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DIPLOMA THESIS

The Use of Mineral Sources by the African Forest Elephant
(Loxodonta cyclotis)

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

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DIPLOMA THESIS ASSIGNMENT

Claire Herlihy, BSc (Hons)

Nature Conservation

Thesis title

The Use of Mineral Sources by the African Forest Elephant (Loxodonta cyclotis)

Objectives of thesis

The aim of this thesis is to use camera trapping technology to advance the knowledge of African forest elephants in their natural habitats with a specific focus on their activity at the Dibo bai in the Messok-Dja conservation area, northwest of the Republic of Congo.

Research objectives:
1. To study the activity patterns of African forest elephants at Dibo bai, investigating their micro-habitat preferences and the effect of the season on their activity.
2. To use camera trap images to identify individual elephants.
3. To contribute to longitudinal studies of forest elephants at bais in the Congo basin.

Methodology

The African forest elephant, an umbrella key species for both ecosystem of African rain forest and conservation, is a frequent visitor of "bais" – natural clearings rich in minerals in the rainforest of the Congo basin. Bais provide elephants with mineral elements which are not found in their diet. Elephants actively search and dig for mineral deposits which, once uncovered, serve as a mineral source for other species. Bais represent important habitat for this critically endangered species and require prioritization in the anti-poaching strategies. Detailed insight into the micro-habitat preferences of forest elephants and their diel activity budget across seasons is needed and will be examined in this thesis.

The proposed extent of the thesis

100 pages

Keywords

African Forest Elephant (Loxodonta cyclotis), Camera Trapping, Bais, Central Africa, Activity Pattern.

Recommended information sources

Adam, M., Tomášek, P., Lehejček, J., Trojan, J., & Jůnek, T. (2021). The role of citizen science and deep learning in camera trapping. Sustainability (Switzerland), 13(18). https://doi.org/10.3390/su131810287

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Declaration

I declare that I have independently written the diploma thesis with the topic "The Use of Mineral Sources by the African Forest Elephant *(Loxodonta cyclotis*)" and that all the information sources included in this piece of work have been cited and included at the end of this thesis in the bibliography. I am aware that my diploma/final thesis is subject to Act No. 121/2000 Coll., on rights related to copyright, and on amendment of some acts, as amended by later regulations, particularly the provisions of Section 35(.) of the act on the use of the thesis. I am aware that by submitting the diploma/final thesis, I agree with its publication under Act No. 111/1998 Coll., on universities and on the change and amendments of some acts, as amended, regardless of the result of its defence. 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. I declare that I have used AI tools in accordance with the university's internal regulations and principles of academic integrity and ethics.

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Abstract

African forest elephants (*Loxodonta cyclotis*) are considered ecosystem engineers for the African rain forest and conservation umbrella species in central Africa. They frequent "bais", natural clearings, rich in minerals in the forest of the Congo basin where they actively search for mineral deposits and reveal necessary nutrients required for their, and other species' diets. The presence of elephants in bais is therefore essential for biodiversity and the resilience of other, also critically endangered species such as Western gorilla (*Gorilla gorilla)*.

Between Feb. 22, 2022, and Feb. 18, 2023, 24 camera traps were active at strategic positions across the Dibo bai (2.148852N, 14.629689E) in the Messok-Dja conservation area, located between the Odzala-Kokoua National Park in the Republic of Congo and Nki National Park in Cameroon. 43,936 images were collected across a total of 6,987 trap nights. The micro-habitat preferences and activity patterns of the Dibo bai forest elephants were assessed using Camelot camera-trapping software and RStudio, and we and were able to compile a catalogue containing 27 identifiable elephants.

Results of activity pattern analysis and investigation of duration of visitations across four habitat types, seasons and dial activity revealed that forest elephants behave conservatively at bais and exhibit a preference for ecotones, specifically the forest edges, spending a total of 84:49:31 hours at the forest edge, more than half of the total time in a camera view investigated. Relative abundance indices are highest during the month of May, and Forest elephants exhibit nocturnal diel activity levels with peaks during dawn hours.

Bais represent an important habitat for this critically endangered species and therefore require prioritisation in conservation and anti-poaching efforts. Furthering this thesis, we hope to establish long term monitoring of elephants and their movements between bais and encourage the protection of land between Odzala-Kokoua and Nki National Parks in order to maintain the connectivity of habitats for forest species.

Keywords: African Forest Elephant (*Loxodonta cyclotis)*, Camera Trapping, Bais, Central Africa, Activity Pattern.

Anotace

Slon pralesní *(Loxodonta cyclotis)* je považován za tzv. Ekosystémového inženýra v africkém deštném pralese a je považován za zastřešujícím druh pro ochranu ve střední Africe. Navštěvuje „bais“, saliny, na minerály bohaté přírodní mýtiny v lesích povodí řeky Kongo, kde aktivně vyhledává ložiska minerálů a odkrývá tyto potřebné živiny jiným druhům. Přítomnost slonů na salinách je proto zásadní pro biologickou rozmanitost i přežívání dalších kriticky ohrožených druhů, jako je třeba gorila nížinná (*Gorilla gorilla*).

Mezi 22. únorem 2022 a 18. únorem 2023 bylo 24 fotopastí rozmístěno na strategických pozicích na salině zvané Dibo bai (2.148852N, 14.629689E) v oblasti Messok-Dja, která se nachází mezi národním parkem Odzala-Kokoua v Konžské republice a národním parkem Nki v Kamerunu. Během celkem 6987 nocí pastí bylo shromážděno 43 936 snímků slonů. Preference stanovišť a vzorce aktivity slonů na Dibo bai byly hodnoceny pomocí specializovaného softwaru Camelot a v programu RStudio. Byli jsme schopni sestavit katalog obsahující 27 identifikovatelných slonů.
Výsledky analýzy vzoru aktivity a zkoumání délky návštěv ve čtyřech typech stanovišť, ročních obdobích a aktivitě ukázaly, že lesní sloni se chovají konzervativně na bais a vykazují preference ekotonů, konkrétně okrajů lesa, kde jsme naměřili celkem 84:49:31 hodin, více než polovinu celkového času stráveného slony před kamerami. Indexy relativní abundance byly nejvyšší během měsíce května a lesní sloni vykazují noční aktivitu s vrcholy během úsvitu.

Saliny představují důležité stanoviště pro tento kriticky ohrožený druh, a proto si zasluhují upřednostnění v ochranářském úsilí a v boji proti pytláctví. V návaznosti na tuto práci doufáme, že se nám podaří zavést dlouhodobý monitoring slonů a jejich aktivit i podpořit ochranu území mezi národními parky Odzala-Kokoua a Nki s cílem udržet souvislá stanoviště zásadní pro pralesní druhy.

Klíčová slova: Slon pralesní (*Loxodonta cyclotis)*, fotopast, Bai, střední Afrika, aktivita

Table of Contents

1. Introduction

The Congo basin, situated in West equatorial Africa, harbours some of the most expansive tropical rainforests globally (Megevand et al., 2013). These ecosystems are vital habitats for large herbivores, notably the African Forest Elephant (*Loxodonta cyclotis*), which has an estimated population size of 10% of the total African Elephant population size of 415,428 ± 20,111 (Blanc et al., 2007; Thouless et al., 2016). Since their classification as a distinct species from African Savannah Elephants (*Loxodonta africana*), Forest Elephants have been categorized as critically endangered (Gobush et al., 2021). The rainforest landscapes within the Congo basin face significant threats from deforestation and habitat fragmentation due to increasing human and livestock populations, exacerbating the issue of poaching, which has escalated to alarming levels (Chase et al., 2016).

Forest elephants play a crucial role in shaping their environment by creating clearings within the forest, facilitating access to nutrient-rich soils and water sources for themselves and other forest-dwelling species (Blake, 2002). Their behaviour, including ground digging and trampling and geophagy (ingesting soil), contributes to the expansion of areas with sparse vegetation coverage (A. Turkalo & Fay, 1995). These clearings, referred to as "bais," serve as important gathering sites for forest elephants, fostering social interactions and information exchange among small foraging groups of up to three individuals (A. K. Turkalo & Fay, 2001). Some of the largest bais have the potential to hold congregations of up to one hundred individuals (A. Turkalo & Fay, 1995).

Due to the elusive nature of forest elephants and the densely vegetated rainforest habitat they inhabit, studying them outside of clearings and bais proves challenging (Thouless et al., 2016). Therefore, research conducted at bais is indispensable for observing their social behaviours in larger groups, documenting activities such as geophagy, examining inter-individual interactions, and gathering data on population demographics (Fishlock & Lee, 2013). Additionally, the spatial distribution of bais within the forest provides valuable insights into the distribution and abundance of elephant populations in the Congo basin.

Bais, being frequented by various forest fauna, are often accessed via well-established trails, which unfortunately serve as avenues for poachers targeting forest elephants

(Vanleeuwe & Gautier-Hion, 1998). Such conservation concerns highlight the importance of assessing elephant activity at bais and devising appropriate conservation strategies.

Given the challenges associated with studying remote species like forest elephants, the use of camera traps emerges as a necessary tool. This method enables remote monitoring with minimal field visitations, thereby reducing disturbances to natural habitats and research costs. Camera traps facilitate the surveillance of larger areas and enable continuous monitoring over extended periods of time compared to direct observation field studies (Abrams et al., 2018). Moreover, they offer the possibility of individual elephant identification, aiding in understanding movement patterns between bais, tracking revisitation rates and creating databases of individuals—a crucial aspect for conservation efforts (Goswami et al., 2012; Rovero & Tobler, 2010).

Further understanding of forest elephant activity at clearings holds significant implications for conservation efforts, ensuring the implementation of effective conservation measures in the last strongholds of this endangered species, including the Messok-Dja conservation area our study site.

2. Literature Review

2.1. Background Information on African Forest Elephants (Loxodonta cyclotis)

The African forest elephant (*Loxodonta cyclotis*) is the smallest and least studied of the three elephant species: the African Savannah elephant (*Loxodonta africana*); the Asian elephant (*Elephas maximus*); and the African forest elephant. Distributed across twenty countries in western and central Africa, forest elephants face significant population challenges, with at least seven countries reporting populations of fewer than one hundred individuals (Thouless et al., 2016). As of 2016, the total population of all elephants across Africa was documented at 415,428, a figure that has since seen a continual decline (Thouless et al., 2016). In contrast to African Savannah elephants, African forest elephants represent only 10% of the overall estimated elephant populations in Africa (Blanc et al., 2007). Their elusive nature, coupled with their habitat, causes them to be difficult to observe through conventional methods like air surveys, and are therefore significantly under studied.

Elephants inhabiting the Congo basin in west equatorial Africa occupy a distinct ecological niche as herbivores and frugivores in dense rainforest habitats (Blake, 2002). Their diet is diverse, but primarily revolves around fruits, resulting in their movements throughout the forest being heavily influenced by the seasonal availability of this resource (Blake et al., 2009). African forest elephants inhabit a range of forest habitats, varying from swamp and lowland rainforests to forest-savannah mosaics and dry forests, with altitudes ranging from sea level up to two thousand meters.

Forest elephants often traverse long distances in search of food and mineral deposits, with their home ranges varying significantly from 10 km^2 to 2,000 km^2, depending on seasonal fluctuations (Blake et al., 2008). Their ranging behaviour is categorised into two distinct types, dictated by the availability of either fruit or water, whichever is scarcer in the current period. During the wet season ranges are primarily guided by the distribution of fruits, whereas during the dry season, they are determined by the location of rivers and swamps (Blake, 2002).

Forest elephants establish and maintain a vast network of pathways throughout the forest which connect feeding grounds and clearings using the fastest courses, often following ridges and meandering paths to avoid steep terrain and watercourses in order to optimise travel time. These paths vary in width, ranging from narrow trails suitable

only for a single elephant, to wider tracks able to accommodate many individuals, increasing in size as they approach areas of congregation. Repeated migrations along these routes maintain the pathways for elephants and other forest animals (Vanleeuwe & Gautier-Hion, 1998). These pathways serve as vital routes for human navigation within the forest, but unfortunately, they also facilitate access for poachers who exploit them to locate elephant groups within clearings. These clearings provide easier targets for poachers, posing a significant threat to the elephant populations.
In 2021, the African forest elephant was officially recognized as a distinct species from the African elephant by the International Union for Conservation of Nature (IUCN), marking a significant milestone. This classification immediately placed the African forest elephant under the critically endangered status (Gobush et al., 2021). Across Africa, elephant populations are experiencing alarming declines, with the African Elephant Status Report of 2016 documenting a decrease of nearly 111,000 elephants (comprising both African species) since 2006 (Thouless et al., 2016).

Between 2002 and 2011, the population of African forest elephants in the Central African region witnessed a 62% decline, with 72% of the remaining population now concentrated in Gabon and the Republic of Congo (Maisels et al., 2013). Given this information, it is imperative to focus conservation efforts on these key regions and throughout the elephant's range across Africa, to safeguard the remaining populations and promote habitat maintenance or restoration initiatives.

Beyond the immediate threats and conservation challenges facing forest elephants, their inherent biological characteristics, such as their large size, high resource demands, low reproductive rates, and long-life spans, further elevate their risk of extinction (Molina-Vacas et al., 2020).

Populations of African elephants are under pressure from poaching, habitat loss associated with human and livestock population growth, deforestation and fragmentation of forest habitats and conflicts with humans and livestock (Chase et al., 2016; Ihwagi et al., 2015; Underwood et al., 2013). Historically, ivory poaching has been primary cause of mortality among African forest elephants (Thouless et al., 2016; Wittemyer et al., 2014). Poaching rates in Africa have greatly increased since 2008, with illegal activities remaining alarmingly prevalent, fuelled by increased access to sophisticated weaponry (CITES, 2018; Kassam & Bashuna, 2004). In certain regions of Central Africa, such as Nyungwe National Park, illegal poaching has driven elephant populations to complete extinction (Daniel & Pancras, 2023).

Poaching not only leads to declines in elephant populations but the movement of remaining elephants is disrupted. When gunshots sound through the forest, elephant vocalisations temporarily increase, followed by a significant decrease suggesting disturbed behaviour and heightened communication among elephants sensing the presence of poachers (Swider et al., 2022). Elephants exhibit a preference for avoiding areas perceived to be under poaching threats, which can impact their visitation patterns to crucial forest sites (Mkuburo et al., 2020).

The incidence of poaching is heavily influenced by seasonal factors, with a notable increase during the dry season when elephants are required to gather in larger numbers around limited water sources, making them more vulnerable (Maingi et al., 2012). Poachers find it easier to access forest clearings due to the presence of roads and by exploiting migration paths used by elephants, allowing them to locate active forest clearings with relative ease (Vanleeuwe & Gautier-Hion, 1998).

After poaching, human-elephant conflict arising from crop raiding is the second most pressing threat to forest elephants. These conflicts are unpredictable and have the potential to turn local communities against the conservation of forest elephants (Mariki et al., 2015). In the coming decade there is an expected increase in human population and land conversion associated with housing and agriculture. This predicted change will increase contact between human and elephant populations as habitat is fragmented and pathways are interrupted therefore increasing opportunities for conflict (Tranquilli et al., 2014).

The establishment of national parks and protected areas serves to protect the natural state of habitats, therefore reducing interactions between humans and wildlife. This restricted access helps mitigate harmful human activities such as logging, ivory and bushmeat poaching, and slash-and-burn agriculture (Dudley et al., 2002). Across the 20 range countries for elephants most grant them the highest level of protection status. However, up to 70% of elephants in range countries live and range outside of protected areas and therefore are vulnerable to poaching (Maisels et al., 2013). In both protected and unprotected forests road access is an important indicator of both elephant density and ease of access for poachers (Blake et al., 2008; Maisels et al., 2013; Yackulic et al., 2011) .

Conservation efforts such as the African Elephant Action Plan and the Elephant Trade Information System, alongside tools such as the National Ivory Action Plan, aim to control poaching levels and support conservation of elephants across their range countries. Since the recognition of forest elephants as a distinct species from African savannah elephants, there is a growing need to gather specific research tailored to forest elephants to enhance understanding and devise targeted conservation strategies for maximum effectiveness.

TRIDOM (Trinational Dja-Odzala-Minkebe Area) in West Africa, encompassing the Republic of Congo, Gabon, and Cameroon, is a critical conservation "hot-spot" for forest elephants. The TRIDOM area aims to integrate several protected areas to form an international network of protected lands, including 85% forest coverage and ranking among the least disturbed forested regions in the Congo Basin (McRae et al., 2016). However, despite its misson, the areas within TRIDOM remain highly vulnerable to the impacts of logging, mineral extractions and climate change (Coldrey et al., 2022). Research efforts concentrated in such areas can provide insights into forest elephants' behaviours in their natural habitat and ensure their ongoing protection. This applies also for Messok-Dja conservation area potentially interconnecting national parks Odzala-Kokoua and Nki (Jůnek & Lhota, 2024).

2.2. The Ecological Importance of African Forest Elephants on tropical Forests and Their Role as Mega-gardeners

African forest elephants act as ecosystem architects within the Congo basin, acting as keystone species by creating, modifying, and maintaining forest habitats for other species in the environment (Cardoso et al., 2020). As generalists, frugivores and bulk processors of plant material, they play an important ecological role in forest structure through activities such as seed dispersal, browsing, and branch breaking (Owen-Smith, 1989). Their impact is evident in the transformation of trees into shorter, denser shrubs, thereby reducing tree density and altering the forest's structural composition (Fullman & Bunting, 2014; Guldemond et al., 2017). Additionally, forest elephants create and maintain extensive pathways and clearings within the forest (Blake & Inkamba-Nkulu, 2004), utilizing their tusks to dig wells, swampy areas, and occasionally caves.

The movement of elephants and other forest animals from these clearings back into the forest distributes micronutrients found exclusively in such clearings throughout the forest (Cromsigt et al., 2018; A. Turkalo & Fay, 1995; A. K. Turkalo et al., 2013). Forest elephants serve as dispersers, particularly for seeds of large trees, which have a higher potential for carbon storage compared to smaller trees (Beaune et al., 2013; Stephenson et al., 2014). Consequently, the loss of large herbivores, especially forest elephants, poses significant risks to carbon storage in African rainforests (Doughty et al., 2015; Malhi et al., 2016), with potential devastating effects on forest structure, clearings, and vegetation communities.

The ranging behaviour of forest elephants is closely linked to the availability of water, distribution of ripe fruit, abundance of browsing material, and location of mineral deposits (Mills et al., 2018). They range large distances along habitual routes to locate these resources and disperse seeds along the way (Vanleeuwe & Gautier-Hion, 1998). Often referred to as "Mega gardeners," forest elephants create distinct patterns of seed distribution, with seeds dispersed by them being among the most widely distributed in the forest due to their extensive ranging distances and prolonged gut passage time, facilitating the colonization of new areas by plant species (Blake et al., 2009; Campos-Arceiz & Blake, 2011; Poulsen et al., 2021). African forest elephants are the most effective seed dispersers in the tropics, dispersing a high number of seeds from diverse species and serving as the exclusive dispersers for several plant species (Campos-Arceiz & Blake, 2011).

While forest elephants follow habitual routes, their seed dispersal patterns exhibit a more random distribution compared to other forest-dwelling animals (Nathan & Muller-Landau, 2000), with their movements being significantly influenced by seasonal variations (Beirne et al., 2020), which can prove advantageous for trees and plants, allowing them to evade pathogens, kin competition, and predation. For some plant species, consumption of seeds by African forest elephants positively impacts germination (Campos-Arceiz & Blake, 2011).

2.3. Forest Elephants at Bais in Central Africa

Open clearings within the forest, known as "bais," are created and maintained by forest elephants through their digging of clay. Bais vary in size throughout the forest, with the largest ones capable of accommodating up to 100 individuals at a time (A. Turkalo & Fay, 1995). These clearings serve as vital access points for elephants and other forest animals to obtain mineral-rich water and soil for geophagy, supplementing their dietary needs (Blake, 2002). By utilizing these bais, micronutrients sourced from minerals are transported into the forest and redistributed throughout the ecosystem (Cromsigt et al., 2018; A. Turkalo & Fay, 1995; A. K. Turkalo et al., 2013).

Forest clearings not only provide nutritional benefits but also serve as social arenas for forest elephants. Elephants tend to spend more time in clearings when other individuals are present, and do not exhibit competition between them (Fishlock & Lee, 2013). The use of bais is highly affected by the possibility for social interaction and there is evidence of strong fission-fusion grouping observed among elephants within these areas (Fishlock & Lee, 2013). However, despite social interactions, most elephants return to their original foraging groups upon leaving the clearing (Fishlock & Lee, 2013).

Male elephants at bais exhibit greater social exploration than females, often forming mixed-sex groups or joining existing ones. Large multi-female gatherings are also common, facilitating information exchange among individuals from different foraging groups (Fishlock & Lee, 2013). Such interactions are crucial for social learning, which plays a significant role in the development of elephant behaviour (Lee & Moss, 1999). Bais provide important learning opportunities, particularly for young adults who have dispersed from their original groups, offering a relatively safe environment with low aggression and competition to exchange knowledge between nonrelated individuals through observation (A. K. Turkalo et al., 2013).

While foraging, forest elephant groups tend to be small, typically consisting of two to three individuals, predominantly comprising a mother and her dependent offspring (A. K. Turkalo & Fay, 2001). The small group sizes are attributed to the patchy distribution of fruit throughout the forest and dense vegetation, which make large group travel challenging (Blake, 2002). Outside of the forest, at forest clearings larger group sizes can be observed (Fishlock et al., 2008).

Around forest clearings there are dense networks of tracks created by forest elephants and other forest animals which frequent bais. These tracks are used to assess the safety of a forest clearing before entering and elephants exhibit a preference for entering clearings downwind to enhance their ability to detect potential predators (Vanleeuwe & Gautier-Hion, 1998).

Forest elephants demonstrate a preference for visiting bais during the night, potentially as a response to poaching threats and to avoid predators. However, nocturnal visitations are less frequent among females with infants, possibly due to heightened aggression during nighttime social interactions (Wrege et al., 2012). Visitations to bais are also influenced by seasonal variations and resource availability within the forest (Blake, 2002; Wrege et al., 2012).

2.4. Researching African Forest Elephants at Bais

Due to their elusive nature within their habitat, African forest elephants pose challenges for observational studies. Nonetheless, conducting research at bais is crucial for understanding population dynamics and individual behaviours as these areas host the largest congregations of forest elephants (Blanc et al., 2007; CITES MIKE, 2020; Thouless et al., 2016). Unlike aerial monitoring, which is feasible for African savannah elephants but challenging in dense forest cover, field research and direct observations or camera trapping technology are viable options for monitoring wild forest elephants.

While direct observation yields accurate data, it is time-consuming and expensive, particularly in remote areas of the Congo basin, and may be limited during nocturnal studies. Camera traps offer an effective alternative, facilitating remote study and ecological monitoring in various conditions (Adam et al., 2021).

Along with camera trapping technology, remote acoustic monitoring can be a useful technique to study species over large areas in remote locations (Wrege et al., 2017). This technique is a useful addition to the remote monitoring tools available to researchers and provides a more complete picture of species within the study area. Recordings of elephant rumbles can reveal information about group responses to gunshots and poaching activities in forest elephants (Swider et al., 2022).

Utilizing deep learning technology and AI advancements can expedite analysis and automate image categorization, enhancing the efficiency of remote monitoring techniques (Adam et al., 2021). Camera trapping is particularly valuable for long-term assessments and is widely used in the Congo basin to enhance knowledge of species who use permanent trails to access clearing, such as forest elephants (Blake, 2002; Klaus-Hügi et al., 2000). Compared to direct observations, camera traps excel in identifying species, especially cryptic species, and are more effective for nocturnal observations (Gessner et al., 2014).

In summary, Camera traps provide high-quality species occupancy data with much lower person-hour requirements than direct observations, enabling simultaneous monitoring of multiple bais for comparisons (Gessner et al., 2014; Matsubayashi et al., 2007). They are the most time and cost-effective solutions to observational research in remote areas (Gessner et al., 2014), facilitating studies on topics like the effectiveness of deterrents against crop-raiding elephants (Ngama et al., 2018). However, their fixed position and limited viewpoint necessitate careful placement and may miss certain perspectives, requiring costly adjustments in the field (Gessner et al., 2014).

2.5. Identification of Individual African Forest Elephants

Whilst observation of a group as a whole is extremely important, identification of single individuals can give more detailed insight into understanding the population structure and determining life history (Goswami et al., 2012). Individual identification is an important aspect of research into ecology and conservation especially, especially concerning wild elephant behaviour. It is also useful when managing captive populations in order to prevent theft, track individuals in illegal trade or to support rewilding programmes (Cress et al., 2014; Gessner et al., 2014).

Several methodologies exist for individual elephant identification. Employing camera traps can be an effective way to create species inventories or observe specific individuals in detail (Rovero & Tobler, 2010). Basic indicators such as distinctive ear shape or markings, tusk characteristics, tail morphology, and body scars can be effective (A. K. Turkalo et al., 2013). Age-related growth patterns in forest elephants typically diverge around 14 years of age (A. K. Turkalo et al., 2013). Therefore, without clear observation of external genitalia, sexing juvenile individuals becomes difficult. Assessing both gender and age dimorphism from images alone proves challenging, especially in the absence of size references. Methods like the System for Elephant Ear-pattern Knowledge (SEEK) focus on ear patterns, using a specific code system to describe shapes and distinctive features (Bedetti et al., 2019). Utilizing codes and strict identification protocols enables application in automated processes, making it compatible with machine learning for rapid individual identification from databases.

Databases, like the one developed by Granli and Poole (2021), enhance accuracy and repeatability in identifying individuals. Utilising computer-aided image recognition speeds up identification and reduces the need for highly trained operators. Integrating camera trapping with machine learning can decrease processing time and improve outputs, although establishing a comprehensive database of specimens may take years (de Silva et al., 2022).

Manual identification is laborious, underscoring the importance of implementing machine learning techniques (Petso et al., 2022). However, it should be considered that individuals lacking distinctive features may be excluded from studies. Identification studies often favour large bulls with prominent ear tears and body scars, which facilitate easier identification. Additionally, natural aging and consequent changes in distinctive features may challenge identification software (de Silva et al., 2022).

By combining camera trapping, standardized identification methods, and machine learning, the repeated monitoring of elephant populations becomes more feasible and effective, critical for long-term conservation and the development of effective conservation strategies (Blanc et al., 2007; Thouless et al., 2016).

2.6. Conclusion

African forest elephants are essential to the health of the rainforest in central and western Africa. They shape the forest structure, ensure the dispersal of diverse plant and tree species, and create essential clearings in the forest which are utilised by many forest animals (Hawthorne & Parren, 2000). However, their range and numbers are in decline across their original ranges, particularly in the Congo basin (Blake et al., 2007, 2008).

The most effective way to observe, collect data and research these forest elephants is by using autonomous and long-lasting camera trapping and Passive Acoustic Monitoring technology at the bais that they frequent. Here they are most easy to observe, and they exhibit the most interactions between one another and behaviours specific to their species (Fishlock & Lee, 2013)**.**

Long-term studies of forest elephants, their activity and occupancy at bais are essential to future conservation efforts. Such studies provide essential information on population composition and any alterations occurring over time, thereby aiding in the development of effective conservation strategies.

3. Aims and Objectives

The aim of this thesis is to use camera trapping technology to advance the knowledge of African forest elephants in their natural habitats with a specific focus on their activity at the Dibo bai in the Messok-Dja conservation area, northwest of the Republic of Congo.

Research objectives:

1. To study the activity patterns of African forest elephants at Dibo bai, investigating their micro-habitat preferences and the effect of the season on their activity.
2. To use camera trap images to identify individual elephants.
3. To contribute to longitudinal studies of forest elephants at bais in the Congo basin.

4. Methodology

4.1. Study Area

This research was conducted within the lowland moist broad-leaf tropical rainforests of the Republic of the Congo, focusing on the Messok-Dja landscape, which is part of the TRIDOM international territorial complex. Situated in the north-west of the Republic of Congo, Messok-Dja (1,456 km^2) lies between the Odzala-Kokoua National Park and Nki National Park, near the border with Cameroon. Safeguarding Messok-Dja as a protected areas holds the potential to establish a vital bio-corridor linking these expansive protected areas, thus mitigating habitat fragmentation for large forest animals in the Congo.

This study was completed at Dibo bai (4.3 ha, 2.148852N, 14.629689E) known for frequent visits of local fauna which is positioned 950 meters southwest of the Dja River and 30 kilometres northwest of Ngbala village, the nearest human settlement. Dibo bai extends up to 380 meters at its longest point and reaches widths of up to 140 meters. The bai has an irregular shape with elongated protrusions into the forest. With an average altitude of 363 meters above sea level, the bai features a natural habitat of lowland forest with wetland characteristics. The undergrowth predominantly comprises of grass species, while the central area of the bai remains open, marked by deep muddy patches and tall herbaceous plants.

The perimeter of the bai is delineated by extensive trails carved out by forest fauna, rendering its edges highly accessible for both researchers and potential hunters.

4.2. Data Collection

During an expedition to the Republic of the Congo in February 2022, 24 camera traps were strategically positioned at various locations around the Dibo bai by Jůnek & Lhota (2024), covering four distinct habitat categories: The central area of the bai, the edge of the bai, within the forest and the perimeter of the forest (Image 1).

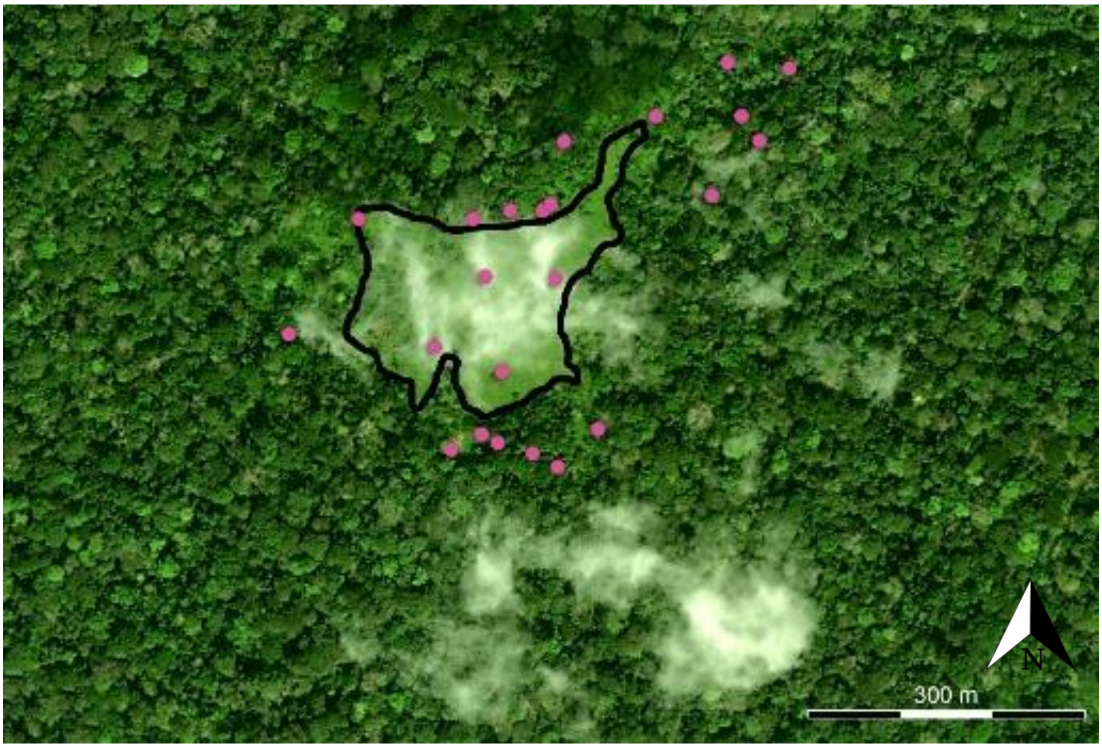

Image 1. Satellite image of Dibo bai forest clearing indicating the location of 24 camera traps. Provided by Tomáš Jůnek.

The placement of these camera traps was informed by a previous aerial survey of the region utilizing a drone, necessitated by the dense vegetation. Additionally, a three-week physical observation study conducted in August 2021 followed by pilot camera-trapping aided in identifying optimal camera trap locations. The positioning of the camera traps, situated between three to twelve meters from targeted observation areas, any potential mineral deposit source found, was carefully considered, when affixing them to tree trunks and branches, accounting for optimal angles and heights to capture a diverse array of forest species.

These camera traps were primarily deployed to non-stop monitor the activity of a wide range of African forest species, however, the data collected is used in this study only for the monitoring of African forest elephants. Consequently, the positioning of the traps was not exclusively tailored to the specific requirements of this study.

The camera traps were installed and activated between February 22nd and February 26th, 2022, and subsequently retrieved by the Jůnek & Lhota team with WWF field specialists on February 18th, 2023. Additionally, four supplementary cameras were deployed on August 24th, 2022, during a control visit to the site.

Over the study duration, two camera traps were damaged: one crushed by an elephant and another deliberately by a human. The monitoring equipment comprised of 23 Spromise TETRAO S308 camera traps equipped with 940nm flash, and one Browning BTC-A8 camera with the same flash. Employing motion sensor technology, these cameras activated upon detecting movement in their field of view, capturing three consecutive images cyclically with minimal delay until the source of activation departed the frame. All camera types were successfully testes during the polit survey between Aug. 2021 and Feb. 2022.

4.3. Sorting of Images

As this study is part of a broader examination into the activity of African forest animals within bais, the obtained images were sorted to remove waste images and were subsequently categorized into species by Jůnek & Lhota (Pers. Comm.).

4.4. Image Analysis

Using Camelot 1.6.16 camera-trapping software, each image was assessed to determine the number of elephants present within the frame, with additional recording of their sex and approximate age (Image 2).

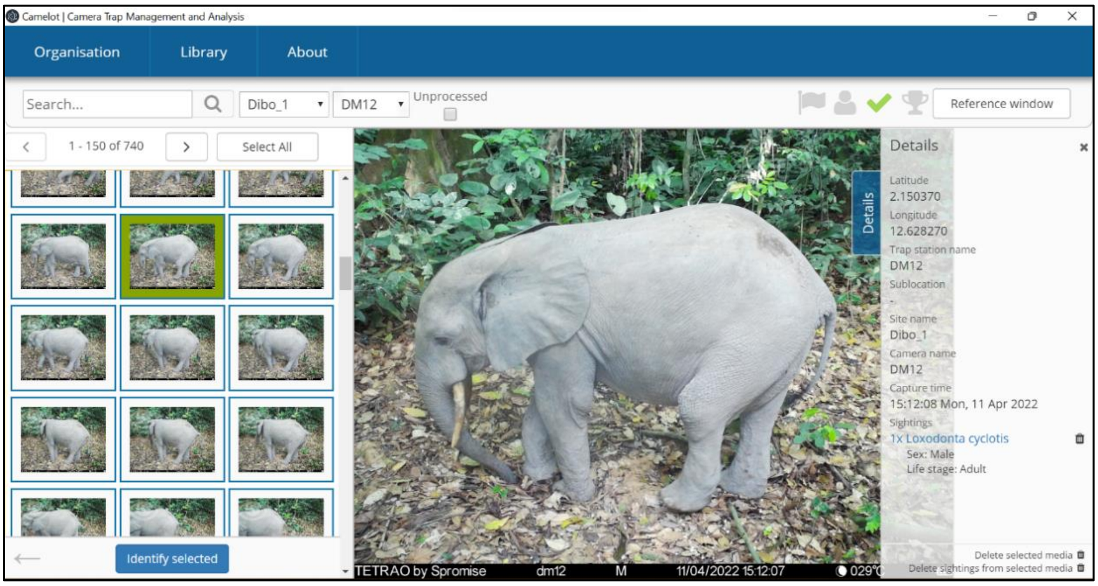

Image 2. Screenshot of Camelot camera trapping software demonstrating image analysis techniques.

Forest elephants exhibit sexual dimorphism, characterized by distinct differences in physical traits between males and females, notably in body size and tusk development. Males typically display larger body sizes and thicker, longer tusks compared to females, whose tusks are often thinner and straighter. Tusk-lessness, primarily observed among females, can also occur genetically in forest elephants. While males tend to have wider heads, especially as they age, this characteristic is not consistently reliable for sex determination (Fishlock et al., 2015).

The predominant method employed in this study for sexing elephants was the examination of external genitalia (Image 3). This approach proves useful even for juvenile individuals which have yet to exhibit any secondary sexual characteristics. However, the effectiveness of this technique is entirely dependent on factors such as the elephant's orientation in the image and whether the activity involved any movement. Additionally, inspection of mammary glands, which undergo swelling during a female elephant's initial pregnancy and remain enlarged thereafter, serves as another valuable technique.

A number of elephants were unable to be sexed or aged due to the position of their bodies in the images, their distance from the camera, or undergrowth blocking their bodies, these elephants are labelled as “Unidentified”.

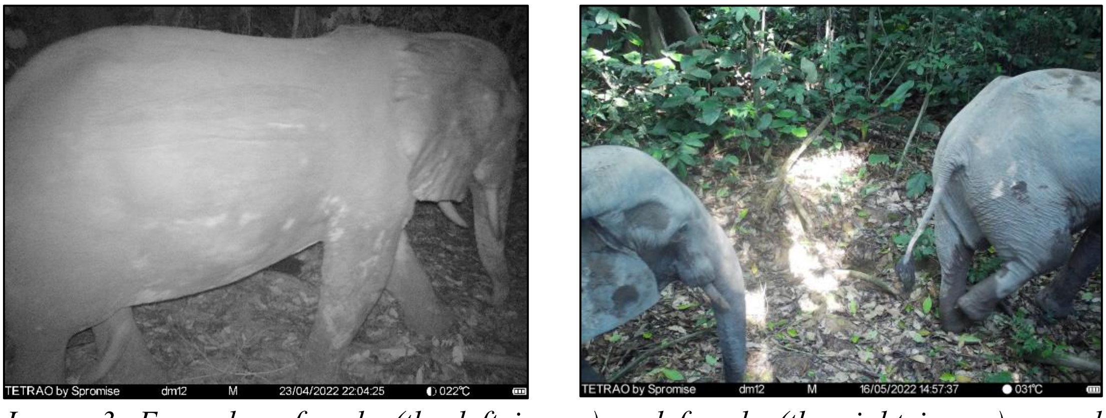

Image 3. Examples of male (the left image) and female (the right image) sexual identification.

Assessing the age of elephants from images primarily relies on indicators such as height and body fullness, particularly evident in extremely young or old individuals. Otherwise, it is very difficult to age individuals accurately without physical inspection of teeth. Consequently, the more conservative methodology was chosen and considering the analysts' limited experience, only two age classes were identified: Adult and juvenile.

Elephants were categorized according to age and sex into the following groups:

- Adults (male, female, or unidentified)
- Juveniles (male, female, or unidentified)
- Unidentified individual elephants

4.4.1. Individual Identification Analysis

Alongside the assessment of number of individuals, individual elephants were also identified. Elephants were examined for any identifying marks such as torn ears, body scars or unique physical profiles. Other features such as ratio of tusk length to trunk length, as well as the length, thickness, and curvature of tusks, were also assessed. Notable traits such as a missing tusk or distinguishing profiles were recorded.

Elephants that could be reliably identified were catalogued, and their images were archived for comparative analysis with subsequent sightings. From this information a catalogue of identification cards was developed wherein each elephant was assigned a unique ID code, which indicates the group they are associated with "MD1" and their sex "F" eg. MD1F14. These ID cards provide clear identification of the individual's sex, age, and any distinctive attributes. Each card includes two full body side profile images and close up images of any noteworthy features.

The compilation of a detailed catalogue documenting sex and age proved invaluable for cases where elephants were observed from challenging angles or under less-than-ideal conditions.

Microsoft Excel was used to investigate the data from individual identification of elephants. An overall assessment of number of males and females and adults and juveniles identified was made. The number of observations of each of the individuals was compared with the number of camera trap locations they were observed at. The number of images collected at each camera trap location was also compared to the number of individuals identified there.

4.5. Data Analysis

After completing the image analysis in Camelot, a full export was taken and the raw data was processed into distinct events, categorised as either 5-minute events (those series of images separated by at least 5-min gap) or 1-hour events (those separated by 1-hour gap) describing the duration of time that an elephant spent in the camera frame.

As a basic descriptor to describe elephant visits at particular sites we applied Relative Abundance Indices (Wolff et al., 1994), calculated as a number of independent (1-hour) events of elephants' captures divided by number of trap nights and multiplied by 100.

Using the time of each event, RStudio (Posit Team, 2024) was employed to analyse diel activity patterns across various experimental conditions. We used *activity* package with 1000x randomisation which fits kernel density functions to animal activity time date (Rowcliffe, 2016). When investigating activity levels at different locations and seasons, and when comparing the overlap in these conditions, 5-minute events were used.

Wald tests were conducted for each condition:

- Wet season (March-May, September-November) & Dry season (June-August, December-February)
- Bai habitat (Open rea of bai and it's edge) & Forest habitat (Forested area adjacent to Bai)
- Bai in dry season & in wet season
- Forest in wet season & in dry season

Additionally, overlap tests were conducted in RStudio to compare diel activity overlap across four experimental conditions:

- Forest habitat versus Bai habitat
- Wet season versus Dry season
- Forest during wet season versus Forest during dry season.
- Bai during wet season versus Bai during dry season.

Analysis of duration of visitations was carried out in Microsoft Excel, focusing on 1-hour events as they provide a more conservative measure and prevent consecutive recordings of the same elephant. Habitat preferences was evaluated by comparing total, average and median event durations across four habitat types, as well as seasonal and diel preferences. Nocturnal and diurnal visitations were defined as activity occurring between 6am and 6pm (diurnal) and between 6pm and 6am (nocturnal).

A total of 99 outlying values were excluded from analysis. 98 events with a duration of less than 6-seconds in length were excluded from the data and labelled as outliers due to the fast movement of elephants across the scope of the camera view. These events are likely to be only movement of elephants travelling through an area of interest and don't include any information about activity of elephants. Single one event with a duration over 4 hours, six minutes and 16 seconds was also excluded as an anomaly. The event was characterised by a large group of mixed age and sex elephants digging and interaction with the soil at an enclosed location: DM5. This event, although very interesting does not match with the rest of the data collected and therefore was excluded when considering the data.

Outliers were included in the initial event count (Table 1) but excluded from subsequent mean and median calculations.

5. Results

In order to investigate the activity patterns and efficacy of identification of individual of forest elephants at Dibo bai this section will cover the topics of activity patterns, habitat preferences, effect of seasonal changes on activity, and individual identification of elephants across different habitat types and camera trap locations.

5.1. Sampling Effort

Across 6,987 trap nights, 24 camera traps deployed collected 43,947 images of the forest elephant. This accounts for 6.3 images per one trap night on average. Out of the detected photographs we were able to identify 725 independent events. Hence, the trapping effort was 0.10 events per one trap night. The distribution of camera traps and effort across locations is below in Table 1. As shown, trapping effort was the highest generally on camera traps in forest (forest edges), lowest at the open area of bai.

Table 1. Trapping effort at different habitat types during camera-trapping study at Dibo bai, Messok-Dja, from Feb. 2022 to Feb. 2023.

Habitat Type	Number of Cameras	Images Collected	Number of trap nights	Number of events	Trapping effort	**Trapping effort (Bai, Forest)**
Bai	3	1900	1078	46	0.04	**0.06**
Bai edge	8	12527	2364	147	0.06	
Forest	5	2870	1427	99	0.07	**0.15**
Forest edge	8	26650	2118	433	0.20	
Total:	24	43947	6987	725	0.10	

5.2. Habitat Preference of Forest Elephants and Seasonal changes

5.2.1. Visiting Pattern at Bai

The number of independent events and Relative Abundance Index report that elephants visit forest edges the most. Figure 1 shows the distribution of elephant relative abundance indices where the highest abundance occurs at the southern most area of

Dibo bai. Although the forest edge areas range from the lowest to the highest relative abundancies.

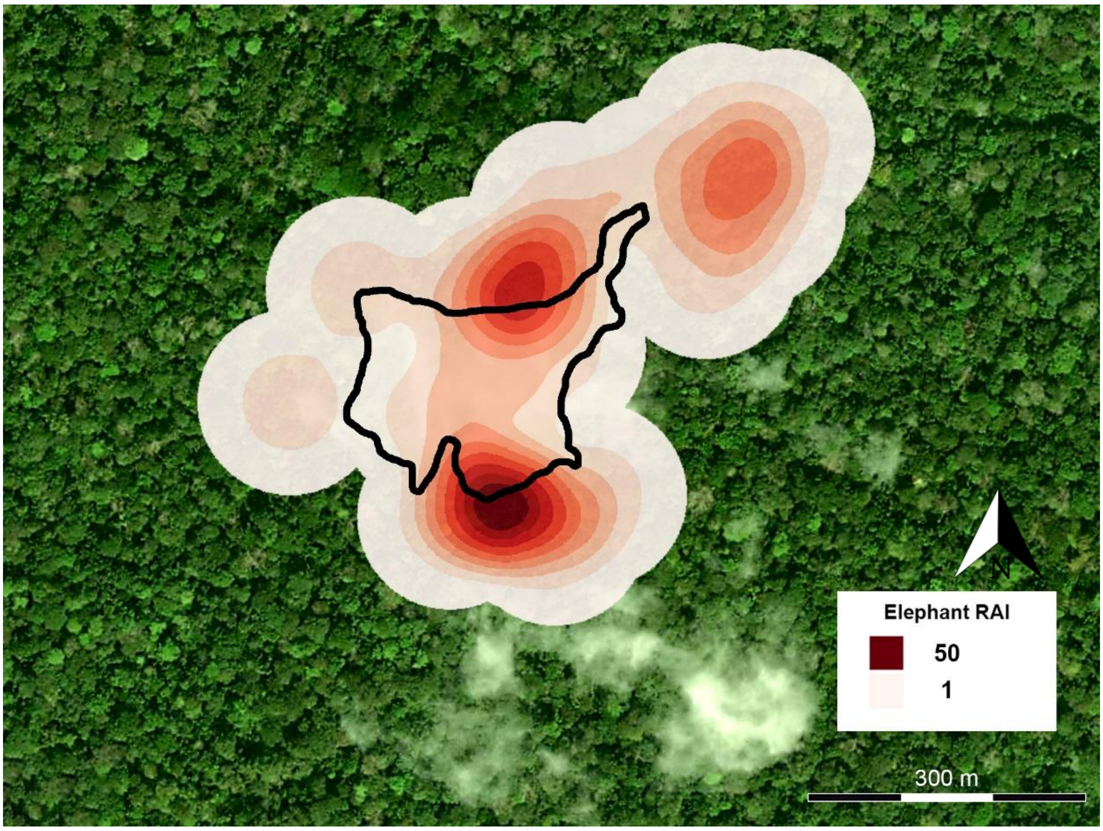

Figure 1. Heatmap of elephant Relative Abundance Indices across Dibo bai. (Provided by Jůnek, QGIS 3.32.2-Lima).

Figure 2 shows RAI changes across the year showing highest indices in April and May and the lowest in the months of Dec. Jan. and Feb. During the first rainy season of the year, specifically in April and May, the abundances of forest elephants increase with the rate of precipitation. However, during October and November, the second rainy season, the abundance of forest elephants does not increase with precipitation rates.

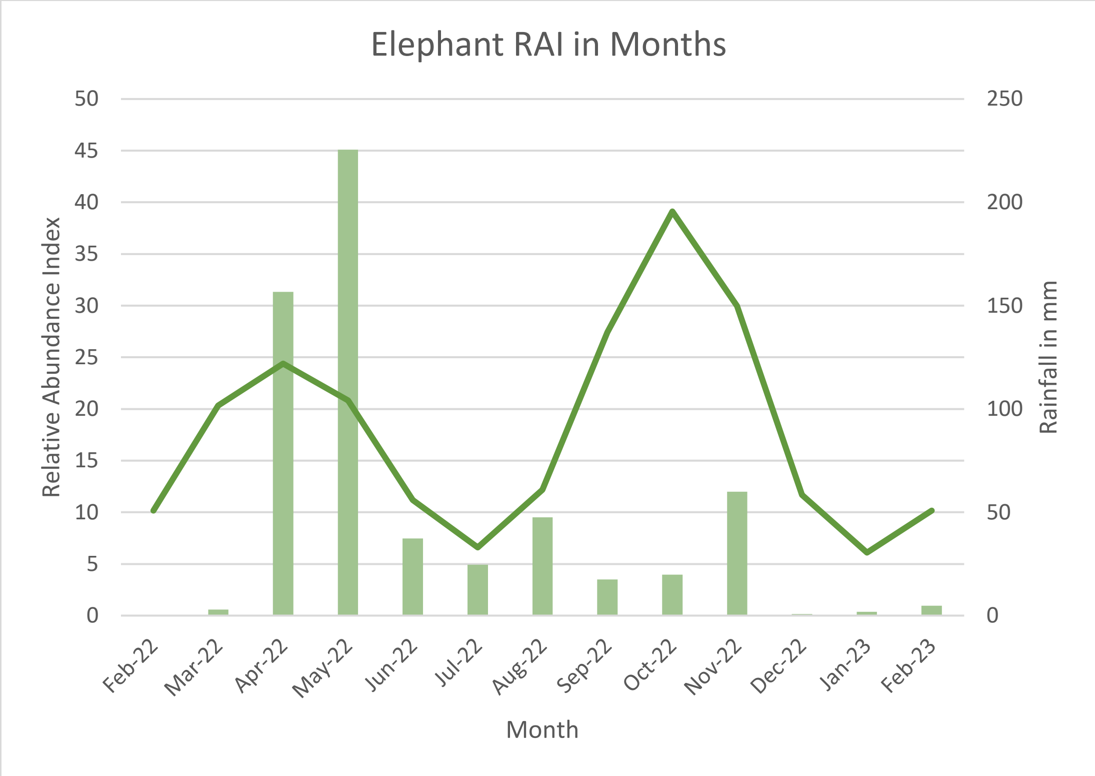

Figure 2. Graph which shows the RAI (relative abundance indices) across all months surveyed. Included is average rainfall in mm each month.

5.2.2. Time Spent at Camera Trap Range

The total number of 1-hour events, excluding outliers, was 626, with a total duration of 127:44:54 hours. On average each event was 10:55 minutes long and the median event was 48 seconds.

Comparisons between visitation duration across different seasons show a preference for wet season visitation in terms of average duration of visit and total number of visitations. Table 2 indicates the total duration of visitations which is significantly higher in wet season months.

Across the four different habitat types, forest elephants visited the forest edge most and for the longest duration. They spent on average almost twice the amount of time per visitation at the forest edge as they did at bai or forest habitat types. The forest elephants visit the edge habitats more frequently than any other habitat. On average, the length of visitation to the bai habitat type is the shortest (Table 3).

When comparing the number of events across bai and forest locations in Table 4 it is clear that more events occur during the night than during the day and more events occur at the forest camera trap locations than at the bai locations (Table 4).

Comparisons between average duration of nocturnal and diurnal events shows that nocturnal visitations are generally longer than diurnal visitations. Both the shortest and longest average visitation times occur at bai locations with longest during the night and shortest during the day. At bai locations the average duration of events is longer during nocturnal hours than diurnal hours, however at forest locations there is no meaningful difference between length of visitation.

Table 2. Mean and median duration of elephant activity in a view range of camera trap in dry and wet seasons at Dibo bai, Messok-Dja.

Seasonal Type	No. Events	Total Duration of Events (hr)	Mean Duration (m)	Median Duration (m)
Wet season	527	117:36:41	**13:23**	01:23
Dry Season	99	10:08:13	**06:09**	00:36
Total:	**626**	**127:44:54**		

Table 3. Mean and median duration of elephant activity and relative abundance indices in a view range of camera trap in different habitat types at Dibo bai, Messok-Dja.

Habitat Type	No. Events	Number of trap nights	RAI	Total Duration of Events (hr)	Mean Duration (m)	Median Duration (m)
Bai	37	1078	4.36	4:13:35	**06:51**	01:25
Bai edge	135	2364	6.26	28:50:42	**12:49**	02:09
Forest	83	1427	7.01	09:51:06	**07:07**	00:37
Forest edge	371	2118	20.63	84:49:31	**13:43**	01:19
Total:	**626**	**6987**	**10.48**	**127:44:54**		

Table 4. Mean and median duration of elephant activity in a view range of camera trap in different habitat types across two diel types at Dibo bai, Messok-Dja.

Habitat Type	Diel Type	No. Events	Total Duration of Events (hr)	Mean Duration (m)	Median Duration (m)
Bai	Nocturnal	102	21:20:28	**12:33**	02:28
	Diurnal	70	11:43:49	**10:03**	01:25
Forest	Nocturnal	293	61:13:46	**12:32**	01:01
	Diurnal	161	33:26:51	**12:28**	01:08
Both	*Nocturnal*	*395*	*82:34:14*	***12:33***	*01:15*
	Diurnal	*231*	*45:10:40*	***11:44***	*01:11*
Total		**626**	**127:44:54**		

5.3. Diel Activity Patterns of Forest Elephants and Seasonal Changes

5.3.1. Activity Level

Table 5 contains the results of the Wald test for activity of each condition. Activity levels are generally similar across all experimental conditions with the highest activity found in the forest habitat type and lowest activity in the bai habitat type with activity levels across the dry and wet season remaining the same (Table 5).

The diel activity patterns of elephants follow a basic trend of high activity during dawn and dusk and low activity during midday when the bai reaches peak temperature. However, at both forest and bai habitats during the dry season, activity is less uniform and lower overall. At forest habitats the frequency of activity is slightly higher than at bai habitats (Figures 3 to 6).

At both experimental types “Forest in dry season” and “Bai in dry season” activity patterns were less uniform and activity frequency was lower overall which is consistent with lower visitation rates during the dry season.

A number of experimental conditions exhibit higher levels of crepuscular activity than others: Bai habitat, Dry season, Wet season, Bai in wet season and Forest in dry season.

Table 5. Wald test results for seasonal and habitat type conditions at Dibo bai, Messok-Dja.

Activity Level	Act	SE	lcl 2.5%	ucl 97.5%
Dry Season	0.58	0.07	0.44	0.70
Wet Season	0.58	0.03	0.53	0.66
Forest	0.61	0.03	0.55	0.69
Bai	0.55	0.05	0.48	0.67
Forest in Dry season	0.51	0.07	0.40	0.67
Forest in Wet season	0.57	0.04	0.52	0.68
Bai in Dry season	0.48	0.09	0.28	0.65
Bai in Wet season	0.51	0.05	0.45	0.65

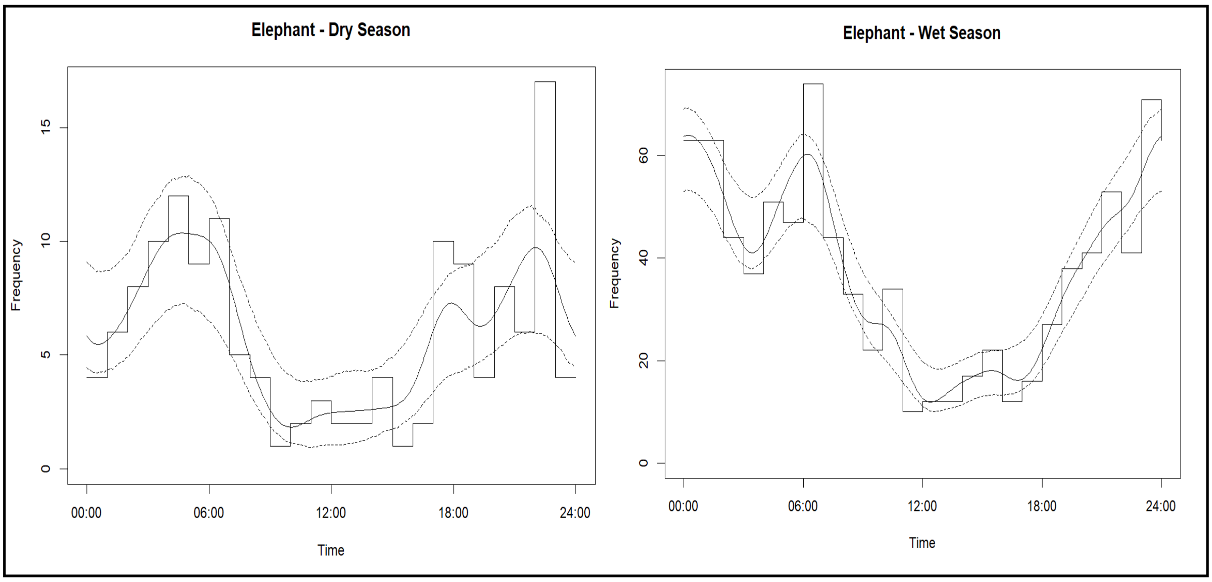

Figure 3. Graphs of activity level of Forest Elephants throughout the day in the Dry and Wet seasons.

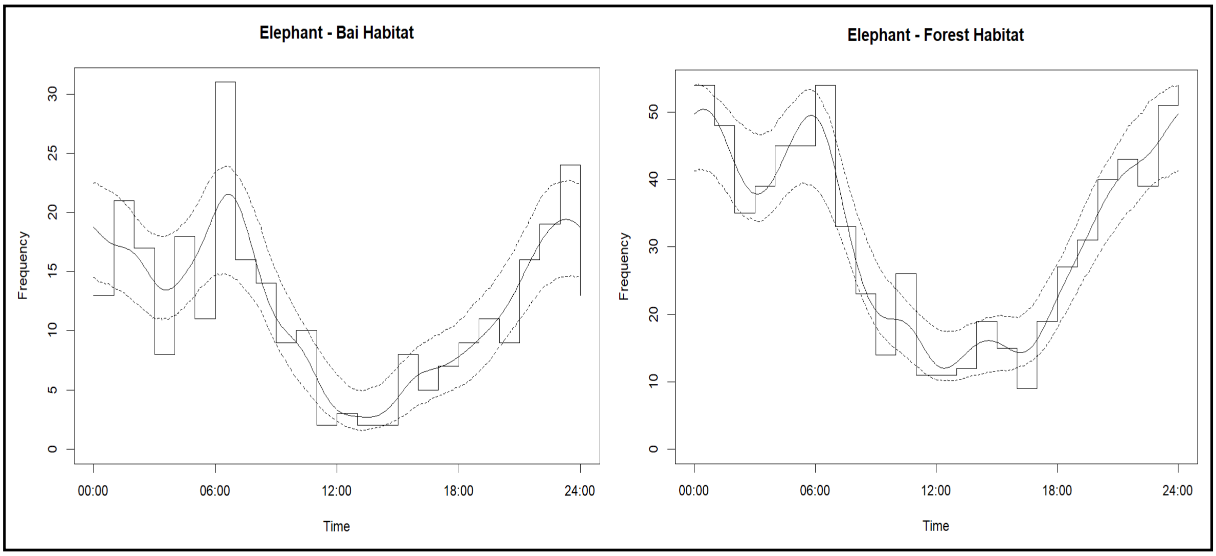

Figure 4. Graphs of activity level of Forest Elephants throughout the day in Bai and Forest habitat types.

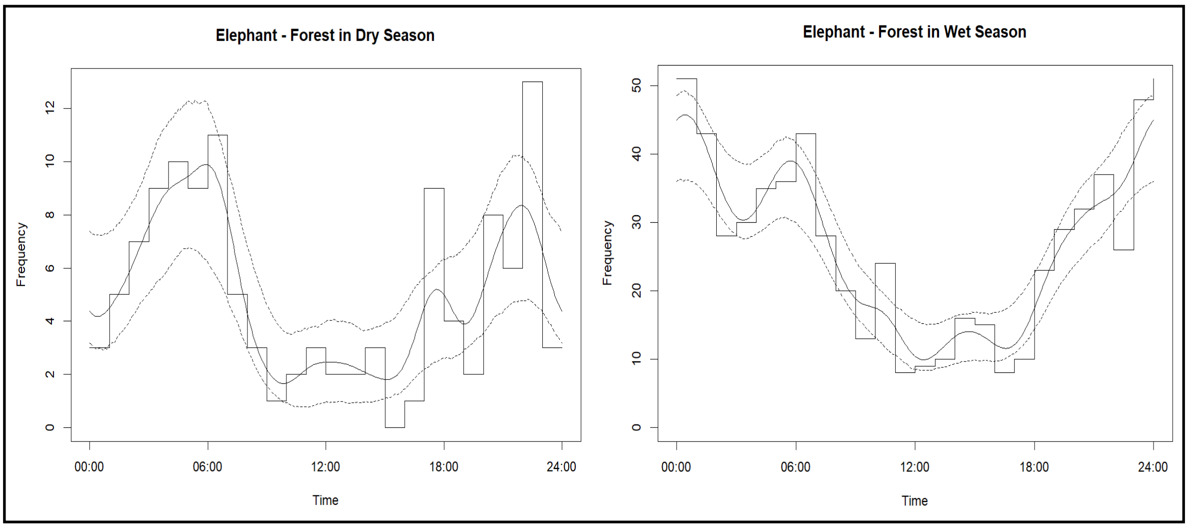

Figure 5. Graphs of activity level of Forest Elephants throughout the day in the Forest habitat type across the Dry and Wet seasons.

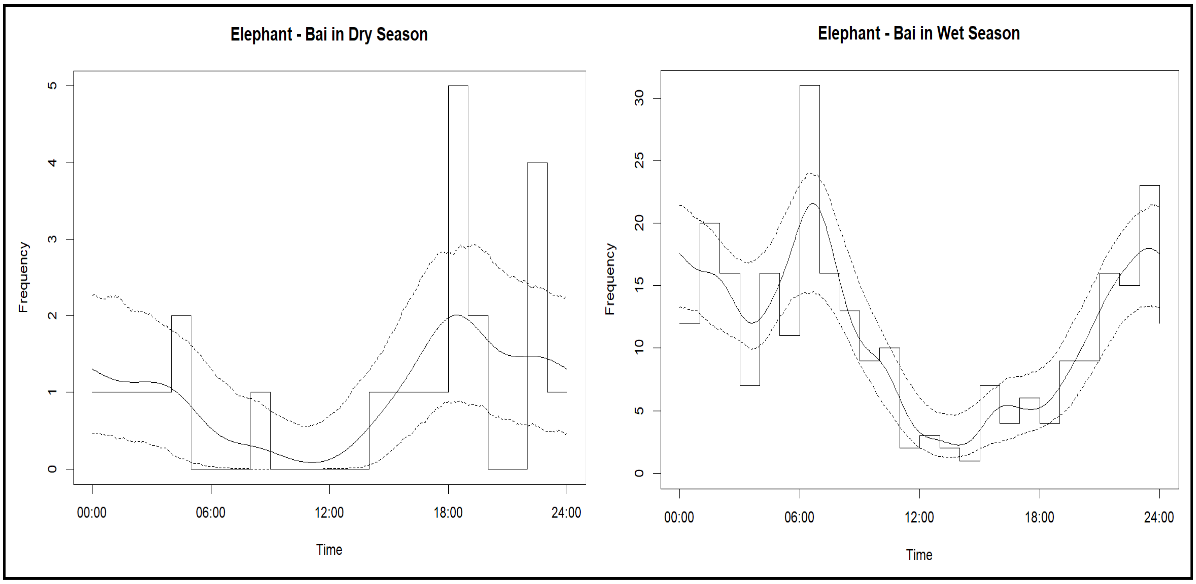

Figure 6. Graphs of activity level of Forest Elephants throughout the day in the Bai habitat type across the Dry and Wet seasons.

5.3.2. Overlap Of Activity Patterns

Table 6 shows the pairwise comparison results of activity levels from Wald and Overlap tests. None of the comparisons have any statistically significant difference and therefore we can conclude that the season and micro-habitat do not have any significant impact on elephant diel activity at and around bais. The overlap results are very similar across all experimental types except Bai in wet season and Bai in dry season, which shows temporal shift of the activity from morning peak in wet season to afternoon-evening peak in dry season (Figure 7).

Table 6. Pairwise comparisons of Wald and Overlap tests of seasonal and habitat type conditions at Dibo bai, Messok-Dja.

Comparison	Overlap	W	SE	**P**
Wet vs. dry season	0.85	0.002	0.08	**0.96**
Forest vs. bai	0.93	1.14	0.06	**0.28**
Wet forest vs. dry forest	0.84	0.51	0.08	**0.48**
Wet bai vs. dry bai	0.67	0.08	0.1	**0.78**

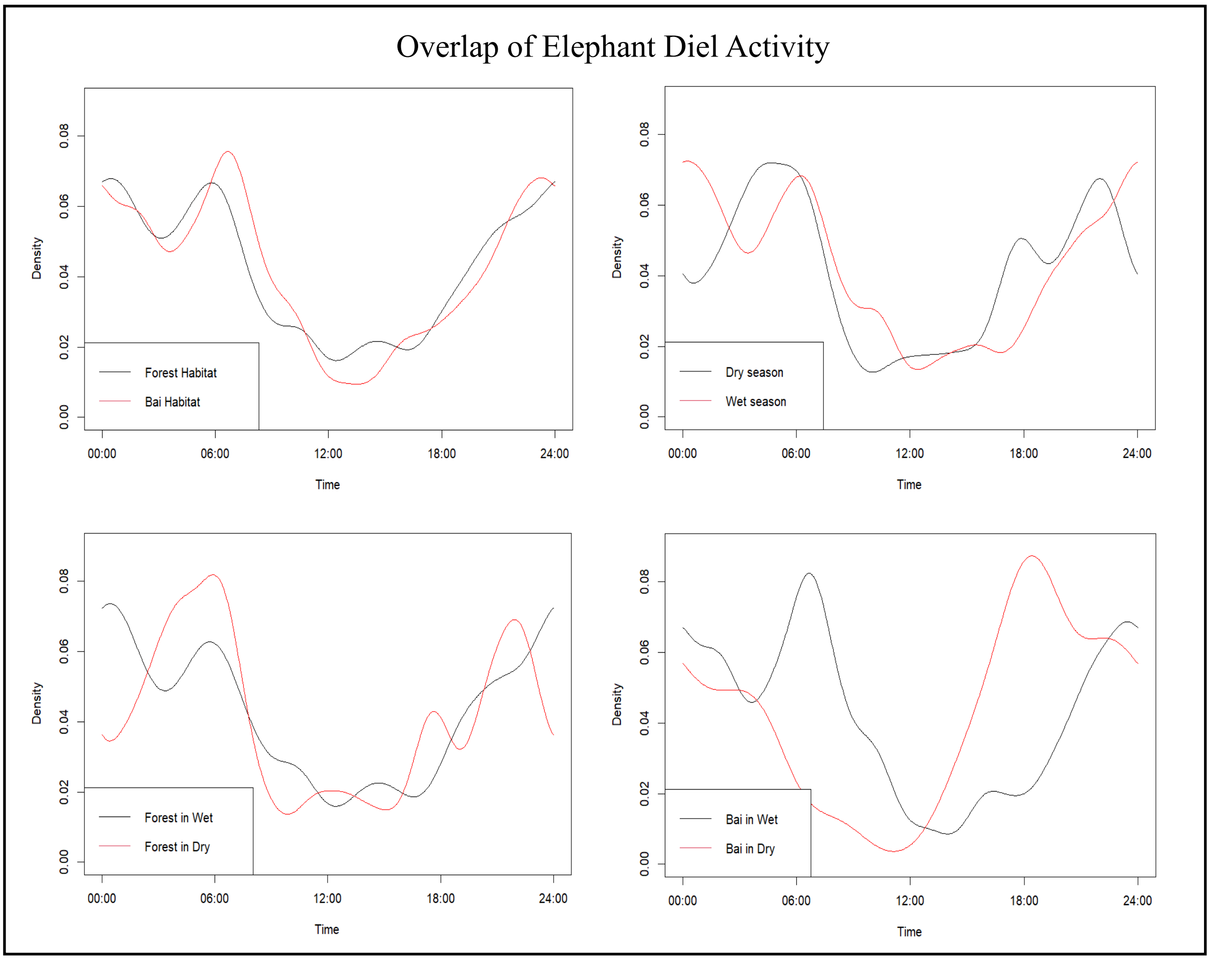

Figure 7. Four graphs which show the overlap of elephant activity in Forest vs. Bai habitat (top left), Wet vs. Dry season (top right), Forest during the wet season vs. Forest during the dry season (bottom left) and Bai during the wet season vs. Bai during the dry season (bottom right).

5.4. Individual Identification of Forest Elephants

From 43,936 images the majority of elephants identified were female (29%), and the most common age classified was adult (68%). The image counts for each type of observation can be found in Table 7.

Table 7. Image counts for each category of forest elephant identification at Dibo bai, Messok-Dja.

Elephant Observed	Number of Images	% of total images	Number of Identified Elephants
Adult Female	9958	22.7	7
Adult Male	10929	24.9	14
Adult Unidentified	9362	21.3	1
Juvenile Female	2841	6.5	3
Juvenile Male	1015	2.3	0
Juvenile Unidentified	8386	19.1	2
Unidentified Elephant	1456	3.3	0
Total:	**43947**	**100**	**27**

A catalogue of 27 distinct elephants was collected. Of these elephants 10 were identified through distinctive ear shapes and tears. An example of one of the identification cards produced for the elephant catalogue can be seen below (Figure 8) The catalogue is available upon request due to security reasons and our aim to protect these individuals from poaching efforts.

Figure 8. Elephant identification cards from the Catalogue of Identified Forest Elephants. Shows the layout of the cards and the distinctive features used to identify this particular elephant:MD1M2 who is a male adult forest elephant.

Of the elephants individually identified 14 were male, 10 were female and three were of unknown sex. There were five juveniles identified and the remaining 22 were adults.

The highest number of locations known to be visited by an identified individual is five. Three elephants were identified in five different locations. Six individuals, 22% of all identified individuals, were only observed in one location (Figure 9).

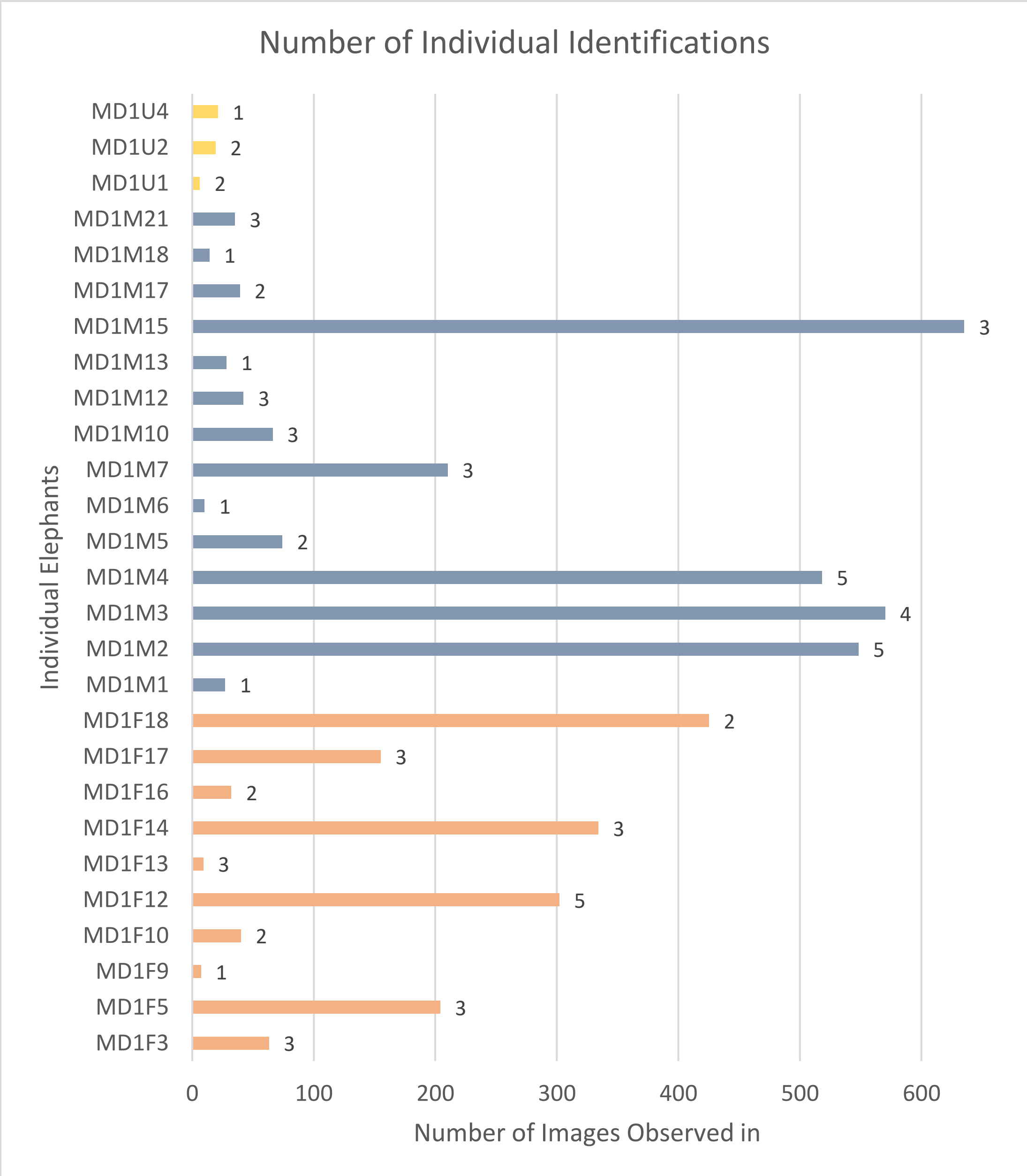

Figure 9. Graph displaying the total number of images where an individual was recorded and the number of locations in which they were observed indicated above the bars. Colour of bar indicates sex (Yellow: Unidentified, Blue: Male, Orange: Female).

Analysing the success of individual identification compared to the number of images collected from each camera trap (Figure 10) shows that camera traps DM6a and DM14 were used to identify the most individuals, of nine each. Whereas, seven camera traps were unsuccessful for individual identification. Camera trap DM1 collected significantly more images than other camera traps but was used to identify only two individuals.

Camera traps located at the edges of bai and forest were most successful for individual identification.

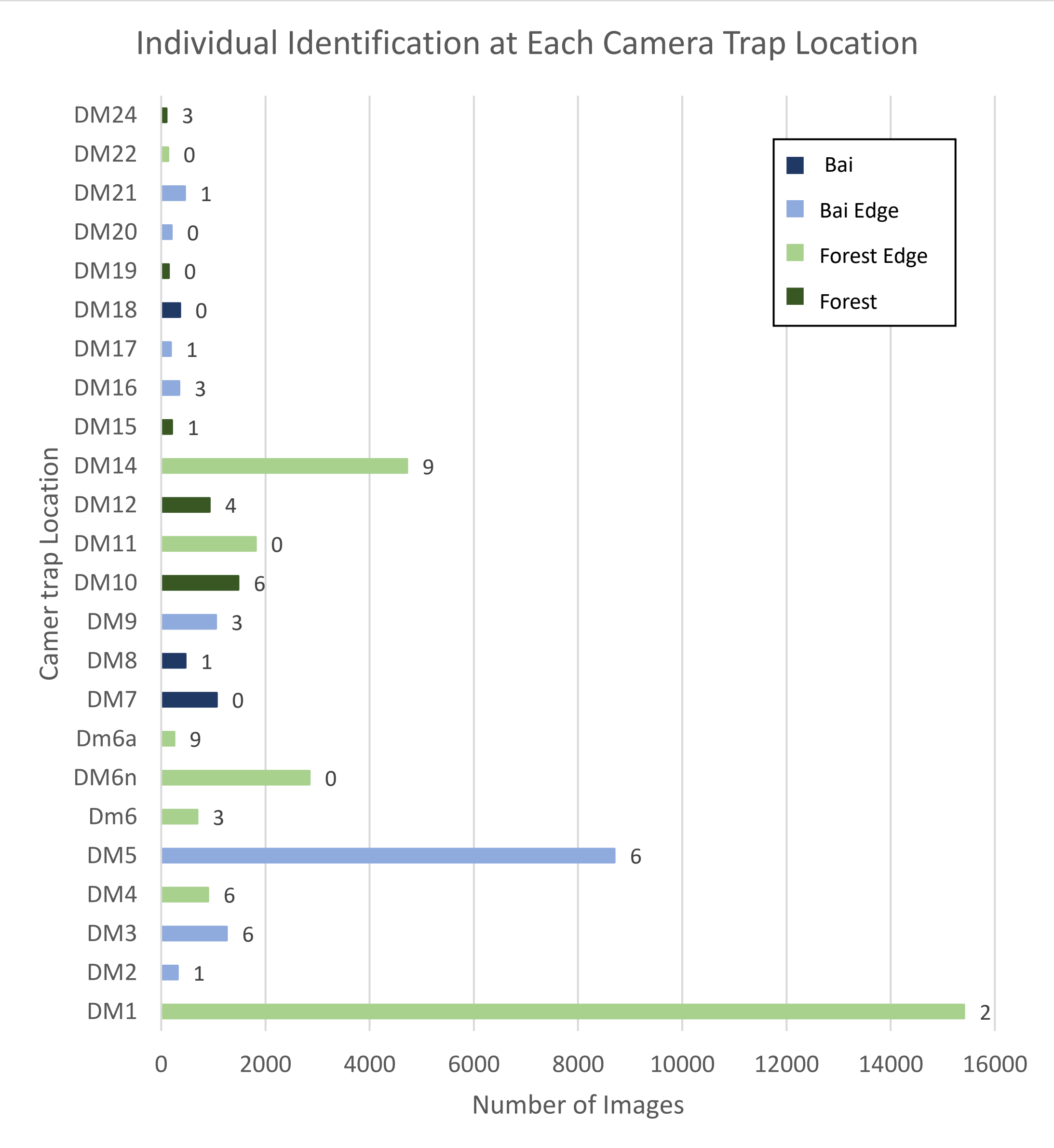

Figure 10. Graph showing the number of images captured at each camera trap locations and the number of individuals identified at each location indicated above each bar.

Table 8 shows the history of detection of identified individuals. Each number represents an independent event of detection of the particular individual. Individual MD1M4 was the most frequently detected, whereas nine individuals were only detected once (34%). Four individuals had a six-month gap between detection events, all displaying a consistent pattern of return in months 4 and 11. The highest detection rates were observed in months 4 and 5 and later in 10 and 11.

Table 8. History of detection of individually identified forest elephants at Dibo bai, Messok-Dja.

	Month											
Elephant ID	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**Total:**
MD1M4	4	1			1	2						**8**
MD1M2	2							4				**6**
MD1M5		6										**6**
MD1F12	1	2				1	2					**6**
MD1F10		5										**5**
MD1M3	3							2				**5**
MD1M15	1	2		1								**4**
MD1F14	3	1										**4**
MD1F1	2		1				1					**4**
MD1M12	2	2										**4**
MD1F17	1							1			1	**3**
MD1M18		2										**2**
MD1M7	1							1				**2**
MD1F5	1					1						**2**
MD1U4	1					1						**2**
MD1M17	1	1										**2**
MD1M10	2											**2**
MD1U2		1										**1**
MD1M6	1											**1**
MD1F13							1					**1**
MD1M21	1											**1**
MD1F16		1										**1**
MD1F18	1											**1**
MD1F3	1											**1**
MD1M1	1											**1**
MD1M13	1											**1**

6. Discussion

6.1. Sampling Effort

Our camera traps were strategically positioned throughout the Dibo bai, ensuring an opportunistic coverage rather than random deployment. Higher numbers of cameras were deployed at the edges of forest and bai habitat types and therefore the highest number of images were collected at these sites. Trapping effort was highest along forest edges which is a useful insight for future studies on forest elephants, which often concentrate solely on open bai areas. Up to our knowledge, no study has already focused in such a detail on annual presence of elephants at bai in Congo basin. Reconfiguring research methodologies employing camera traps and Passive Acoustic Monitoring of the bai and at its vicinity, combined with machine learning data analysis would enrich those longitudinal studies based primarily on direct observations from watchtowers (Fishlock et al., 2008; A. K. Turkalo et al., 2013). On the other hand, due to the 1-year span of the data this study cannot provide such comparative analyses across multiple years as cited studies. Trapping effort we reported gives us, however, useful recipe for use of detectors in intended long-term cost-effective monitoring array in Messok-Dja.

Camera trapping is a valuable tool for data collection, offering insights into the behaviours and movements of forest elephants (Fishlock et al., 2015). However, the sheer volume and complexity of data generated by this method poses challenges in terms of data management and analysis. Detailed image analysis of 43,947 images is extremely time consuming and effectively handling this wealth of information requires rigorous methodologies to extract meaningful patterns and trends amidst the noise and variability inherent in wildlife monitoring studies (Fishlock et al., 2015). One particular event lasting 4 hours, six minutes and 16 seconds showcased a sizable congregation of multiple elephants engaging in behaviours such as geophagy and digging the clay (Image 4). While the interaction captured during this event may warrant further investigation in subsequent ethological studies, it was considered an anomaly and thus excluded from calculations of duration in this thesis. In future studies, to handle such large numbers of images longer gaps between camera bursts can be implemented as elephants on average tend to be in front of the camera for longer than 12 minutes.

Image 4. Image from Camelot showing activity at DM5 during the 4hr outlier event. Behaviours such as digging, foraging, and social interaction can be observed.

6.2. Habitat Preferences of Forest Elephants and Seasonal Changes

6.2.1. Seasonal Changes to Activity

Forest elephant movements are highly influenced by seasonal fluctuations, particularly in relation to precipitation, a trend which aligns with the observations of this study (Beirne et al., 2020; Birkett et al., 2012; Blake, 2002; Wrege et al., 2012). Elephants in the wet season exhibit a preference for seasonal water sources and forest clearings over permanent water sources, as well-documented in the literature (Babaasa, 2000; Bastille-Rousseau et al., 2020; Blake et al., 2009). During the wet season, visitations to Dibo bai confirmed an increase in frequency and duration compared to the dry season. This can be attributed to the increased ease of access to these resources associated with high levels of activity around the bai and water-logged soils allowing easier access for geophagy. Our research demonstrates the forest elephants at Dibo bai concentrate in large numbers at mineral sites during the wet season, coinciding with the fruiting season because of their requirement for fruit (Blake, 2002).

During the dry season, elephant activity and behaviour become more constrained (Birkett et al., 2012). They engage more in browsing activities, seeking areas rich in browse materials, and avoiding open areas such as the centre of the bai (Barnes, 1983; Field, 1971). Which is reflected in our findings, showing decreased activity during the dry season, particularly at bai habitats. Decrease in elephants' visits on Dibo bai in June-August could be caused by fruiting season of locally abundant "wild mango" fruit (*Irvingia gabonensis*) with fat and protein rich nuts (Jůnek & Lhota, 2024).

Females and non-weaned calves are particularly susceptible to stress during the dry season due to the low nutritional value of available food, leading to potentially restricted movements (Birkett et al., 2012). Given that the majority of the elephants detected in our study were female, the visitation patterns exhibited here are likely heavily influenced by female elephant activity constraints.

Relative abundances of forest elephants were notably high during the first wet season recorded between April and May, in accordance with precipitation trends and current research (Djoko et al., 2022). However, during the second wet season (Sept-Nov), abundances significantly decreased. This decline could be attributed to annually highest precipitation rates, potentially leading to increased food diversity and dispersion, leading to increased ranging distance and dispersal from Dibo bai, as observed by (Djoko et al., 2022). These declines in abundance could also be explained or exacerbated by the presence of three gunshots in the area in early September (Jůnek & Lhota, 2024). Long- term PAM monitoring is required to confirm this trend across Messok-Dja. Such disturbances are likely to prompt elephants to vacate the area and hesitate to return as the main influence on the spatial distribution of elephants is human presence (Theuerkauf et al., 2001).

6.2.2. Habitat Type Preferences

Our findings show that forest elephants exhibit a clear preference for forest edge areas. Specifically, forest elephants visited forest edges more frequently and spent nearly twice as much time there compared to non-edge habitats. Moreover, the relative abundance index for elephants was highest at forest edge habitats, indicating a strong affinity for these ecotone environments.

This preference for forest edge habitats is consistent with our understanding of forest elephant behaviour and ecological dynamics. Forest elephants are more likely to visit areas with higher tree species richness and abundant fruit availability (Djoko et al., 2022, Blake, 2002; Blake & Inkamba-Nkulu, 2004; Cardoso et al., 2020; Mills et al., 2018; Poulsen et al., 2018). Forest elephants are known to display deliberate and conservative behaviours when navigating their surroundings. They often circle forest clearings, utilizing established trails to determine optimal entry points and assess the clearing for any potential threats or competition (Vanleeuwe & Gautier-Hion, 1998). This behaviour underscores the critical importance of forest edges by forest clearings for forest elephants.

Forest edges typically host trail systems connecting bais and important resources (Blake & Inkamba-Nkulu, 2004, Jůnek & Lhota, 2024). Moreover, they serve as vital areas for eavesdropping on activity within forest clearings or monitoring the movements of other individuals, valuable techniques for assessing the safety of the area or understanding local circumstances (Bates et al., 2008). Consequently, these areas are utilized more frequently than open spaces and may represent safe havens where elephants feel comfortable remaining for extended periods even at sites with detected gunshots, as at Dibo bai.

6.2.3. Diel activity pattern

Overall, forest elephant activity appears consistent and conservative despite seasonal and habitat changes. During the daytime hours, when sun exposure and temperatures are at their highest, elephants tend to spend more time in forested areas to take advantage of canopy cover and shield themselves from the heat (Blake et al., 2003; Mills et al., 2018). Our findings indicate increased visitations and longer durations spent in forests compared to bai habitats during the day. Daytime forest use may also serve as a strategy to evade hunting or predation pressures (Mills et al., 2018).

At Dibo bai it was observed that nocturnal visitations outnumbered diurnal visitations, with nocturnal events lasting for longer durations in open bai rather than in forest, on average. This pattern aligns with existing understanding indicating that forest elephants preferentially visit open forest clearings during the night to minimize encounters with predators and poachers, while also engaging in nighttime social interactions (Wrege et al., 2012).

Regarding diel activity patterns, there is slightly heightened daily activity around noon in both wet season and forest habitat experimental conditions. During the wet season Dibo bai becomes inaccessible by boat, making it more challenging for humans to access (Jůnek & Lhota, Pers. Comm.). This reduction in human presence may lead to increased forest elephant daytime activity due to a perceived decrease in threat to safety. The forest not only provides refuge from the heat but also conceals elephants from view. Hence, increased daily activity observed across forest habitats may be influenced by these factors.

6.3. Identification of Individual Elephants

The primary focus of this thesis did not centre on individual elephant identification, though it presented an intriguing but somewhat secondary aspect of the study.

The methodology developed for this purpose (Fishlock et al., 2015) was devised alongside the analysis, potentially resulting in oversimplification. Ear markings were used as the predominant method for identification due to their objectivity when compared to other identification indicators and their ease of use by a relatively inexperienced analyst. However, sex, age and associations with other elephants were also used to identify individuals. The challenge arose, while using a methodology, in identifying juvenile elephants, as they typically lack distinct scars or markings crucial for this methodology, thereby skewing the identification process towards older adults. Similarly, it is possible that using a methodology which relies heavily on ear markings and scars would also create a bias towards male adults due to their greater likelihood of bearing scars through competitive interactions. As such there were more males identified in this study than females.

Creation of the ID cards and the ID catalogue ensured a number of repeatable criteria were recorded for each individual elephant and is useful for future expansion of this work. Some elephants included within the ID catalogue were only identified once but were included in the catalogue due to their distinctive features such as torn ears, as these features are easy to recognise and are unique, allowing them to be reidentified easily. Upon completion of the ID catalogue, the cards were reviewed by the supervisor of this study to assess their accuracy. However, there was no secondary image analysis to corroborate the findings of the main analyst. This gap in validation of repeatability occurred due to constraints such as time limitations.

Nevertheless, the developed ID cards have the potential for broader applications within the Congo basin, with the initial draft already utilized during recent field expeditions (Jůnek & Lhota, Pers. Comm). Comparing the catalogue to individuals across neighbouring regions could yield valuable insights into elephant migration patterns, although this endeavour would require further exploration.

The pattern of individual elephants return follows the relative abundance information for elephants at Dibo bai and the trend of increased visitation to bais in the wet season, and during periods of increased fruit availability (Birkett et al., 2012; Blake, 2002). Our results shows that 35% of identified individuals did not return to the bai again (or were unidentified). This implies to a need of parallel monitoring scheme with improved placement of cameras at surrounding bais in the core area of Messok-Dja along with gunshot detection via PAM to understand movement of elephant groups across the landscape.

6.4. Camera Trap Positioning

Despite a substantial dataset of images, resulting in an average of more than 2 events per day, 43.7% of images could not be attributed to either sex or age guilds. This suggests that our camera placement was suboptimal and should be improved for future studies. Consequently, identification was challenging, and the results should be interpreted with caution.

The data used in this study was taken from camera traps positioned specifically to capture a wide range of forest mammal species. Forest elephants were the largest of the forest animals expected to be captured by these cameras and consequently, there were instances where the camera placement proved suboptimal for discerning sex, age, or individual identification, particularly when elephants were in close proximity to the camera. In some cases, portions of the elephant's body were cut out of the frame, or only the front of their head was visible (Image 5), and at times, such as in Image 6 foliage had fallen over the camera trap or was obscuring the elephant's bodies.

Image 5. Example of image from DM11 in which the elephant is obscured from view.

Image 6. Example of image from DM2 in which the camera frame is covered by foliage.

Oftentimes the cameras along trails consistently captured images showing only the right flank of an individual and therefore capturing flank profile images for the ID catalogue proved difficult. This limitation also proved to be an issue for identifying sex of the individual. Any identification of an individual based on distinctive markings on one side of the body were also limited by the view of the images. Although nocturnal visitations were more frequent and for longer durations, the identification using the images captured during these times were challenging, especially as they were more likely to be blurred (Image 7).

Image 7. Example of image from DM3 in which nocturnal identification is not possible.

When assessing the size of an elephant the angle of the camera factored heavily in the ease of determination. Without references the size of an elephant is difficult to assess. Nonetheless, size proved instrumental in determining both age and sex when referenced appropriately within the frame.

As seen in Figure 10, the camera trap location with the highest number of images collected was not the most successful for identifications.

Despite these challenges, there were instances where camera trap positioning was ideal for accurately identifying sex, age, and observing distinguishing features useful of individual identification. These locations were often the areas of highest activity where elephants would turn and moved their bodies rather than just travel through the frame. One such example is from camera trap location DM14 depicted in Image 8.

At this location elephants often stood for prolonged periods and repositioned their bodies at different angles within view of the camera. The camera was positioned at the perfect height and distance from the area of interest to capture the entirety of the elephant. These camera positionings are useful to understand at Dibo bai as they can be preferentially used for identification of elephants in the future, however, without preliminary camera placements it is difficult to assess how appropriate the camera trap positioning will be for observing forest elephants at other forest clearings.

Image 8. Example of image from DM14 showcasing perfect conditions for identification.

Elephants are known to target and destroy camera traps in the field, and during our study we have lost two cameras at Dibo bai (Jůnek & Lhota, Pers. Comm.). Hence, any use of pillars for camera traps to obtain ideal view on elephants would result in the collapse of such structure and/or damage to equipment. Researchers must understand that placement of cameras in the field will always be a trade-off between ideal image and risk of its damage, theft, or rotation away from the target. Such non-standardisable images will likely challenge any applications of machine learning in upcoming automated identification process using artificial intelligence.

7. Conclusion

The aim of this thesis was to investigate the activity patterns of forest elephants, critically endangered and keystone species, at Dibo bai using camera trapping technology and to identify individual elephants. Camera trapping is considered the most effective method of studying wild forest elephants (Gessner et al., 2014), which our study yielding 43,947 elephant images confirmed. The use of camera traps is an effective and cost-effective way to identify elephants, if positioned correctly for the species. ID catalogue of elephants might serve as an alternative for collaring when cameras are deployed over the landscape, also to uncover crop raiding individuals. Migration pattern and connectivity of elephant population in gradually fragmenting habitats and finding solution in human-elephant conflicts are becoming topical in Northern Republic of Congo.

Key findings from this study revealed that forest elephants exhibit a conservative activity pattern, aligning with existing literature. Notably, they display a nocturnal activity and preference for visiting ecotone habitats and frequent forest clearings more often and for longer durations during the wet seasons when access of humans is limited. Forest elephants in Messok-Dja perform such diel, spatial, and temporal behaviour that we can conclude they have likely encountered hunters, potentially also from neighbouring Cameroon. This poses a hypothesis that elephants may be entering Messok-Dja from Cameroon to find refuge, highlighting the critical importance of prioritizing patrols and protection efforts in the area.

Our results not only corroborate previous research but also connect longitudinal studies in the forest clearings of the Congo basin. This study establishes a baseline for long-term monitoring of bais, not only within the study area but also across forest elephant strongholds.

7.1. Future Research

There are still challenges to be addressed and in order to build upon the findings of this study we primarily need to focus on improving the placement of camera traps for effective identification. Results indicate that number of cameras might be lowered in favour to expand study on other bais.

With the creation of the ID catalogue, there arises an opportunity to monitor elephant movements from Dibo bai to neighbouring bais in the region, or to track habitat preferences of individual elephants. Moreover, the catalogue holds potential for expansion as more elephants are identified at Dibo bai.

Further investigations should include genetic sampling of elephants and mineral composition analysis at Dibo bai to identify specific minerals of importance in the area. Exploring potential connectivity with Odzala-Kokoua National Park is crucial for maintaining healthy forest elephant populations. Additionally, continued annual acoustic research is necessary to correlate gunshots with the presence or, more importantly, absence of forest elephants from forest clearings.

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