro).

Figure 2: Aerial images of the bays in Messok-Dja, blue triangle represents the placement of the recording device.

Figure 3: Average highest and lowest daily temperatures in Ouessou, Republic of Congo (Cedar Lake Ventures, Inc.: Climate and average weather year round at Ouessou. (on-line) [cit. 2024.03.21], available at <<https://weatherspark.com/y/150010/Average-Weather-at-Ouessou-Congo---Brazzaville-Year-Round>>).

Figure 4: Average monthly rainfall in Ouessou, Republic of Congo (Cedar Lake Ventures, Inc.: Climate and average weather year round at Ouessou. (on-line) [cit. 2024.03.21], available at < <https://weatherspark.com/y/150010/Average-Weather-at-Ouessou-Congo---Brazzaville-Year-Round>>).

Figure 5: Scheme of camera trap placement (red dots) on and around the Dibo bay. The blue triangle represents the placement of the AudioMoth (Jůnek & Lhota 2024).

Figure 6: Spectrogram of a mantled guereza roaring sequence detected in recordings from Messok-Dja

Figure 7: Spectrogram of a chimpanzee pant-hoot vocalization detected in recordings from Messok-Dja.

Figure 8: Spectrogram of a chimpanzee scream vocalization detected in the recordings from Messok-Dja.

Figure 9: Spectrogram of repeated gorilla cough grunts detected in the recordings from Messok-Dja.

Figure 10: Spectrogram of repeated gorilla single calls detected in the recordings from Messok-Dja.

Figure 11: Spectrogram of a hoot series vocalization detected in the recordings from Messok-Dja.

Figure 12: Spectrogram of an elephant rumble detected in the recordings from Messok-Dja.

Figure 13: Spectrogram of multiple elephant trumpet vocalizations detected in the recordings from Messok-Dja.

Figure 14: Spectrogram of a gunshot sound detected in the recordings from Messok-Dja.

Figure 15: Comparison of daily vocal activity patterns of mantled guerezas between the Dibo bai in spring (n = 87) and the Messok bai (n = 117).

Figure 16: Comparison of mantled guereza daily vocal activity patterns at the Dibo bai between the spring (n = 87) and the autumn period (n = 44).

Figure 17: Daily vocal activity patterns of chimpanzees (n = 22) and mantled guerezas (n = 87) on the Dibo bai in spring.

Figure 18: Daily vocal patterns of Mantled guerezas (n = 87) and sightings by camera traps (n = 31) during the spring at the Dibo bai.

Figure 19: Daily vocal patterns of chimpanzees (n = 22) and sightings by camera traps (n = 27) during the spring at the Dibo bai.

Figure 20: Daily vocal patterns of western lowland gorillas (n = 28) and sightings by camera traps (n = 54) during the spring at the Dibo bai.

Table 1: Acoustic Indices of particular species with the total number of vocalizations in each category in brackets. Instances of gunshot sounds given in total numbers.

Table 2: Overlap and standard error values calculations for each of the compared pairs.

Table 3: Total numbers of independent events of detections of particular species captured by camera traps on the Dibo bai.

Table 4: Overlap and standard error calculations for each of the compared pairs.