Sharing space between humans and forest elephants: A comprehensive review

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Abstract

Introduction: Human-wildlife coexistence is an increasingly important challenge in multiple-use landscapes where conservation goals intersect closely with human development needs. In Central and West Africa, the range of forest elephants (*Loxodonta cyclotis*) extends beyond the boundaries of protected areas. This spatial overlap presents multifaceted challenges for both forest elephants and human communities.

Methods: Through an extensive literature review, we synthesize current knowledge on human-forest elephant coexistence in Central and West Africa by assessing the spatial distribution of research efforts, identifying key challenges associated with human-forest elephant cohabitation, and analyzing the multi-dimensional factors that influence coexistence outcomes. The review highlights current science gaps and explores potential pathways toward improved coexistence strategies.

Results: Based on data recorded at 46 research sites across nine forest elephant range countries, we identified four key coexistence challenges: challenges to elephant safety and conservation, competition for natural resources, agriculture-related conflicts, and human safety and health concerns. A dynamic interplay of environmental conditions, natural resource availability, anthropogenic disturbances, farming practices, biological aspects, socio-cultural dynamics, and institutional frameworks characterizes the coexistence of humans and forest elephants.

Discussion: We propose a framework that integrates seven interrelated strategies to support coexistence: (a) understanding spatio-temporal availability of natural resources, (b) mapping key ecological features and prioritizing habitat connectivity, (c) mapping human land-use and limiting harmful anthropogenic disturbances, (d) limiting high-risk farming practices and promoting cooperative land-use strategies, (e) studying the behavior of conflict-prone elephants, (f) improving positive perceptions of forest elephants, and (g) strengthening law enforcement and institutions. Understanding and managing human-forest elephant interactions is essential to ensuring the long-term survival of forest elephants and supporting sustainable development of local communities.

Keywords: African forest elephant (*Loxodonta cyclotis*), human-wildlife interactions, socio-ecological systems, conservation strategies, Central Africa, West Africa

1. Introduction

Human-wildlife coexistence (HWC) describes the dynamic relationship between human and wildlife populations sharing multiple-use landscapes (Pooley et al., 2021), ranging from conflicts to mutually beneficial interactions (Nyhus, 2016). Wildlife conflicts have become more frequent and diversified over the last decades (Frank and Glikman, 2019; Lamarque, 2009), largely driven by human population growth and resulting land-use changes (Shaffer et al., 2019; Harich et al., 2013). These conflicts have significant physical (e.g., injuries, disease transmission), economic (e.g., crop damage, livestock attack, property destruction), legal (e.g., fines, imprisonment linked to illegal killings), and/or psychological (e.g., safety, well-being, identity) consequences for local communities (Gross et al., 2022). Retaliation against wild animals can pose a serious threat to species' survival and food web balance (Kuiper et al., 2023). Conflicts also have far-reaching impacts on ecological processes and ecosystem dynamics (Badiora and Oresanwo, 2022). These challenges highlight the complexity of achieving sustainable coexistence that supports both conservation goals and human development (Gao and Clark, 2023).

In African countries, people and elephants have a long history of cohabitation, dating from Paleolithic times (Lev and Barkai, 2016). They have coexisted in socio-ecological systems throughout their historical coevolution as they share common resources and environmental requirements (Lev and Barkai, 2016). But today, an estimated 41% of African elephant populations inhabit areas with a high risk of conflict with human populations (Di Minin et al., 2021). This is particularly true for forest elephants (*Loxodonta cyclotis*), whose range extends beyond the boundaries of designated protected areas (Laguardia et al., 2021; Brittain et al., 2020). Forest elephants require extensive and well-connected habitats across the landscape to achieve long-distance movements in search of food sources, minerals, water, and reproductive partners (Blake and Maisels, 2023). They can travel over 2800 km annually (Mills et al., 2018) and have home ranges of up to 2226 km^2, exceeding the size of most National Parks in Central Africa (Blake et al., 2008). Consequently, they move through human-occupied landscapes, with direct (e.g., crop destruction, threats to personal safety) and indirect (e.g., financial instability, decline in well-being) negative consequences for human populations (Shaffer et al., 2019). The spatial overlap between forest elephant home ranges and human land-use is a focal point for conservation and conflict management strategies (IUCN, 2023; Gross et al., 2022).

The African forest elephant has experienced a dramatic decline, primarily driven by intense ivory poaching fueled by the international market, habitat loss, and retaliatory killings following conflicts (Breuer et al., 2016; Thouless et al., 2016; Blake et al., 2007; Gross, 2007). Consequently, the species is critically endangered according to the IUCN Red List of Threatened Species (CITES Appendix I). The long-term survival of one of the largest terrestrial mammals is severely threatened in West Africa, as evidenced by fragmented habitats (Thouless et al., 2016) and recent localized extinctions (Kouakou et al., 2020). In Central Africa, forest elephant populations have declined by 62%, and the species' range has been reduced by 30% over ten years (2002–2011) (Maisels et al., 2013). Gabon remains the primary stronghold of forest elephants, with an estimated 95,110 individuals, accounting for over half of the global population (Laguardia et al., 2021).

In this context, developing human-elephant conflict mitigation strategies is crucial to enhancing the sustainability of conservation initiatives and improving coexistence levels. Wildlife conflicts typically occur within socio-ecological systems where wildlife and human space use overlap (Pozo et al., 2018). Therefore, future strategies must extend beyond the boundaries of protected areas and incorporate a nuanced understanding of the diverse and interconnected drivers of conflict (Gross et al., 2022). This requires a holistic, multi-dimensional perspective that integrates ecological, farming, social, and institutional factors (Zimmermann and Stevens, 2021; Dickman, 2010). Key considerations include land-use dynamics shaped by wildlife (Madden et al., 2021; Wall et al., 2021). Understanding how humans and wildlife navigate shared landscapes (Buchholtz et al., 2019) is crucial for minimizing negative interactions (Reyna-Hurtado et al., 2023).

The complexity of interactions at the human-wildlife interface remains poorly understood, especially in the case of the African forest elephant. There is currently no comprehensive regional synthesis for Central and West Africa, which limits a broader understanding of human-elephant coexistence (HEC) dynamics across these regions. Through an extensive literature review, we aim to synthesize current knowledge on human-forest elephant coexistence in Central and West Africa by (a) assessing the spatial distribution of research efforts, (b) identifying key challenges associated with human-forest elephant cohabitation, and (c) analyzing the multi-dimensional factors that influence coexistence. By analyzing movement data, habitat use patterns, and conflict case studies, the study aims to highlight existing knowledge gaps and explore potential pathways toward improved coexistence strategies.

2. Methods

An extensive literature review was conducted using the international search engines Scopus and Google Scholar, as well as the African Elephant Library, containing more than 8000 scientific articles (https://www.savetheelephants.org/research/elephant-library/). The literature search was based on the following equation to capture relevant studies about African forest elephants in relation to human communities and related impacts: ("African forest elephant" OR "forest elephant" OR "*Loxodonta cyclotis*" OR "*Loxodonta africana cyclotis*") AND (human* OR people OR community OR communities

OR villager* OR farmer* OR population*) AND (coexistence OR conflict* OR "land-use" OR movement OR damage* OR "crop raiding" OR destruction* OR safety OR injury OR threat* OR disturbance* OR pressure* OR poaching OR killing*). The literature review was conducted up to June 2025, with no limitation imposed on the publication year.

Sources that inform this review include peer-reviewed publications, MSc and PhD theses, and reports from the grey literature. For the literature published in English, we assessed article eligibility by examining the title, abstract, and keywords. Articles were selected if they met the following criteria: (a) the study concerns the forest elephant, also mentioned as *Loxodonta cyclotis*, *Loxodonta* spp., or *Loxodonta africana cyclotis* (i.e., past subspecies name), (b) the study is conducted within species' range according to the IUCN database (https://www.iucnredlist.org/), (c) the study is conducted within a forest or a bistable forest zone based on the map of biomes in tropical Africa (Aleman et al., 2020), and (d) the study deals with the cohabitation between forest elephants and human populations (i.e., land-use patterns, conflicts). Although located outside the forest elephant's range, Kibale National Park was included in the study as it represents a major hybrid hotspot (Bonnald et al., 2021). In addition to these initial findings, we used the "ResearchRabbit" software (https://researchrabbitapp.com) and the "Cited by" tool in Google Scholar. "ResearchRabbit" is an innovative citation-based literature mapping tool designed to enhance the research process by efficiently exploring academic literature on the topic of interest. The "Cited by" tool of Google Scholar provides a list of publications referencing the article.

Each selected publication (n = 109) was thoroughly examined to extract relevant information regarding the study location, the temporal scale of the study, the methodological approach used, the type(s) of human-forest elephant coexistence challenge assessed (e.g., elephant safety and conservation challenges, competition for natural resources, agriculture-related conflicts, human safety and health concerns, spatial overlap/landscape use), and the dimension(s) addressed (e.g., natural resources availability, environmental and climatic characteristics, human disturbances, farming systems and agricultural practices, social and cultural dimensions, and institutional and policy frameworks) (Appendix A). All extracted data were compiled in a datasheet to facilitate systematic comparison and analysis across studies (Appendix B).

3. Results

3.1 Research efforts on human-forest elephant coexistence

Our review identified 46 research sites in nine countries within the forest elephant range where studies on human-forest elephant coexistence have been conducted (Fig. 1). Despite the significance of human-forest elephant coexistence across their range, research efforts are unevenly distributed. Research is heavily concentrated in and around National Parks, forest reserves, and other conservation areas. There is, however, a notable lack of empirical evidence on the mutual impacts of forest elephants and humans beyond the periphery of protected areas. Most studies are site-specific, with recurring emphasis on locations like the Kakum Conservation Area (Ghana), the Bia Conservation Area (Ghana), and Kibale National Park (Uganda). Moreover, comprehensive national-level datasets on HEC are scarce, although some studies provide valuable insights.

Agriculture-related conflicts are the most frequently reported form of coexistence challenge (*n* = 59), followed by elephant safety and conservation challenges (e.g., poaching, retaliatory killings) (*n* = 29). In contrast, competition for natural resources and human safety concerns were less frequently documented (*n* = 6 and 9, respectively).

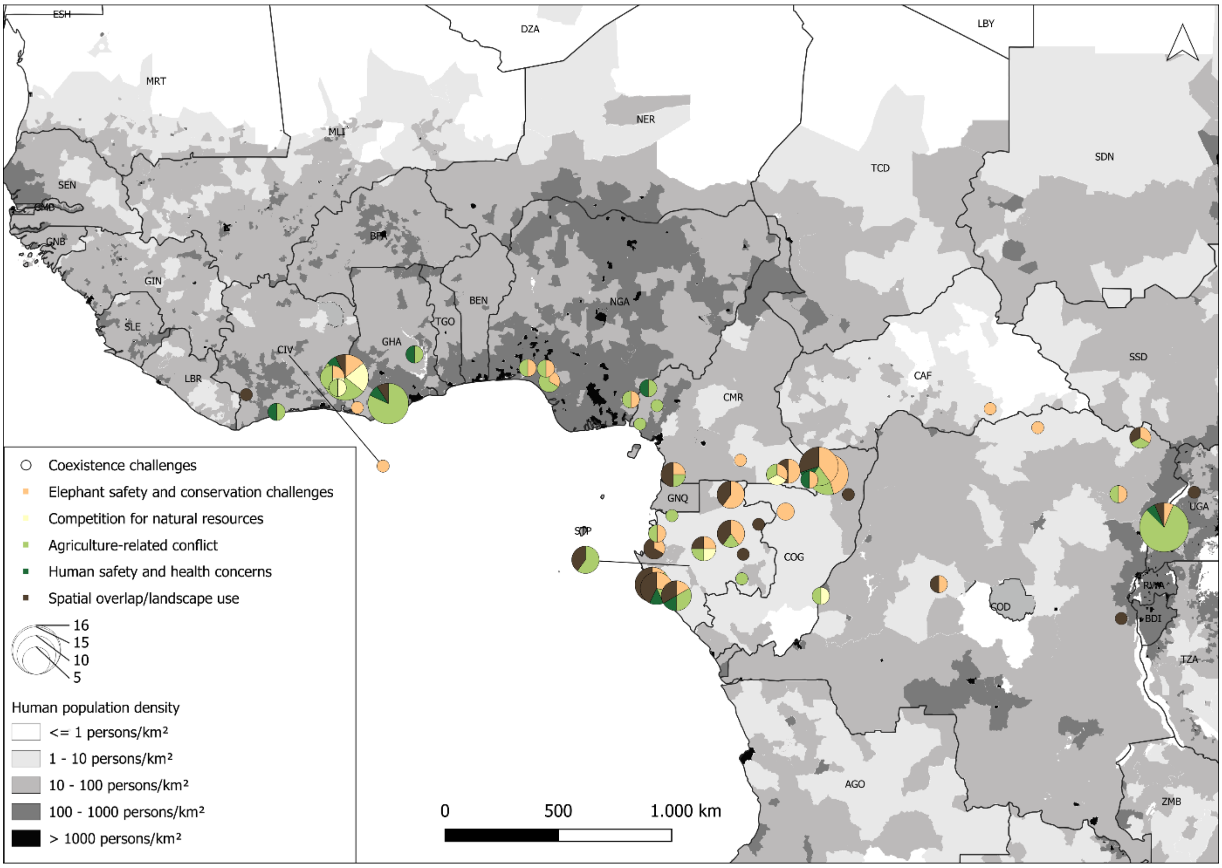

Fig. 1. Distribution of studies dealing with human-forest elephant coexistence across forest elephant's range juxtaposed with human population density. The size of the pie charts represents the number of studies published at a given location (range 1–16). Sources of spatial data: the fourth version of the Socioeconomic Data and Applications Center (SEDAC) Gridded Population of the World (GPW) (2020, pixel resolution: 1 km²) (https://sedac.ciesin.columbia.edu/data/collection/gpw-v4).

3.2 Key challenges of human-forest elephant coexistence

3.2.1 Elephant safety and conservation challenges

Poaching is a major challenge to coexistence between people and elephants. The persistent threat to elephant safety, both inside and outside protected areas, reflects complex tensions around resource use (Terada et al., 2021; Nsonsi et al., 2017). Data from the MIKE (i.e., Monitoring the Illegal Killing of Elephants) programme reveal that approximately 3% of recorded elephant carcasses (773 records) are following conflicts with human societies (for savanna and forest elephants) (Kuiper et al., 2023). But this figure underrepresents the wider patterns of illegal poaching. Forest elephant populations have experienced dramatic declines in Central Africa (Maisels et al., 2013; Blake et al., 2007), including in well-known hotspots such as Boumba Bek-Nki (Cameroon), Bangassou (Central African Republic), Ndoki-Dzanga (Congo, Central African Republic), Garamba and Salonga National Parks (DRC) (Fonkwo, n.d.; Blake et al., 2007; Smith et al., 1995). In Gabon, despite strong conservation efforts and an extensive protected areas network, forest elephants remain under threat (Brand et al., 2020; Poulsen et al., 2017). For instance, the Minkébé National Park lost over 25000 elephants (80% of its population) between 2004 and 2014, largely due to cross-border poaching pressure (Poulsen et al., 2017). Other significant poaching fronts were located in Southern Nigeria (Wahab et al., 2021; Omoregie et al., 2019) and Western Ghana (Danquah and Oppong, 2013).

3.2.2 Competition for natural resources

An estimated 478 million people in Africa rely on natural resources for food security and livelihoods (Fedele et al., 2021). Forest elephants similarly depend on natural resources for their survival : they consume a variety of wild plants (Ndi et al., 2022), including wild mangos (*Irvingia* spp.), fruits of ebom (*Anonidium mannii*), white tiama (*Entandrophragma angolense*), eveuss (*Klainedoxa gabonensis*), kimbala (*Plagiostyles africana*), and parasol trees (*Musanga cecropioides*) (Inogwabini et al., 2013). Forest elephants and humans compete for access to water resources and non-timber forest products (NTFPs), leading to direct ecological and socio-economic consequences for both species (Breuer and Ngama, 2021). Some commercially logged timber species, like moabi (*Baillonella toxisperma*), are also critical fruit sources for forest elephants (Memiaghe, 2023). Water access is also a point of conflict: forest elephants have for example damaged drinking water sources in the Bia Conservation Area (Ghana) (Harich et al., 2013).

3.2.3 Agriculture-related conflicts

Resource conflicts are particularly severe in agricultural areas, where forest elephants can cause considerable damage to cultivated plants. Small-scale subsistence and cash-crop farming form the primary livelihood strategies for communities living near protected areas in West and Central Africa. Forest elephants are perceived as the most problematic wildlife species (Terada et al., 2021; Harich et al., 2013) due to their ability to destroy an entire year of production (Kyokuhaire et al., 2023). Forest elephants have also been reported to damage food supplies stored in granaries or along roads (Kouao et al., 2020). Forest elephant incursions into community-owned lands can result in substantial economic losses for farmers and impact communities' food security, livelihoods, and socio-economic development (Galley and Anthony, 2024; Mackenzie and Ahabyona, 2012). Households adjacent to protected areas report high interannual yield variance due to crop damage (Naughton et al., 1999). In southwest Gabon, the incursion of elephants into villages and the destruction of crops are among the primary causes of impoverishment of local farming communities (Mbamy et al., 2024). Extreme conflicts have forced farmers to abandon cultivated fields around Moukalaba-Doudou National Park in Gabon, resulting in a progressive depopulation of the area (Terada et al., 2021). The broader regional economic impacts include reduced agricultural productivity and potential increases in food prices, affecting the local and national economy (Terada et al., 2021; Fairet, 2012; Walker, 2012).

3.2.4 Human safety and health concerns

Local communities, including farmers, people collecting NTFPs or firewood, and those going to rivers, may encounter forest elephants in shared habitats. Humans use elephant trail systems to access remote areas of the forest (Remis and Jost Robinson, 2020). For centuries, the Baka people of Central Africa have relied on forest elephant trails for subsistence hunting and traveling the forest (Remis and Jost Robinson, 2020). Forest elephants were responsible for ten human fatalities and 17 injuries over a 25-year period in the Takamanda-Mone Landscape in Cameroon (Fuashi et al., 2014). Similar human-elephant conflict incidents have been reported in Ivory Coast (Kouao et al., 2020). Unexpected encounters with elephants have also caused fear and panic among rural communities in Ghana (Galley and Anthony, 2024; Nkansah-Dwamena, 2023; Nutsuakor et al., 2015) and Uganda (Mackenzie and Ahabyona, 2012). In Kibale National Park, households affected by crop damage reported higher rates of disease (Mackenzie and Ahabyona, 2012). Farmers' physical and psychosocial welfare can be affected, especially when they are compelled to guard fields overnight and are exposed to stress, tiredness, and insect-borne diseases (Matsuura et al., 2024; Fairet, 2012). In some cases, guarding fields is the responsibility of children and can lead to poor school results (Mackenzie and Ahabyona, 2012). Ultimately, negative interactions with forest elephants have a cascading effect, exacerbating existing problems such as alcohol consumption (Galley and Anthony, 2024).

3.3 Multi-dimensional factors shaping human-forest elephant coexistence

The human-elephant conflict in West and Central Africa is a complex issue resulting from a diverse range of factors. This multifaceted dynamic can be understood through the following dimensions: natural resources availability, environmental and climatic characteristics, human disturbances, farming systems and agricultural practices, biological and behavioral traits of elephants, socio-cultural dimensions, and institutional and policy frameworks (Table 1).

3.3.1 Natural resources availability

The spatial distribution and abundance of natural resources (e.g., fruiting trees, water, mineral deposits) influence forest elephant populations and the patterns of human-elephant interactions. Although forest elephants are generalist herbivores, they critically depend on fruit tree species like *Irvingia gabonensis* or *Sacoglottis gabonensis* (Blake, 2002). Research suggests that forest elephant presence and movement are positively influenced by the local availability of crucial fruit tree species (Djoko et al., 2022; Benitez and Queenborough, 2021; Cardoso et al., 2020; Short, 1983). Forest elephants are also highly sensitive to surface water availability, with the abundance of water sources constraining their habitat use in western Ghana (Danquah, 2016). Forest elephants in Gabon stay near perennial water sources during dry seasons in response to relative water limitation (Mills et al., 2018). Additionally, forest clearings and areas rich in mineral deposits attract prolonged elephant presence and foraging activity (Blake and Maisels, 2023). Natural permanent forest clearings were identified as strong predictors of elephant density in northern Congo (Stokes et al., 2010).

Therefore, the location of natural resources influences the spatio-temporal patterns of HEC. For example, forest elephants are particularly attracted to agricultural fields containing fruiting tree species, such as *Pseudospondias microcarpa*, *Irvingia gabonensis*, *Chrysophyllum africanum*, and *Tetrapleura tetraptera* in Gabon (Ngama et al., 2019), as well as *Carica papaya* and *Tieghemella heckelii* in Ghana (Dakwa et al., 2016). Mango trees also attract elephants to villages near Lopé National Park (Memiaghe, 2023). Open water sources near croplands have been identified as critical gathering points for elephants in the periphery of Kibale National Park (Reyna-Hurtado et al., 2023). Similarly, fields experiencing the most damage in the Malebo region (DRC) were located along elephant trails leading to permanent water points (Inogwabini et al., 2013). Seasonal changes in fruit availability can further reduce or increase crop damage (Bilenga Moukodouma et al., 2023). In the Kakum Conservation Area, crop damage declined when fruits became more available in nearby forests (Danquah et al., 2007).

3.3.2 Environmental and climatic characteristics

Research suggests that vegetation characteristics, climate, and environmental features play a fundamental role in shaping forest elephant distribution, movement, and HEC dynamics.

Forest elephant habitat use is linked to vegetation characteristics, as reflected in both ground-based measures and remote sensing indices. A positive correlation between canopy cover and elephant abundance suggests a preference for dense forests in the Ivory Coast (Theuerkauf et al., 2001) and the DRC (Mubalama and Banswe, 2023). In western Ghana, elephants' preference for secondary forests (Danquah, 2016) - often adjacent to settlements and agricultural areas - heightens the risk of human-elephant conflicts (Fairet, 2012). Additionally, tree species richness affected forest elephant presence and relative abundance (Djoko et al., 2022). At broader spatial scales, satellite-based vegetation indices (e.g., Enhanced Vegetation Index (EVI), Normalized Difference Vegetation Index (NDVI)) are indicators of habitat selection by elephants (Wall et al., 2021; Mills et al., 2018). In Ghana, a decline in EVI was associated with higher incidences of crop damage, linking vegetation density to HEC (Lavelle, 2018).

Rainfall is another crucial factor, influencing both elephant movement and the temporal occurrence of crop damage incidents. GPS tracking shows that elephants increase their movement during rainy seasons, potentially moving away from permanent water sources (Beirne et al., 2021, 2020; Schuttler et al., 2012; Blake, 2002). However, regional variation exists, as elephants in Congo reduce their movements during peak rainfall periods (Molina-Vacas et al., 2020). Beyond direct effects on movement, rainfall shapes human-elephant interactions by influencing crop cycles and fruit availability, increasing competition for natural and non-natural resources during periods of scarcity (Nutsuakor et al., 2015; Danquah et al., 2007; Barnes et al., 2007; Chiyo et al., 2005; Lahm, 1996). Temperature seasonality may promote nocturnal behavior (Beirne et al., 2021) and reduce travel distance of forest elephants (Beirne et al., 2021; Molina-Vacas et al., 2020).

Furthermore, (Wall et al., 2021) suggest that savanna and forest elephants have smaller ranges where the terrain is steep. Supporting this, no incidents of crop damage were recorded in plantations with slopes greater than 25% in Gabon (Ngama et al., 2019). The lunar cycle influences nocturnal movement of forest elephants in Ghana, with significantly less crop damage at full moon (Barnes et al., 2007).

3.3.3 Anthropogenic disturbances

Research suggests that negative human-forest elephant interactions have intensified due to increasing anthropogenic disturbances. Human encroachment on forest landscapes has increased the risk of negative interactions with forest elephants (Maurice et al., 2023). Additionally, human activities have induced demographic, behavioral, and spatial changes in forest elephant populations, which may exacerbate conflicts (Breuer et al., 2016). The Human Footprint Index (HFI), a measure of cumulative human pressure, has been shown to constrain elephant movements at both continental (Wall et al., 2021) and local scales (Beirne et al., 2021). Land-use changes driven by human population growth, extractive-use concessions (e.g., gas, oil, mining, logging), and agricultural expansion have significantly impacted elephant populations in West (Boafo et al., 2004) and Central Africa (Blake et al., 2008). In other regions (e.g., Gabon), rural exodus has coincided with increased crop damage (Memiaghe, 2023; Walker, 2010; Lahm, 1996).

Forest elephants avoid areas of high hunting pressure (Kely et al., 2021; Danquah, 2016; Yackulic et al., 2011) and respond acutely to gunfire (Swider et al., 2022). As a result, they may take refuge in secure areas, including villages (Nomoto and Akomo-Okoue, 2025; Breuer et al., 2016). Research and ecotourism areas have also contributed to providing safe habitats for elephants in Taï National Park (Ivory Coast) (Kely et al., 2021). The response of forest elephants to logging activities varies by region (Scalbert et al., 2025; Wrege et al., 2024; Stokes et al., 2010), but in Ghana, logging has attracted elephants close to park boundaries (Barnes et al., 1995). In Gabon, elephants have continued to inhabit areas undergoing oil prospection, but have adapted by becoming more nocturnal (Wrege et al., 2010).

According to Blake et al. (2008), the size of roadless wilderness is the main factor determining the home range size of forest elephants in the Congo Basin. Generally, the presence and abundance of elephants increase with distance from major roads (Danquah, 2016; Stokes et al., 2010; Blake et al., 2007; Buij et al., 2007; Blom et al., 2004; Barnes et al., 1991) and settlements (Mubalama and Banswe, 2023; Danquah, 2016; Buij et al., 2007; Theuerkauf et al., 2001; Barnes et al., 1991). Road avoidance behavior intensifies in response to higher local hunting pressure in Gabon (Laurance et al., 2006), while some secondary or abandoned roads may be permeable to movement (e.g., Cameroon, Scalbert et al., 2023a; Gabon, Mills et al., 2018). Elephants adjust their speed near human-built infrastructures (Molina-Vacas et al., 2020; Kim, 2019).

3.3.4 Farming systems and agricultural practices

Risk factors related to farming practices include field size, proximity to the closest protected area, and degree of field isolation. Research consistently indicates that the number of elephant incursions increased with larger field sizes (Maurice et al., 2023; Harich et al., 2013; Monney et al., 2010; Oppong et al., 2008; Barnes et al., 2005; Naughton-Treves, 1998) and closer proximity to park boundaries or forest edges (Kyokuhaire et al., 2023; Rogers et al., 2023; Mackenzie and Ahabyona, 2012; Monney et al., 2010; Oppong et al., 2008; Barnes et al., 2005; Sam et al., 2005). Isolated fields may also be more vulnerable to elephant foraging than those in clusters (Barnes et al., 2005), particularly when surrounded by secondary forests (Fairet, 2012).

Although forest elephants primarily target food crops, they also damage cash crops such as cocoa and coffee trees (Kamiss and Turkalo, 1999). Their foraging preferences are influenced by crop phenology (Awukuvi et al., 2025; Ngama et al., 2019; Amundala et al., 2018; Monney et al., 2010; Oppong et al., 2008; Danquah et al., 2007; Sam et al., 2005). Crop diversity can influence elephant activity: monoculture farms near the Bia and Kakum Conservation Areas experience less damage than mixed-crop farms (Oppong et al., 2008; Barnes et al., 2005; Sam et al., 2005). The palatability (Rogers et al., 2023), quality (Awukuvi et al., 2025), and nutritional value (Rode et al., 2006) of crops also affect elephant preferences. Specific agricultural practices, such as post-harvest cocoa storage methods, can increase crop vulnerability to elephants as observed in the Bia Conservation Area (Harich et al., 2013).

Farmers may protect their crops by investing in guarding or technical deterrents (e.g., scarecrows, fire, fences, trenches, beehives), which can affect the occurrence and intensity of damage (Rogers et al., 2023; Ngama et al., 2019, 2016; Naughton-Treves, 1998). In Kibale National Park (Uganda), crop damage was less frequent in villages where farmers employed lethal deterrents (e.g., traps, snares, poison) (Naughton-Treves, 1998). Household income has been found to affect the likelihood of crop damage, with lower-income households being more vulnerable due to limited access to effective deterrents (Kyokuhaire et al., 2023). Ultimately, agriculture-related conflict in Okomu National Park (Nigeria) is linked to illegal farming along its boundaries (Digun-Aweto et al., 2019).

3.3.5 Biological and behavioral traits of elephants

The biological traits of forest elephants contribute to the complexity of HEC, as their movements depend on intrinsic factors reflecting the individual's internal condition. Sex-related differences in movement patterns are notable: males have larger annual and monthly home ranges (Beirne et al., 2021; Wall et al., 2021; Mills et al., 2018), longer travel distances (Kolowski et al., 2010), and lower site fidelity than females (Beirne et al., 2021), except in North Congo (Molina-Vacas et al., 2020). These differences likely reflect distinct reproductive and social strategies: females typically travel in family units, while males are more solitary, especially during musth. Male elephants in Gabon are slightly more nocturnal than females (Beirne et al., 2021), and exhibit greater risk-taking behavior to access fruits (Meyer et al., 2022). In Uganda, young males (10–14 and 20–24 years) were more involved in agriculture-related conflict (Chiyo and Cochrane, 2005), while in Ghana and Gabon, groups were also implicated (Johnson et al., 2019; Sam et al., 2005). Crop damage in Uganda peaks during periods of high reproductive competition (Chiyo and Cochrane, 2005).

Recent findings based on GPS collaring of 96 elephants across Gabon indicate that individual behavior plays a significant role in determining the movement of forest elephants (Beirne et al., 2021). Different individuals exhibit highly variable home ranges, independent of the environmental context, which contributes to the complexity of understanding their movements and ecological needs (Kolowski et al., 2010). Analysis of individual cases reveals contrasting behavioral patterns to crop availability in Ivindo National Park (Mbamy et al., 2024). Elephant behavior can be strongly influenced by individual experiences, such as showing unusual aggressive behavior in response to the death of a conspecific (Breuer and Ngama, 2021).

3.3.6 Social and cultural dimensions

Human perceptions and attitudes strongly influence coexistence with forest elephants. Socio-economic factors, such as ethnicity, education or occupation, influence how individuals perceive and interact with forest elephants (Nsonsi et al., 2017). However, these relationships are context-specific, as variations in social norms within and between communities can lead to differing perceptions and responses to elephant presence. In some communities, African elephants hold symbolic and cultural value (Usongo, 2003; Hill, 1998).

Conservation initiatives in Gabon and Congo have influenced local attitudes toward forest elephants (Terada et al., 2021; Nsonsi et al., 2017), while tourism development can affect experiences of cohabitation (Ndong, 2018). However, unequal distribution of benefits from these activities often creates tensions over participation and benefit-sharing (Terada et al., 2021). In Uganda, involving communities in non-lethal deterrent projects led to a reduction of perceived human-elephant conflict (Kolinski and Milich, 2021). Ultimately, conflicts among community members and other stakeholders (i.e., protected area managers, policymakers, government authorities, NGOs) can further intensify the perceived costs of conflicts. For example, in Nigeria, tensions between farmers and rangers have been documented in parallel of HEC challenges (Digun-Aweto et al., 2019).

3.3.7 Institutional frameworks and policies

The absence of robust conservation frameworks and policies exacerbates the challenges of coexistence. Poor governance structures and weak enforcement of existing wildlife protection laws continue to exacerbate threats to forest elephants (Kuiper et al., 2023; Maisels et al., 2013). Although international (e.g., CITES) and national legal frameworks exist, these are often inconsistently implemented, underfunded, and poorly monitored. In several countries, high levels of corruption within governmental institutions undermine conservation efforts (Gross, 2007). In the Democratic Republic of Congo, the Republic of Congo, and the Central African Republic, civil wars have facilitated poaching, transport and illegal trade of ivory (Funk et al., 2022; Beyers et al., 2011; Gross, 2007). This trade has been stimulated by high global demand and the increase in market value of ivory. Ultimately, the lack of economic incentives for local communities exacerbates the problem. In Central Africa, national compensation schemes for elephant-related losses are often inadequate or non-existent, undermining community support for conservation initiatives (Breuer and Ngama, 2021).

Table 1. Factors reported to be significantly correlated with forest elephant land-use and conflict in West and Central Africa. The factors are classified into seven categories: natural resources availability, environmental and climatic characteristics, anthropogenic disturbances, farming systems and agricultural practices, biological and behavioral traits of elephants, social and cultural dimensions, and institutional and policy frameworks. The list is non-exhaustive, and the factors are non-mutually exclusive.

Category	**Factor**	**References**
Natural resources availability	Fruit trees	Bilenga Moukodouma et al., 2023; Memiaghe, 2023; Djoko et al., 2022; Benitez and Queenborough, 2021; Beirne et al., 2020; Cardoso et al., 2020; Ngama et al., 2019; Dakwa et al., 2016; Ngama et al., 2016; Danquah et al., 2007; Short, 1983
	Water sources	Reyna-Hurtado et al., 2023; Mills et al., 2018; Danquah, 2016; Inogwabini et al., 2013; Fairet, 2012
	Minerals (bais)	Blake and Maisels, 2023; Stokes et al., 2010
Environmental and climatic characteristics	Vegetation structure, including secondary regrowth	Danquah, 2016; Fairet, 2012; Smith et al., 1995
	Canopy cover	Mubalama and Banswe, 2023; Theuerkauf et al., 2001
	Tree species richness	Djoko et al., 2022
	Enhanced Vegetation Index (EVI)	Mills et al., 2018; Lavelle, 2018
	Normalized Difference Vegetation Index (NDVI)	Wall et al., 2021
	Rainfall	Beirne et al., 2021; Beirne et al., 2020: Molina-Vacas et al., 2020; Nutsuakor et al., 2015; Schuttler et al., 2012; Danquah et al., 2007; Barnes et al., 2007; Chiyo et al., 2005; Blake, 2002; Lahm, 1996
	Temperature	Bilenga Moukodouma et al., 2023; Beirne et al., 2021; Molina-Vacas et al., 2020
	Topography	Wall et al., 2021; Molina-Vacas et al., 2020; Ngama et al., 2019; Kim, 2019
	Lunar cycle	Barnes et al., 2007
Anthropogenic disturbances	Presence of humans/human population density	Mubalama and Banswe, 2023; Kouakou et al., 2020; Amin et al., 2020; Maisels et al., 2013; Blom et al., 2004
	Hunting activities	Wrege et al., 2024; Djoko et al., 2022; Kely et al., 2021; Danquah, 2016; Danquah and Oppong, 2013; Maisels et al., 2013; Yackulic et al., 2011; Remis and Hardin, 2009; Laurance et al., 2006; Naughton-Treves, 1998
	Logging activities	Scalbert et al., 2025; Wrege et al., 2024; Memiaghe, 2023; Djoko et al., 2022; Stokes et al., 2010; Barnes et al., 1995
	Roadless wilderness size	Blake et al., 2008

	Distance to roads	Molina-Vacas et al., 2020; Danquah, 2016; Stokes et al., 2010; Blake et al., 2007; Buij et al., 2007; Laurance et al., 2006; Blom et al., 2004; Barnes et al., 1991
	Distance to villages/settlements/farmlands	Mubalama and Banswe, 2023; Molina-Vacas et al., 2020; Kim, 2019; Danquah, 2016; Buij et al., 2007; Theuerkauf et al., 2001; Barnes et al., 1991
	Habitat degradation and fragmentation	Boafo et al., 2004
	Rural exodus of villagers	Memiaghe, 2023; Walker, 2010; Lahm, 1996
	Distance to research/ecotourism areas/lodges	Kely et al., 2021; Molina-Vacas et al., 2020
	Human Footprint Index (HFI)	Beirne et al., 2021; Wall et al., 2021
	Distance to protected area boundary	Kely et al., 2021; Stokes et al., 2010; Blake et al., 2007
	Conservation management status of the area	Kouakou et al., 2020; Stokes et al., 2010
Farming systems and agricultural practices 	Field size	Awukuvi et al., 2025; Maurice et al., 2023; Harich et al., 2013; Monney et al., 2010; Oppong et al., 2008; Barnes et al., 2005; Naughton-Treves, 1998
	Degree of field's isolation	Fairet, 2012; Barnes et al., 2005
	Proximity of field to protected area boundary or forest edge	Kyokuhaire et al., 2023; Rogers et al., 2023; Mackenzie and Ahabyona, 2012; Monney et al., 2010; Oppong et al., 2008; Barnes et al., 2005; Sam et al., 2005; Naughton-Treves, 1997; Barnes et al., 1995; Dudley et al., 1992
	Number of crop types	Oppong et al., 2008; Barnes et al., 2005; Sam et al., 2005
	Crop phenology	Awukuvi et al., 2025; Ngama et al., 2019; Amundala et al., 2018; Monney et al., 2010; Oppong et al., 2008; Danquah et al., 2007; Sam et al., 2005
	Other crop characteristics (availability, quality, palatability, nutrient concentration)	Awukuvi et al., 2025; Mbamy et al., 2024; Rogers et al., 2023; Rode et al., 2006
	Specific agricultural practices	Harich et al., 2013
	Guarding intensity or use/quality of deterrents	Rogers et al., 2023; Ngama et al., 2019; Ngama et al, 2018; Ngama et al., 2016; Naughton-Treves, 1998
	Income level of farmers	Kyokuhaire et al., 2023
	Illegal farming	Digun-Aweto et al., 2019
	Sex	Meyer et al., 2022; Beirne et al., 2021; Wall et al., 2021; Molina-Vacas et al., 2020; Johnson et al., 2019; Mills et al., 2018; Kolowski et al., 2010; Chiyo and Cochrane, 2005

Biological and behavioral traits of elephants	Age	Johnson et al., 2019; Chiyo and Cochrane, 2005
	Personality	Mbamy et al., 2024; Beirne et al., 2021; Kolowski et al., 2010
	Level of elephant aggressiveness	Breuer and Ngama, 2021
	Health physiological status	Ngama, 2018
Social and cultural dimensions	Cultural value of forest elephants	Usongo, 2003; Hill, 1998
	Socio-economic factors	Nsonsi et al., 2017; Hill, 1998
	Benefits from conservation	Terada et al., 2021; Nsonsi et al., 2017
	Level of tourism development	Ndong, 2018
	Community involvement in research projects	Kolinski and Milich, 2021
Institutional and policy frameworks	Absence of law enforcement	Kuiper et al., 2023; Maisels et al., 2013
	Poor governance/corruption	Kuiper et al., 2023; Maisels et al., 2013
	Civil war	Funk et al., 2022; Beyers et al., 2011
	Lack of economic incentives	Breuer and Ngama, 2021

4. Discussion

4.1 Knowledge gaps and research perspectives

Our geographical analysis of research efforts on human-forest elephant coexistence reveals substantial knowledge gaps across the species' range. The database is limited to specific study sites located near protected areas. Consequently, some regions within the forest elephant's range remain under-documented, notably due to security issues, poor infrastructure, and funding limitations. This spatial bias limits our ability to identify major conflict hotspots and the broader dynamics of human-forest elephant interactions. Moreover, there is no centralized database that systematically compiles cases of agricultural or security issues at either the regional or national level. Data collection methods vary widely in terms of accuracy, scale, and community involvement. Therefore, adopting a standardized, community-based data collection protocol is crucial (Songhurst, 2017).

Most existing research on human-forest elephant coexistence focuses primarily on crop damage. We suggest extending the scope of research beyond agriculture-based conflict to provide a more nuanced understanding of the challenges faced by forest elephants and human populations. We also suggest that future work should extend to the diversity of interactions (i.e., positive, negative, neutral) between humans and forest elephants. Negative interactions alone do not accurately represent the entire situation (Kansky and Knight, 2014; Dickman, 2010). Studies often overlook neutral or beneficial interactions that may occur over time, resulting in an incomplete comprehension of the system. In some regions, forest elephants and humans may coexist peacefully, but these places remain poorly documented as researchers tend to focus on the negative aspects of coexistence.

Additionally, the coexistence level is shaped by a complex interplay of factors that interact across multiple spatial and temporal scales. Some factors are specific to local conditions, such as resource availability, while others are larger-scale drivers of conflict processes. While the factors shaping HEC are well documented, their seasonal variation and interaction with local environmental and human contexts generate high spatial and temporal variability, making reliable predictions challenging. Therefore, to address this complexity, holistic views involving all dimensions of coexistence need to be employed (Zimmermann and Stevens, 2021). Drivers need to be identified through site-specific studies to inform more effective conflict management beyond conservation areas (Gross et al., 2018).

4.2 Toward human-forest elephant coexistence

Given the significant knowledge gaps identified, adopting a comprehensive and integrative approach is essential to advance coexistence efforts. Therefore, we propose a conceptual framework that integrates key pathways based on the multiple dimensions of human-elephant coexistence (Fig. 2).

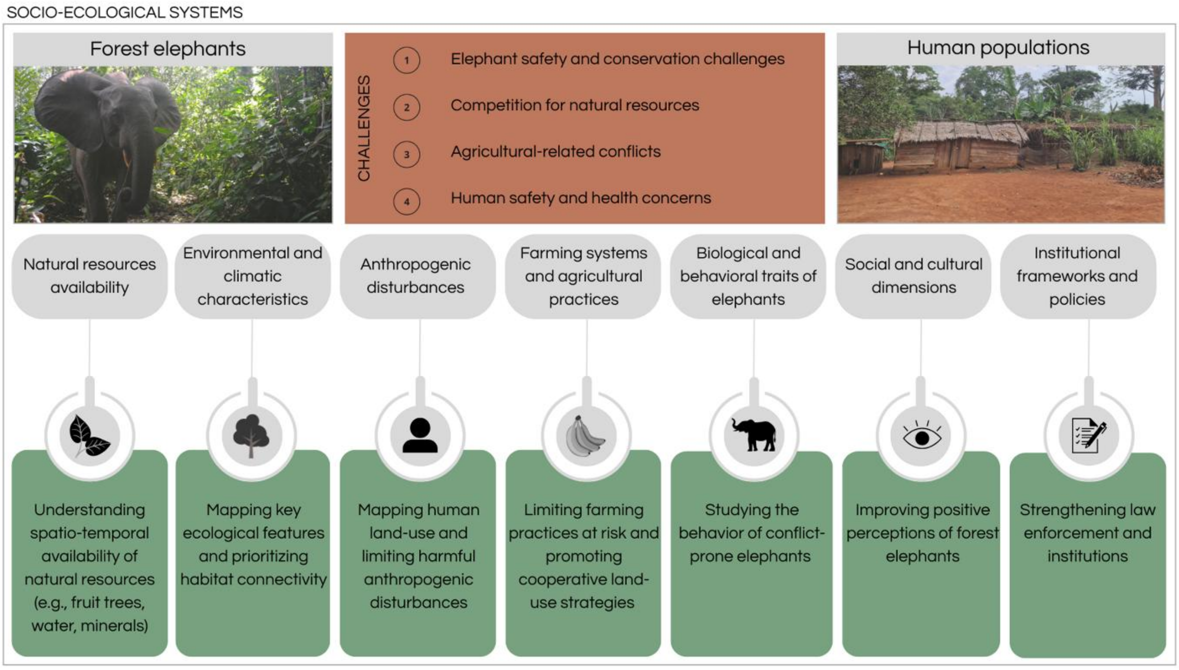

Fig. 2. Conceptual framework of the study on human-forest elephant coexistence. The framework integrates seven interrelated strategies designed to support coexistence initiatives. The framework operates across multiple spatial scales, ranging from specific local sites where targeted interventions are implemented, to broader regional and transboundary landscapes that require coordinated habitat connectivity and policy actions.

4.2.1 Understanding spatio-temporal availability of natural resources

The distribution and availability of natural resources (e.g., fruiting trees, water, minerals) influence forest elephant foraging activity, ultimately affecting the patterns of human-elephant interactions. A comprehensive understanding of the spatio-temporal dynamics of these resources, including seasonal changes, is crucial for mitigating negative human-elephant interactions (Benitez and Queenborough, 2021; Beirne et al., 2020). Promoting land-use practices that limit cultivation near high-risk zones represents a practical approach to mitigate human-elephant conflicts (Naughton et al., 1999). High-risk zones include areas near mineral-rich forest clearings (i.e., bais), water points, fruiting tree clusters, and permanent trails. However, land scarcity, economic constraints, and local land tenure systems often limit the capacity of people to modify land-use (Hartter et al., 2011). Complementary measures, such as enhancing alternative water points away from villages or protecting fruiting trees within forests, can further reduce the likelihood of negative interactions (Memiaghe, 2023).

4.2.2 Mapping key ecological features and prioritizing habitat connectivity

Environmental and climatic factors (e.g., vegetation structure, tree species composition, rainfall, temperature, topography, lunar cycle) can significantly influence forest elephant habitat use, movement patterns, and HEC dynamics. Climate change is increasingly recognized as a major driver of ecological change in tropical ecosystems. Recent models project significant drying in West Africa and shorter wet periods in Central Africa (Diedhiou et al., 2018), which may strengthen the effects of resource scarcity on elephant populations. Climate-driven changes in fruit production could have negatively impacted elephant body condition, as suggested in Lopé National Park (Bush et al., 2020), and can increase competition with humans over limited resources (Benitez and Queenborough, 2021). These insights highlight the need to prioritize habitat connectivity and access to water and fruit sources during dry periods. In line with the Global Biodiversity Framework adopted by the UN Convention on Biological Diversity in 2020, this requires regional-scale mapping of migration corridors and reinforcement of ecological linkages (Brennan et al., 2022).

4.2.3 Mapping human land-use and limiting harmful anthropogenic disturbances

Limiting harmful anthropogenic disturbances is essential to ensuring the survival of the African forest elephant, which is particularly vulnerable due to its slow reproductive rate (Turkalo et al., 2017). While strong enforcement of anti-poaching laws and enhanced surveillance in high-risk areas remain important for reducing illegal killings, conservation efforts must rely on complementary approaches. For example, meaningful community participation, shared management of resources, and collaborative decision-making processes can help reduce current pressures on elephants. Within this framework, participatory mapping is a critical tool, enabling the identification of village boundaries, traditional land-use zones, and ecologically sensitive areas. At the same time, the illegal ivory trade must be effectively controlled across the entire supply chain, from elephant-range countries to ivory destination markets (Blake et al., 2007).

4.2.4 Limiting farming practices at risk and promoting cooperative land-use strategies

The scale and spatial configuration of farming, the attractiveness of crops, and the deterrent use are key factors influencing the vulnerability of agricultural areas. In this context, cooperative land-use strategies can foster collective responsibility and reduce individual risk. However, the feasibility of cooperative farming can vary considerably among villages based on cultural habits, land availability, and the historical context of human-wildlife interactions (Matsuura et al., 2024; Naughton et al., 1999). Farmers could also select less attractive crops like chili peppers (*Capsicum* spp.) (Parker and Osborn, 2006), ginger (*Zingiber officinale*), onion (*Allium cepa*), garlic (*Allium sativum*), and lemon grass (*Cymbopogon citratus*) (Gross et al., 2016). Studies in Ghana indicate that forest elephants rarely damage fields protected by chili pepper fences (Wiafe and Sam, 2014; Harich et al., 2013). Moreover, non-lethal deterrents can help prevent forest elephants from encroaching on cultivated lands or important trees: visual deterrents (spotlights, scarecrows, fires), acoustic deterrents (drums, cans, bells, gunshots), olfactory deterrents (*Capsicum* spp. sprays) and barrier systems (trenches, wire string fences, chili fences, beehives fences, electric fences) (Shaffer et al., 2019; Nelson et al., 2003). Their effectiveness varies depending on local environmental and social contexts, particularly regarding the funding and management of the systems. Strategic deployment of crop protection methods should be prioritized during high-risk periods (e.g., rainy season), when forest elephant activity tends to increase (Danquah et al., 2007).

4.2.5 Studying the behavior of conflict-prone elephants

Forest elephants exhibit inter-individual variation in movement behaviors and habitat preferences. These results support the integration of behavioral ecology (e.g., differences in sex, age, temperament, physiological condition) into HEC strategies. The complexity of addressing HEC stems in part from the species' movement patterns, which are shaped not only by environmental conditions and anthropogenic pressures but also by individual-level characteristics. Some individuals, particularly males, are more prone to extensive movements, increasing the likelihood of conflicts with human populations (Swan et al., 2017). Moreover, some elephants demonstrate risk-taking behaviors (Mimeault and Weladji, 2025) that make them disproportionately vulnerable to poaching pressure. Understanding these individual differences can support the identification of so-called "problem individuals" and the development of targeted interventions, including selective deterrence, enhanced early warning systems, and behavior-based relocation. Forest elephant populations could notably be surveyed using empirical observations and ecological knowledge of local people, especially within hard-to-reach areas (Brittain et al., 2020).

4.2.6 Improving positive perceptions of forest elephants

Understanding and addressing people's perceptions and tolerance toward forest elephants are essential to fostering coexistence (König et al., 2020). Effective conservation strategies must go beyond ecological considerations to include socio-cultural dimensions, particularly by recognizing the diverse values that communities associate with forest elephants. (Mackenzie et al., 2017) propose a dynamic exchange between people's perceptions and management strategies of protected areas. Furthermore, Kansky et al. (2016) stress the importance of considering intangible costs (e.g., fear, stress) and intangible benefits (e.g., cultural identity, spiritual significance) because these factors can have a greater influence on tolerance than direct, tangible impacts such as crop damage. Improving perceptions also requires effective compensation mechanisms for losses to life and crops caused by elephants. Current compensation schemes need to be enhanced in terms of transparency, fair allocation of resources, and payment timing (Breuer and Ngama, 2021).

4.2.7 Strengthening law enforcement and institutions

Strengthening national institutions and organizations in charge of resource management and wildlife conservation will be crucial to limit negative human-elephant interactions (Beyers et al., 2011). It relies on the collaborative efforts of all stakeholders, including governments, conservation organizations, extractive industries, local populations, and researchers. Integrating local knowledge into policy discussions is in line with the post-2020 Global Biodiversity Framework, which calls for the participation of Indigenous Peoples and Local Communities (IPLCs) in conservation decision-making. On an international scale, coordinated management of wildlife corridors is also essential, especially when cross-border movements are involved (Hofmann et al., 2021). Conservation efforts should also ensure equitable distribution of benefits and be supported by diversified livelihood opportunities that reduce dependence on external funding (Terada et al., 2021).

4.3 Positive dimensions of human-forest elephant coexistence

While cohabitation between forest elephants and human communities presents significant challenges, there are also positive aspects to coexistence. Considering the importance of elephants to ecological functions (e.g., seed dispersal, nutrient recycling, carbon sequestration) and socio-cultural integrity (e.g., cultural identity, spiritual enrichment), their decline would severely affect forest structure, ecosystem functions, biological diversity, and human welfare (Poulsen et al., 2017; Ngouhouo Poufoun et al., 2016; Campos-Arceiz and Blake, 2011).

Forest elephants play a critical ecological role as seed dispersers and ecosystem engineers (Poulsen et al., 2021, 2018; Campos-Arceiz and Blake, 2011; Blake et al., 2009), shaping the structure and diversity of tropical forests (Rosin et al., 2020). In Central Africa, their presence supports the regeneration of high wood-density tree species (Berzaghi et al., 2021), including economically valuable species such as *Autranella congolensis*, *Detarium macrocarpum*, *Klainedoxa gabonensis*, and *Mammea africana* (Scalbert et al., 2023b). The forest elephant also contributes to nutrient recycling by transferring nitrogen, sodium and carbon into the soil, which improves soil fertility and forest productivity (Poulsen et al., 2018). Forest elephants' disturbances enhance carbon stocks (Berzaghi et al., 2019), thereby playing an indirect but significant role in global climate regulation (Berzaghi et al., 2021). In Lopé National Park, elephant trails at forest edges act as natural firebreaks, protecting fire-sensitive forest interiors (Cardoso et al., 2020). These trails also facilitate access to remote forest areas for both humans and wildlife (Remis and Jost Robinson, 2020). A recent study highlights that forest elephants also shape the composition of terrestrial mammal communities in Congo (Versavaud et al., 2025).

Although ecotourism focused specifically on forest elephants is less developed than that for savanna elephants, initiatives in Central Africa, such as in Pongora and Ivindo National Parks (Gabon), have demonstrated the potential for elephant-centered tourism (Ndong, 2018). In the Dzanga-Sangha Forest Reserve, tourism generated revenues for local populations (Remis and Hardin, 2009). Community-based ecotourism can enhance wildlife conservation and support local economies when communities are involved in decision-making and revenues are equitably shared (Ndong, 2018).

5. Conclusion

The coexistence of forest elephants and human communities is a crucial challenge at the nexus of wildlife conservation and socio-economic development in Central and West Africa. As human land-use increasingly overlaps with elephant habitats, both the frequency and intensity of negative interactions are likely to increase. The main challenges of human-elephant coexistence must be addressed urgently due to their consequences for both human communities (e.g., livelihoods, safety, well-being) and forest elephants (e.g., movement disruption, reduced abundance). Sustainable human-forest elephant coexistence requires a multi-dimensional approach that integrates ecological, environmental, agricultural, behavioral, socio-cultural, and institutional strategies. Together, these interconnected strategies provide a socio-ecological framework to guide future research and management strategies.

CRediT authorship contribution statement

Justine Broers: Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization, Formal analysis, Funding acquisition. **Cédric Vermeulen**: Writing – review & editing, Supervision, Methodology, Conceptualization, Funding acquisition. **Stephanie Brittain**: Writing – review & editing. **Steeve Ngama**: Writing – review & editing. **Simon Lhoest**: Writing – review & editing, Supervision, Methodology, Conceptualization, Funding acquisition.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary data

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