INVESTIGATING FOREST ELEPHANT CROP DEPREDATION TO GUIDE LANDSCAPE MANAGEMENT FOR VILLAGER-ELEPHANT COEXISTENCE

by

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A DISSERTATION

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DISSERTATION ABSTRACT

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Title: Investigating Forest Elephant Crop Depredation to Guide Landscape Management for Villager-Forest Elephant Coexistence

Forest elephant destruction of villagers' crops in and around Gabon's national parks has persisted despite intensive efforts to control the problem by blocking elephant access to crops. I developed an alternative approach to craft spatially integrated landscape management strategies that simultaneously meet the needs of villagers and elephants, which I call a landscape framework for human-elephant coexistence. To craft the coexistence framework, I investigated factors influencing CDIs in two villages at Lopé National Park, Gabon. In chapter 2, I used content analysis of semi-structured interviews with 46 villagers and conservation professionals to explore how interacting landscape processes lead to CDIs. This generated a conceptual framework characterizing how six broadscale CDI drivers set in motion five landscape change dynamics, which in turn lead to five generalizable problem types that directly contribute to CDIs in village areas. In chapter 3, I combined the stakeholder interviews with a mapped census of native fruit tree distribution along elephant trails in the two villages and nearby forest, and long-term fruit phenology data to assess CDI distribution in relation to seasonal availability of native fruits and domestic crops. The results indicate that neither crop nor native fruit availability, nor the interaction between them, is a definitive factor controlling CDIs. Instead, they suggest that the spatial and temporal distribution of elephant resources and human activities within mosaics of natural and managed landscapes combine to influence elephant foraging behaviors, which in

turn set the stage for CDIs. In chapter 4, I reframed each of the five problem types into a coexistence strategy, and identified a toolbox of 59 actions to form the core of the landscape coexistence framework, and used chapter three results to inform how strategies could be applied at local extents. Two of the five strategies were targeted to fulfilling elephant needs, two toward villager needs, and one toward reducing the spatial overlap of elephant foraging and villager cropping activities. The landscape coexistence framework serves as an overarching structure through which participatory planning could be conducted at the scale of individual villages or an entire national park like Lopé.

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“English is so hierarchical. In Cree, we don't have animate-inanimate comparisons between things. Animals have souls that are equal to ours. Rocks have souls, trees have souls. Trees are 'who,' not 'what.“ Tomson Highway

CHAPTER 1 : INTRODUCTION

1.1. The context of crop depredation in Gabon

In Gabon, a central African nation located on the continent's Atlantic coast, and elsewhere in rural Africa and Asia, human communities use the land with wildlife, and their inevitable interactions cause harm to both. Villagers plant crops for food and family income in or near places where wildlife is accustomed to feeding. This practice is especially problematic when wildlife includes elephants, a protected species which existence is essential for a healthy ecosystem, and at serious risk of extinction by illegal poaching. Furthermore, the resource management policies and settlement patterns of human communities have reduced the quantity and quality of elephants' preferred food in natural areas, which creates a further threat to elephants. Elephants cope by eating villagers' crops, which threatens villagers' livelihood; elephants' size makes managing their behavior very challenging. This dissertation analyzes the nature of the conflict between elephants and villagers, identifies factors that might be managed more effectively to reduce conflicts and suggests strategies to address them to promote healthy coexistence for elephants and people.

The primary focus of this research is crop depredation incidents (CDIs), in which elephants consume and trample crops when they are foraging in villagers' crop fields, known in Gabon as "plantations", which are established through slash and burn clearing of forest each year (Osborn and Hill 2005, Pittiglio et al. 2014). CDIs can lead to increased poverty, less food to feed families, and even death (Lahm 1996, Naughton-Treves 1997, Parker and Osborn 2006, Walker 2012, Madden and McQuinn 2014). Crop losses vary with locations and elephant populations but can reach higher than 70% (Walker 2012, Seoraj-Pillai and Pillay 2017, Gross et al. 2018, Ngama et al. 2019). Regardless of CDIs, socioeconomic conditions are already fragile in most African villages due to the lack of employment and infrastructure. If CDIs continue, villagers will lose their primary food and income sources and the last vestiges of traditional lifestyle, and will stop growing crops and abandon the villages for cities (Seoraj-Pillai and Pillay 2017). Through these CDIs, the existence of both forest and savanna elephants in Africa, already threatened by poaching and habitat loss, is further threatened by desperate villagers killing them to protect their crops.

In Central Africa, elephant crop depredation incidents are among the most significant challenges to the success of elephant conservation. CDIs are a particular challenge with the critically endangered forest elephant (*Loxodonta cyclotis*), a smaller and more reclusive species than the better-known savanna elephant (*Loxodonta africana*), which is endangered (White et al. 1993, Groves 2000, Grubb 2000, Breuer et al. 2016). To reduce CDIs, people have tried a variety of traditional and modern strategies, such as planting unpalatable crops like chili peppers and placing beehives at the edge of plantations where their stings can repel elephants. However, these strategies are relatively ineffective in reducing CDIs as the elephants adapt to them over time (Naughton-Treves 1997, Parker and Osborn 2006, Sitati and Walpole 2006, Walker 2012, Ngama et al. 2016). Park agencies are introducing other strategies, such as installing electric fences that are successful as people can harvest their crop (Davies et al. 2011) even though elephant continue to try to reach crops within the few months after the establishment of this electric fence. All these crop protection methods provide only short-term solutions (Sitati and Walpole 2006, Osipova et al. 2018, Gross et al. 2019).

Discussion on CDIs has increased over recent decades (Naughton-Treves 1998, White and Ward 2010, Seoraj-Pillai and Pillay 2017) without a clear understanding of the factors that influence CDIs or identification of ways to mitigate them without negatively impacting both people's livelihoods and elephant conservation efforts. Without effective crop protection strategies, elephants will continue to destroy crops, and villagers will hunt them legally or illegally to protect their plantations. These dual reactions will accelerate the decline of these villages (Fairet 2012) and elephant populations (Maisels et al. 2013, Thouless et al. 2016a, Poulsen et al. 2017, Turkalo et al. 2017).

In the context of the needs of human communities and the needs of critically endangered elephants, this research analyzes forest elephant CDIs associated with the proximity of plantations to natural- or human-made regenerating forests referred to as secondary forests in this research. Secondary forest historically provided elephants with their natural food resources. In that context, solutions to this conflict have focused on protecting crops for villager livelihood by deterring or repulsing endangered wildlife (Barnes et al. 1991, Walker 2012). However, the focus should include recognition that the decreased availability of native fruit due to other human-caused changes in the habitat leads elephants to eat crops high in nutritional value and palatability (Eltringham 1990, Naughton-Treves 1997, Naughton-Treves 1998, Parker and Osborn 2006). Reducing CDIs requires a deeper understanding of factors contributing to these incidents to accommodate both human and elephant needs in an integrated management plan.

1.2. Considering other elephant needs in CDI management

Crop depredation incident management has focused to date on people's needs, mainly crop protection, without considering elephants' needs, including elephant security, because elephants are seen as a danger. These needs can be complex, particularly for forest elephants, who are less studied than African savanna and Asian elephants. Much can be learned by examining their decision-making patterns around foraging to reach food for nutrient balance.

1.2.1. Foraging theory of nutrient balance

Foraging theory explains how wildlife species, including forest elephants, move around to locate resource patches able to provide their nutritious food needed. This nutritional need can guide their four foraging actions (Pyke 1984, Stephens and Krebs 1986, Raubenheimer et al. 2009). These four foraging action choices include: finding a resource patch; eating nutritiously; determining when to leave the patch; and getting to a new patch that provides further nutrition or leads most efficiently to a new patch (Pyke 1984). First, the elephants choose a patch based on their need to achieve balanced nutrient intake of various food types. Second, the need to maintain a nutritionally balanced diet can also stimulate their departure from a resource patch. Third, over time, resource scarcity and unpalatability stimulate departure in search of a new resource patch. Fourth, elephants' movements between patches reflect a goal of taking the shortest route to quickly reach a new patch or a longer one that includes food along the way (Blake and Inkamba-Nkulu 2004). Forest elephants could be driven by food diversity and quality to gain necessary nutrients (Merz 1981, Blake and Inkamba-Nkulu 2004, Rode et al. 2006, Mills et al. 2018), as it has been shown for African savanna elephants (Sach et al. 2019). This desire for nutritious food can explain the choice of highly nutritious crops by some elephants (Chiyo et al. 2005, Vogel et al. 2019, Djoko et al. 2022).

1.2.2. A heuristic approach to understanding elephant foraging decision-making

Predictions of elephant forage decision-making can be challenging because they require understanding elephants' perspectives on food attraction and choice. However, heuristic approaches have been developed to understand how wildlife makes decisions (Petit and Bon 2010, Mielke et al. 2018, Boult et al. 2019). The heuristic approach (Gigerenzer and Gaissmaier 2011, Owen et al. 2017) draws on multiple sources of knowledge of animal decision-making and, more specifically, the factors that influence elephants' foraging and movement decisions. The goal is to guide the development of testable land management propositions that maintain elephants' food availability while protecting crops essential for villagers' well-being. (Dickman 2010, White and Ward 2010, Hoare 2012, Shaffer et al. 2019). Land management and large-scale design should meet the needs of both people and elephants, or help one of them without harming the other, to create conditions for successful coexistence.

1.3. Coexistence approach

Human-wildlife coexistence is generally based on human interests and tolerance of wildlife without considering wildlife needs (Sinu and Nagarajan 2015, Frank 2016, Nyhus 2016, Yurco et al. 2017, Crespin and Simonetti 2019, de Silva and Srinivasan 2019). Frank (2016) proposed an alternative: defining coexistence as the result of actions that satisfy human and wildlife interests through tradeoffs designed to express each party's priority needs. Managing these prioritized needs could offer the least harm in a land-sharing environment (Morehouse and Boyce 2017, Tiller and Williams 2021).

1.3.1. Human-elephant coexistence

Healthy coexistence, and not mere tolerance, is essential for three main reasons. First, coexistence could improve the precarious livelihoods of people by protecting crops while creating jobs by managing the landscape to maintain its conditions in the long term. Second, coexistence could enhance forest elephant conservation by increasing elephants' security and ensuring food availability. Third, a functional forest, essential for climate change mitigation, can be maintained, with elephants contributing to forest dynamics with tree diversity and carbon sequestration. Elephants spread seeds and other nutrients across the forest through their dung (Chapman et al. 1992, Blake et al. 2009, Beaune et al. 2013). Forest elephants shape the forest during their movement to reach habitats, resource patches, and food. Forest elephants maintain the health and function of tropical forests with the sequestration of carbon (Berzaghi et al. 2021, 2022) and preserve forests as a source of food and medicine for people (Hermans-Neumann et al. 2016, Cheng et al. 2017, Poulsen et al. 2018).

The study of human-elephant coexistence is an emerging area of research. One important focus pertains to elephant population sizes and behaviors. Eltringham (1990) presented conditions for the coexistence of humans and certain types of wildlife, such as elephants, based only on understanding elephant population size and resource availability in a landscape dominated by human land use. He promoted tolerance of elephants, for example, through financial compensation and alternative cropping systems. Songhurst et al. (2016) focused on elephant behavior by investigating savanna elephants' risk avoidance behaviors when foraging. Songhurst et al. (2015) initiated a more complex multidisciplinary human-elephant coexistence project focusing on multiple aspects, such as elephant movement and ecology, and the impact of the conflict on human livelihood and farming activities.

1.3.2. Coexistence approach through Landscape Architecture

Most human-elephant research in disciplines such as ecology, sociology, and economics have looked at their interactions from only human or elephant perspectives (Kremen and Merenlender 2018, Crespin and Simonetti 2019). Thus, understanding and management of CDIs have been limited because of the lack of comprehensive investigation that includes human and elephant interactions. However, the need for coexistence may require an understanding of human-elephant interactions across multiple scales, integrated space, and time. The discipline of Landscape Architecture embeds approaches from planning and design that deepen understanding of CDIs and can help identify large-scale interventions that could result in healthier habitats for wildlife and people.

Concepts in Landscape Architecture illuminate human-elephant interactions by revealing factors that may influence elephant crop depredations (CDIs) across space and time (Deming and Swaffield 2011, Lenzholzer et al. 2013, Jorgensen 2014, Meijering et al. 2015). Landscape approaches integrate multiple knowledge sources through research for beneficial design outcomes. This research aims to assist human-elephant coexistence by integrating multiple knowledge sources to guide the planning of landscape management that will satisfy the needs of both humans and elephants or the needs of one without harming one when satisfying the other.

1.4. Significance of the project

A landscape-based analysis of CDIs can contribute to expanding the application of landscape architecture to conservation planning. It can also contribute to the emergence of practical human-elephant coexistence research through deeper understanding of the spatial and temporal dimensions of the CDI problem and its solutions. These dual analyses can allow identifying manageable problems that should guide seeking strategies to satisfy human and elephant needs. Humans can be satisfied by maintaining viable crop production and improving socioeconomic conditions, while critically endangered forest elephants can be satisfied by supporting their security and food availability. This analysis emphasizes strategies that can discourage elephants from foraging in the village areas, including housing and plantations, and simultaneously enhance elephants' attraction to resources in natural or designed areas as resource hotspots that could be located at a safe distance from human land use.

1.5. Dissertation structure

This dissertation investigates both general and village-specific problem types to identify villagers' and forest elephants' needs as they relate to elephant crop depredation incidents (CDIs). The research was framed for design because determined problem types guide the selection of coexistence strategies with actions that can satisfy villagers or elephants without harming either or both. These two investigations, and the selection of strategies with actions, are condensed in the three main chapters in the form of publishable manuscripts; chapters 1 and 5 provide a brief introduction and conclusion.

In chapter 2, problem types that lead to CDIs in Gabon are derived from villagers' and conservation professionals' perceptions, gathered through semi-structured interviews, and analyzed through content analysis to determine the landscape context, drivers, dynamics, and problem types influencing CDIs in Gabon. These drivers, dynamics, and problem types were linked with interviewees' perceptions in a framework that includes multiple-use forest, protected areas, and village areas with surrounding forest and housing sites. The five problem types include decreased elephant security; reduced reliability of fruit production; regular human-elephant negative interactions; ineffective crop protection; and village socioeconomic conditions. The two first problem types can contribute to the departure of forest elephants from the forest due to disruptions of their safety and food availability to find new food resources across the forest landscape to reach village areas where they have a more regular negative interaction, which is also favored by ineffective crop protection and village socioeconomic conditions.

In chapter 3, I also used villagers and villagers' and professionals' combined perceptions (presented in chapter 2) to identify local problems at both village and park scales with the case of two selected villages in and adjacent to Lopé National Park. These local problems were derived from investigating social conditions and the seasonal variation of forest elephant crop depredation in relation to native and domestic food availability. Villagers presented social conditions in the context of CDIs in each village based on their culture and needs. These social conditions, culture, and needs influenced the perceptions of local problems in each of the villages as being common or specific to these selected villages. Long-term phenology of 20 important elephant fruit trees in the park over 18 years showed a decline in fruit production over time. Field observation within the village areas and associated forest in the park indicated that native fruits could be found in both village areas and forest in similar abundance so that elephants may not differentiate the two areas when they forage, and leading them to substitute crops and domestic fruit, including mangoes, for their native plant diet.

In chapter 4, the five problem types were expressed as strategies to develop a conceptual framework, referred to as a coexistence framework providing management solutions designed to satisfy villagers, elephants, or both through participatory engagement. These coexistence strategies were further assessed to identify various actions able to satisfy both or one of the populations without harming the other. These actions and further literature review and follow-up interviews provide a toolbox to manage the identified local problem in the landscape context.

These chapters provide insights into factors influencing forest elephant crop depredation and how negative interactions between humans and elephants in Gabon have increased over time. As Gabon turns to forest elephant conservation through its national parks network, managing CDIs by satisfying the needs of both villagers and elephants could create conditions for human and wildlife coexistence. In the 21st century, human cultural heritage and biodiversity cannot be considered separately from one another. Rather, both should be given respect and priority for their importance in our socio-ecological landscape systems:

"The way we see the world shapes the way we treat it. If a mountain is a deity, not a pile of ore; if a river is one of the veins of the land, not potential irrigation water; if a forest is a sacred grove, not timber; if other species are biological kin, not resources; or if the planet is our mother, not an opportunity–then we will treat each other with greater respect. Thus is the challenge, to look at the world from a different perspective" (David Suzuki).

CHAPTER 2: KEY PROBLEMS DRIVING FOREST ELEPHANT CROP DEPREDATION IDENTIFIED THROUGH STAKEHOLDER INTERVIEWS IN GABON AFRICA

Contributions

This chapter is co-authored by Hervé R. Memiaghe, Mike J. Mikolo Yobo, Christine Enright, Nelson Ting, Dennis Galvan, and Bart R. Johnson. It was written by H. R. Memiaghe under B. R. Johnson's guidance. H. R. Memiaghe, Nelson Ting, Dennis Galvan, and C. Enright developed the research design and methods. H. R. Memiaghe conducted interviews, then analyzed the data with assistance from C. Enright, M. Mikolo Yobo, and B. R. Johnson. All authors discussed the results and contributed to edits and revisions.

2.1. INTRODUCTION

Elephant crop depredation incidents (CDIs) occur when elephants consume and trample villagers' crops (Osborn and Hill 2005, Pittiglio et al. 2014). CDIs have persisted despite intensive efforts to control them (Hoare 2012, 2015), leading to increased poverty, less food to feed families, and even death (Lahm 1996, Naughton-Treves 1997, Parker and Osborn 2006, Walker 2012, Madden and McQuinn 2014). CDI persistence has been attributed to the short-term effectiveness of crop protection methods, as elephants find ways to continue depredating crops or move to other areas with no crop protection (Osipova et al. 2018). Faced with the loss of their livelihoods (Shaffer et al. 2019, Nyumba et al. 2020, Terada et al. 2021), people may kill elephants to protect their crops (Lahm 1996, Walker 2012, Hoare 2015, Mariki et al. 2015, Hans Enukwa 2017, Mills et al. 2018, Epanda et al. 2019, Roe and Booker 2019, Twitcher 2020, Rakotonarivo et al. 2021, Terada et al. 2021), increasing the threat to elephant species already globally endangered from poaching (Blanc 2008, Choudhury et al. 2008, Gobush 2021b, 2021a). These dual threats to people and elephants require understanding not only the factors influencing CDI persistence but identifying management approaches that can help meet both villagers' and elephants' needs (Frank 2016, Morehouse and Boyce 2017, Tiller and Williams 2021).

In this chapter, we interviewed villagers and conservation professionals to develop a conceptual framework for the interacting processes that lead to CDIs. The framework is built on understanding the needs of both villagers and elephants as a foundation for developing land management strategies that create conditions for human-elephant coexistence.

2.2. MATERIAL AND METHODS

2.2.1. Study Area

Almost 80% of Gabon is rainforest habitat for wildlife, with 10% of the country set aside as national parks. Gabon is home to approximately 95,000 forest elephants, representing more than 70% of the remaining individuals of this species (Maisels et al. 2013, Laguardia et al. 2021). Elephant conservation in Gabon is a priority for three main reasons. First, Gabon has been pursuing sustainable economic development, including ecotourism, even as it intensively extracts other natural resources like oil and timber. Second, Gabon has one of the lowest human densities in Africa, with just over 2 million people (World Population Review 2018) distributed across 267,667 km^2 (7 people/km^2), roughly 40% of whom live in the capital of Libreville. Third, biodiversity conservation has been implemented on a national scale, with 13 national parks established in 2002, including Lopé National Park in central Gabon (Figure 2.1), which served as the focus for this study.

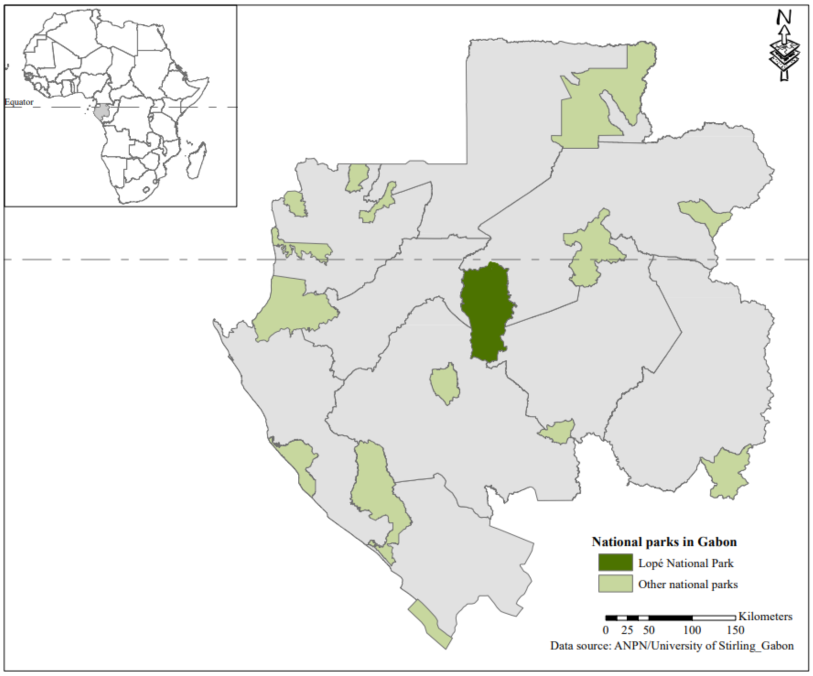

Figure 2.1. Gabon's 13 National Parks. Dashed line shows the equator in both panels.

2.2.2. Data collection

We collected narratives of CDIs in Gabon using semi-structured interviews of key stakeholders, including villagers and conservation professionals. Applying a standard set of questions within an open conversation allows participants to discuss issues in their own way and to lead the conversation's direction. The framework promotes participants' in-depth contributions through narrative explanation while allowing the interviewer to follow up with additional questions (Leedy and Ormrod 2001, Wengraf 2001, Galletta 2013, Lune and Berg 2016). The interviews were in-person to fit better with Gabonese culture, where traditional knowledge is transmitted orally (Bonhomme 2007, Diogo and Cerena 2015).

Participant Selection

Interviews were conducted with two stakeholder groups: villagers, who were selected from two villages, Kazamabika and Ramba, near Lopé National Park, and conservational professionals, including national park rangers and forestry agents stationed in that park, and researchers in the socioeconomics and ecology of human-elephant interactions, elephant behavior, and forest ecology around Gabon. Lopé National Park has one of the highest known incidences of CDIs (Walker 2012) and is a repository of relevant local ecological and environmental data.

Participant selection was unique to each stakeholder group. For villagers, a preliminary visit in 2018 established a relationship with residents at both sites. Twenty-four villagers agreed to be interviewed after permission was obtained from their village chiefs. Interviews took place in January-February 2020, the short dry season when only permanent residents were present. Participants were grouped in two age groups: adults over 65 years old and adults 18 to 64 years old to differentiate those whose adult lives included the period prior to biodiversity conservation efforts. Professional participants were identified through three strategies: conservation network, the snowball method (Biernacki and Waldorf 1981, Naderifar et al. 2017, Gundur 2019), and a literature review. Interviews took place from January-June 2020. The first interviews were conducted with professionals in the lead author's conservation network in Gabon who have been working on elephant conservation and human-elephant conflict. During these interviews, they identified other people whom the lead author could contact. One researcher who had worked in Gabon was identified through a literature review. A total of 22 professionals were interviewed: three forestry agents, nine park agents, and ten researchers.

Interview Procedures

The two stakeholder groups were interviewed using different procedures. Villager interviews occurred over four weeks (two weeks in each village). At least one or two villagers were interviewed in the afternoon each day after their work at subsistence crop fields, known locally as plantations[1], and their homes. Professionals were interviewed either in person or remotely. In-person professional interviews took place in Libreville or at Lopé National Park, particularly in the town of Lopé. Remote interviews were conducted with professionals located in other sites in Gabon or in other countries.

Interviews lasted from 15 minutes to an hour, depending on the length of participants' storytelling through semi-structured interviews. Three central research questions were introduced to participants to encourage them to include these topics in their storytelling (Table A1). Other questions emerged as they told their stories. With their permission, all interviews were recorded to maintain conversational flow and to capture their whole story. Interviews were conducted primarily in French, the official language spoken by most of Gabon's population. Since a few elderly participants communicated only in one of the 50 native languages spoken in Gabon (Rékanga 2007), a family member served as a translator between French and their native

[1] Subsistence crop fields, known in Gabonese French as "plantations," are established during the long dry season (June to September) through slash and burn practices that convert forest to short-term production areas for 1-2 years before they are abandoned and turn into secondary forest. This form of agriculture is variously referred to as slash and burn, shifting cultivation, and swidden agriculture, with no single, accepted term for the practice or the individual plots. We use the term "slash and burn" because it describes the practice of cutting and burning forest.

language. The family members were interviewed prior to their elders to avoid influencing the family members' stories. Foreign researchers from the United Kingdom or the United States were interviewed in English.

2.2.3. Data analysis

Almost all interview recordings were transcribed directly into English after multiple reviews to ensure that each story was accurately captured by carefully considering the content and context of their responses. When the context could not be translated directly from their native language, words, expressions, and sentences were written in French and later translated into English. The final English transcripts were analyzed through qualitative content analysis composed of thematic and quantitative analysis with CDIs as the unit of study by stakeholder group (Gore and Kahler 2012, Bernard 2017, Mayberry et al. 2017).

Thematic analysis of the transcripts

Thematic analysis was conducted in three phases. In phase one, transcripts were read to identify passages (typically one or more sentences) that responded to one of the two primary interview topics: the context of crop depredation incidents (CDIs) across space and time, and drivers of changes in resources used by elephants across space and time. Each topic included a main question with 7-9 sub-questions that could be used to follow up on an interviewee's responses to a question (Table A1). This full suite of questions guided the identification of transcript passages related to each main question, and these passages were interpreted to code their main ideas. In phase two, all passages and codes were categorized by main question and linked to an identifier number randomly assigned to each interviewee. Data were further analyzed to verify the link between passages and codes and to condense the number of codes. After multiple verifications of the passage expressions and codes, and their groupings, the codes were categorized into CDI themes and subthemes for further analysis. Finally, we conducted a quantitative analysis to determine the percentage of interviewees who characterized each theme and associated subthemes by stakeholder group, and across all interviewees. Interviewees who referred to multiple coded items in a category (theme or subtheme) were counted only once.

2.3. RESULTS

Results are reported in three parts: (1) interview participant demographic profiles, (2) identification of CDI themes and subthemes, (3) proportions of interviewees identifying each theme by stakeholder group, and 4) a conceptual framework that integrates the different themes.

2.3.1. Participant Demographic Profile

Twenty-four villagers (52%) and 22 conservation professionals (48%) were interviewed for a total of 46 participants. Twelve Villagers came from each of the two selected villages. They included seven adults over 65 years old and five adults 18 to 64 years old at Kazamabika, and four adults over 65 years old and eight adults 18 to 64 years old at Ramba. Professionals included nine (20%) park agents, three (6%) forestry agents, and 10 (22%) researchers.

2.3.2. Theme Identification

Four central themes were derived to capture participants' characterization of CDIs and their causes: landscape context, drivers, dynamics, and problem types. Landscape context identified the locations associated with each driver, dynamic, and problem type. The derivation of the four themes was broadly inspired by the conceptual framework of Emerson et al. (2012) for developing collective plans of action through collaborative governance. Drivers characterized broad-scale factors that fostered CDIs by changing socio-ecological system (SES) dynamics in the landscape contexts. Dynamics characterized the CDI-relevant landscape change processes resulting from the drivers. Problem types characterized outcomes of the dynamics that, by affecting the fulfillment of human and elephant needs, became the proximal causes of CDIs. In our reconceptualization, drivers turn the wheels of landscape change in specific locations to set the dynamics in motion, leading to the immediate problem types that contribute to CDIs. Each identified interview passage thus became a schema, or fundamental unit of explanation for the CDI problem, and was coded to represent a causal chain from landscape context → subdriver → subdynamic → subproblem. After all, passages were coded for these four themes; each theme was examined to consolidate its subunits into a reduced set of higher-level categories.

2.3.3. Landscape context, drivers, dynamics, and problem types influencing CDIs

In addition to the summaries below, transcribed narratives for each main category of driver, dynamic, and problem type are provided in Appendix A under separate tables for each theme (Tables A3, A5, and A7).

Landscape Context

Interviewees' descriptions of the causes and consequences of CDIs were associated with three landscape contexts: multiple-use forest, protected area, or village area. People primarily use multiple-use forest areas for extracted natural resources such as harvestable trees and wildlife that may be hunted (e.g., for bushmeat), including illegal poaching. Protected areas are sites where most natural resource extraction is excluded, and biodiversity conservation is the priority. Village areas include both inhabited spaces and nearby forest areas that villagers use for plantations, hunting, and gathering non-timber products such as native fruit and other vegetables.

Drivers

Six categories of drivers emerged from the descriptions of villagers and professionals: 1) elephant foraging behaviors, 2) logging, 3) conservation policies, 4) village-elephant habitat spatial overlap, 5) rural exodus, and 6) disruption of native fruit production (Figure 2.2), each derived from 1-8 subdrivers (Table A2). *Elephant foraging behavior* was the most frequently identified driver of CDIs. It was brought up by 70% of interviewees, and nearly equally by villagers and professionals. This driver was derived from eight subdrivers related to forest elephants' needs to access food and be in a safe place. The most frequently described were elephant hunting/poaching (26%) and elephant crop preferences (24%), primarily by professionals, and fences pushing elephants to other sites (17%), primarily by villagers. The *logging* driver was identified by 52% of interviewees, predominantly professionals (82%). It was derived from four subdrivers, with logging by far the most frequently described, and the only one named by villagers. The *conservation policies* driver was identified by 41% of interviewees, primarily professionals. It was derived from two subdrivers related to elephant habitat protection: elephant hunting prohibition (35%) and park establishment (20%). The *village-elephant spatial overlap* driver was identified by 37% of interviewees, primarily professionals. It was derived from two subdrivers related to transformation of the forest for villager behaviors: village location (28%, primarily villagers) and plantation expansion (13%, primarily professionals). The *rural exodus* driver was identified by 26% of interviewees with substantial number of both professionals and villagers. It was derived from three subdrivers with village depopulation mentioned most often by both stakeholder groups. The final driver, *disruption of native fruit* *production* was identified by 15% of interviewees, all professionals, based on one subdriver related to the decrease of fruit availability due to changing climate.

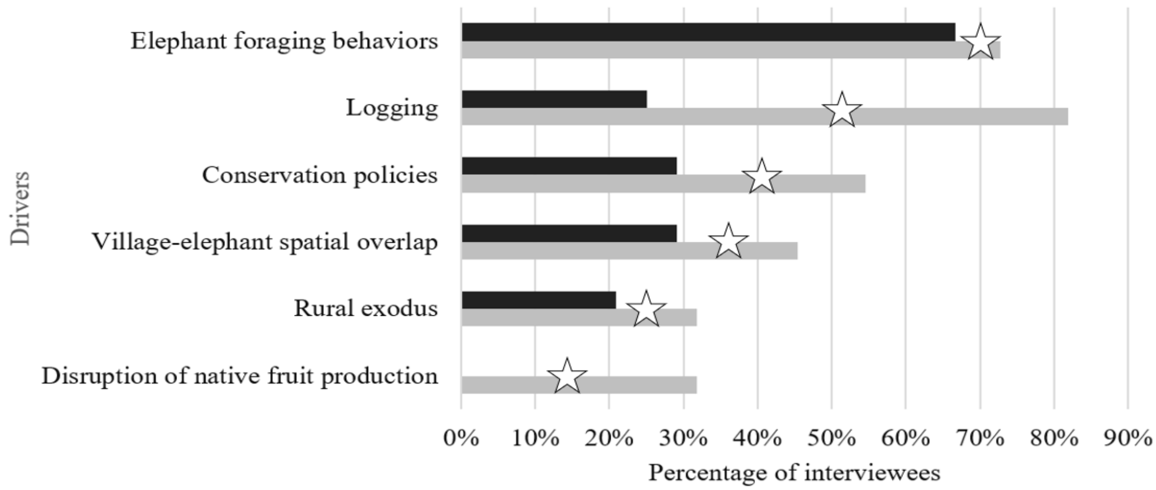

Figure 2.2. Interviewees' perceptions of drivers influencing CDs by villagers (black) and conservation professionals (gray). Stars show average across all interviewees. Because interviewees comprised almost equal numbers of villagers (n=24) and professionals (n=22), the percentages also reasonably represent the relative number of stakeholders by type.

Dynamics

Five categories of dynamics emerged from the descriptions of villagers and professionals: 1) Increased human-elephant interactions, 2) Reduced capacity to protect crops, 3) Forest structural change, 4) Reduced native fruit availability, and 5) Decreased elephant safety in native habitats (Figure 2.3). The first two dynamics were described by similar percentages of professionals and stakeholders, while the last three were noted predominantly by professionals (Table A4). *Increased human-elephant interactions* were the most frequently identified dynamic, brought up by 78% of interviewees. It was derived from ten subdynamics focused on themes that emphasized how village areas had become safe areas for elephants to forage. The most common

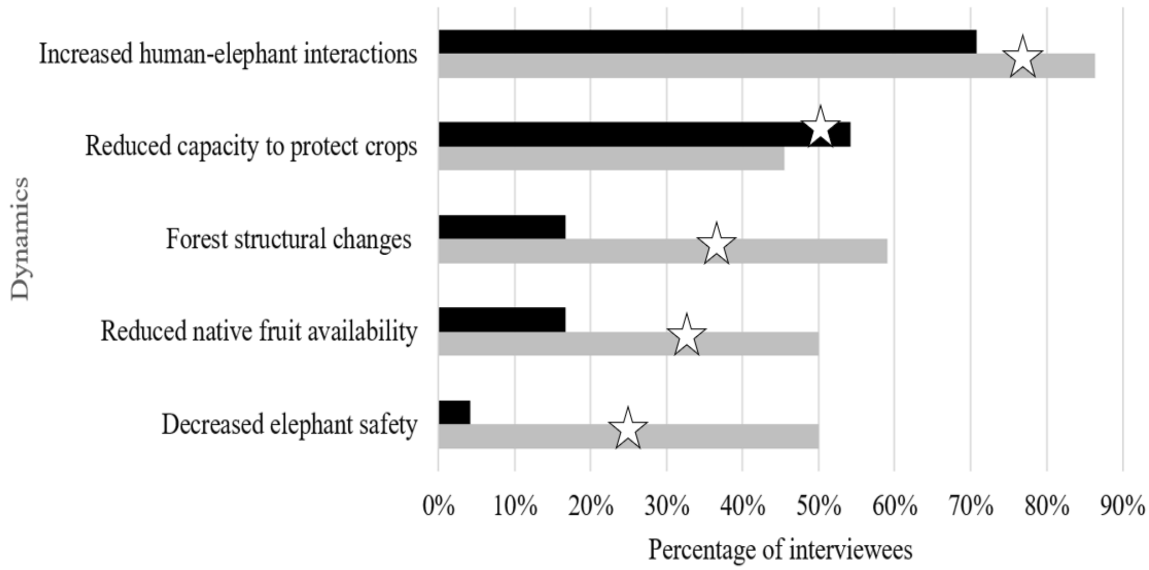

Figure 2.3. Interviewees' perception of dynamics influencing CDIs by villagers (black) and conservation professionals (gray). Stars show average across all interviewees. Because interviewees comprised almost equal numbers of villagers (n=24) and professionals (n=22), the percentages also reasonably represent the relative number of stakeholders by type.

subdynamics were safe sites for elephants (30%), inclusion of crops in elephants' diet (26%), protected forest elephants (15%), and decreased native fruit production (13%), with substantially different emphases by the two stakeholder groups. *Reduced capacity to protect crops* was identified by 50% of stakeholders, with somewhat greater emphasis from villagers. It was derived from four subdynamics related to villager and elephant behavior changes. Professionals emphasized identified altered social dynamics, while villagers focused on partial or ineffective crop protection. *Forest* structural *change* was identified by 37% of stakeholders, primarily professionals. It was derived from three subthemes that indicated forest degradation and habitat transformation, and both stakeholder types focused on how village areas have become elephant habitats. *Reduced native fruit availability* was identified by 33% of interviewees, primarily professionals. It was derived from two subthemes that indicated reduced numbers of native fruit trees and decreasing fruit production. *Decreased elephant safety* was identified by 26% of stakeholders, again primarily professionals. It was derived from two subthemes related to hunting and poaching, and noise and machinery from logging operations.

Problem types

Five problem types emerged from villager and professional perceptions of CDIs: 1) regular human-elephant negative interactions, 2) ineffective crop protection, 3) reduced reliable native fruit, 4) decreased elephant security, and 5) village socioeconomic conditions (Figure 2.4).

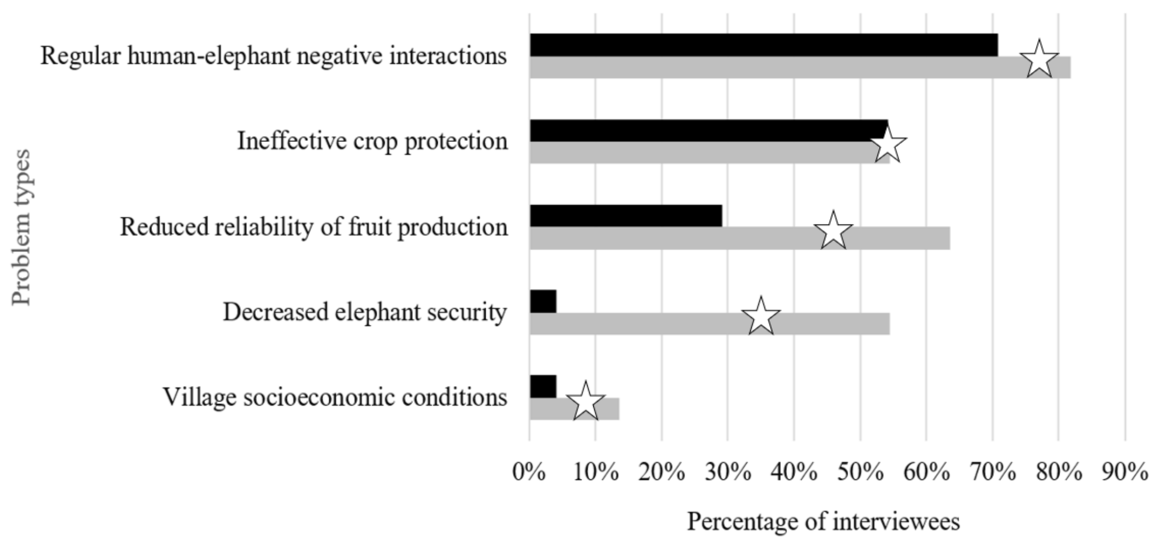

Figure 2.4. Interviewee's perception of problem types influencing CDIs by villagers (black) and conservation professionals (gray). Stars show average across all interviewees. Because interviewees comprised almost equal numbers of villagers (n=24) and professionals (n=22), the percentages also reasonably represent the relative number of stakeholders by type.

The first two problem types were identified almost equally by villagers and professionals, while the last three were identified primarily by professionals (Table A6). *Regular human-elephant negative interactions* were the most frequently identified dynamic, brought up by 76% of interviewees. It was derived from seven subproblems that indicate elephant disturbance, food disruption, interest to crops, villager issues, and the proximity of both. Among the subproblems, interviewees identified three: more elephants in village areas (48%), disturbance of elephant habitat (35%), and village food resources that attract elephants (28%). The first and third subproblems were primarily identified by professionals, and the second by villagers. *Ineffective crop protection* was identified by 54% of interviewees, equally by the two stakeholder groups. It was derived from four subproblems. Among the subproblems, the increased presence of elephants in the village and the absence of people in the village were the most mentioned by professionals and villagers, respectively. *Reduced reliability of native fruit production* was identified by 46% of interviewees, primarily professionals. It was derived from two subproblems that were most often brought up by professionals, native fruit scarcity (46%) and disturbance of elephant habitat (24%). *Decreased elephant security* in the forest was identified by 28% of interviewees, primarily professionals. It was derived also from two subproblems, mostly related to unsafe forest (primarily professionals). *Village socioeconomic conditions* was the least frequently identified problem type, brought up by 9% of interviewees. It was derived from only one problem type, the absence of people in the village primarily brought out by professionals.

2.3.4. Conceptual framework of stakeholder perception of factors influencing CDIs

The four themes of landscape context, drivers, dynamics, and problem types represent a decomposition and classification of interviewees' descriptions of how and why CDIs occur. Interviewees related crop depredation incidents (CDIs) to multiple factors beginning with broad-scale drivers of socio-ecological system (SES) changes that foster CDIs. For example, SES changes can alter human and elephant behaviors or resources available in the three landscape contexts: multiple-use forest, protected areas, and village areas (Figure 2.5). Multiple-use forest and protected areas were each associated with four drivers, and village areas were associated with five. The relative width of each connecting arrow was determined by the number of interviewees whose passages connected the two (Table A8). Similarly, each driver influenced one or more dynamics (Table A9), leading to the identified problem types (Table A10), which influence CDIs (Table A11). In all cases, the width of an arrow represents the number of interviewees who made that connection. When multiple passages from a single interviewee connected two themes, that connection was counted only once in the computation of arrow width.

Next, we describe the main linkages that flow through the diagram for each landscape context and illustrate how individual passages were decomposed into the linkages from context to driver, dynamic, and problem type. Both the category and subcategory of each theme is shown, with the latter in parentheses.

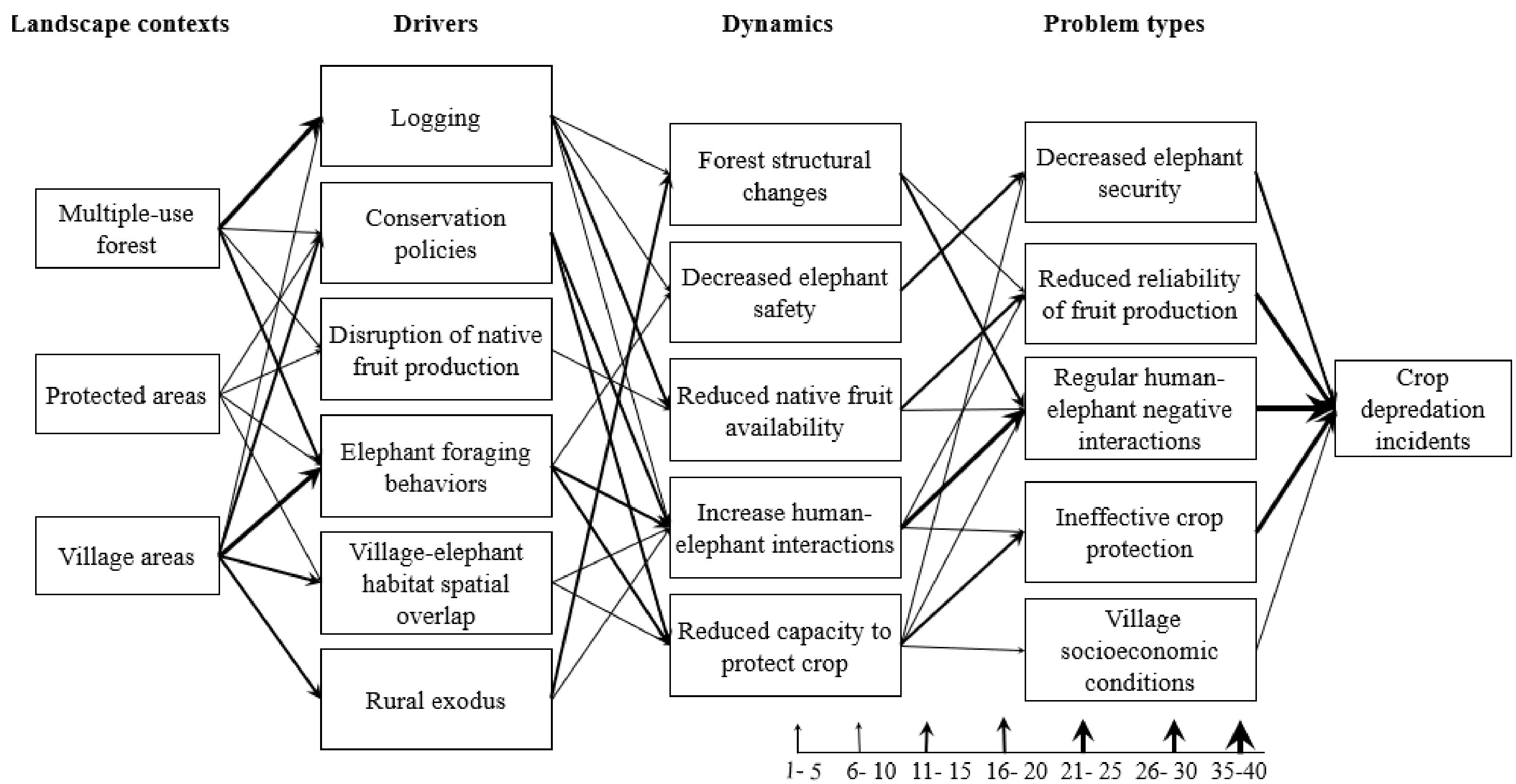

Figure 2.5. Conceptual framework showing how respondents linked landscape context to drivers, dynamics, and problem types influencing CDIs Arrow width is proportional to the number of respondents reporting a linkage between themes.

In multiple-use forest, as shown by the arrows to the four connected drivers, interviewees focused most on how logging contributes to four dynamics: forest structural change, decreased elephant habitat security, reduced native fruit availability, and increased people-elephant negative interactions. Forest structural change, for example, then contributed to two problem types: reduced reliability of fruit production and regular human-elephant negative interactions. Both interactions were described and embedded in the data that produced Figure 2.5, for example, as "*There are less natural fruiting trees in the forest due to past logging"* (ID, 13), and "*Elephant fruiting trees were logged in the past. Elephants were then lost in the forest and came to the villages.*" (ID, 19). The latter interviewees' passage was coded as multiple-use forest → logging → reduced native fruit availability (reduced number of native fruiting trees) → regular human-negative interactions (more elephants in village areas).

In protected areas, interviewees mentioned mostly the disruption of native fruit production and elephant foraging behaviors as drivers of change. The first driver was linked to the reduced native fruit availability dynamic that affects two problem types, primarily the reduced reliability of fruit production. Interviewees expressed this connection, for example, as "*I had the same feeling* [change in climate condition affecting native fruit production] *at Loango* [park] *because I did ten years overall there, and talking to people, I was feeling that the dry season was expanding more and more, beginning earlier, and the rainy season beginning late. It was not drier but more expanded, and also the small dry season that used to start in December, moved to January" (ID 45)*. Here, the codes were protected area → disruption of native fruit production (climate change) → reduced native fruit availability (decreased native fruit production) → reduced reliability of fruit production (native fruit scarcity). Another interviewee stated, "*A tree like Gabonese chocolate* [bush mango] *gives fruit every 2 to 3 years; if one gives* *fruit this year, it will wait for 2 to 3 more years for giving new fruits. [Elephants] are obliged to come to the village to find a little bit food like mango* [domestic mango], *guava* [within the village areas]" (ID 13). This was coded as [protected area → disruption of native fruit production (climate change) → reduced native fruit availability (decreased native fruit production) → regular human-elephant negative interactions (village with food sources that attract elephants).

In village areas, elephant foraging behaviors, village-elephant habitat spatial overlap, and conservation policies stood out as the most important drivers of changes to landscape dynamics that in turn created linked problem types that contributed to CDIs. For example, elephant foraging behaviors were linked to three dynamics, with the most reported being increased human-elephant interactions. This dynamic was related to three problem types expressed mostly through regular human-elephant negative interactions that increased CDIs. For example, these linkages were expressed by one interviewee as "*They* [elephants] *were coming* [within the village areas] *because crops attract them"* (ID, 46). "*Elephants could come to the village as a refuge, and go where it is quieter, and follow to where there is more food"* (ID, 35). The latter was coded as village area → elephant foraging behaviors (safety/food availability for elephants) → increased human-elephant interactions (safe site for elephants) → regular human-elephant negative interactions (village with food sources that attract elephants).

2.4. DISCUSSION

We investigated conditions associated with the persistence of forest elephant crop depredation incidents (CDIs) based on both villagers' and conservation professionals' knowledge. Villagers contributed more to understanding the factors around their village, whereas professionals perceived these incidents across larger areas. The two stakeholder groups' knowledge thus contributed different perspectives that were combined to conceptualize the factors and processes behind CDIs in Gabon.

The commonalities and differences in their perspectives (Figures 2.2, 2.3, 2.4) likely reflect their experiences and values of what is important. For example, while both villagers and professionals identified elephant foraging behaviors as a top driver of CDIs, the professionals, whose job is conservation, were three times more likely to identify logging as a CDI driver than villagers, many of whom have been employed by the forestry industry for different activities. Overall, professionals, whose job it is to consider these issues, were likely to provide more comments than villagers, reflected in the higher average percentages of professionals identifying different drivers, dynamics, and problem types. This weights the width of the arrows in figure 2.5 toward professionals' knowledge simply because they brought up more issues and serves as a reminder that the perspectives and deep experience of villagers, who experience CDIs and their impacts directly, should be given careful attention, particularly because they may be less verbose in their commentaries.

It is not surprising that villagers and conservation professionals focused on different factors, given the nature of each group's experiences and priorities. Should these factors become part of future collaborative planning efforts, it may be useful to prioritize those issues on which both groups agree as starting points for planning discussions. Points of agreement provide opportunities to build trust and to identify initial actions that may be easy to implement. Differences in perspectives around other issues should be investigated further to identify points of contention and to look for possible resolution or compromise.

We frame our discussion of the problem types that occur in multiple-use forest, protected areas, and village areas by examining how the distillation of our conversations with stakeholders built a complex picture of the factors contributing to CDIs. This narrative begins with the landscape contexts associated with six broad-scale socioecological drivers that have stimulated five processes of dynamic landscape change which in turn have led to five problem types that directly contribute to CDIs (Figure 2.5). Important to the goals of developing strategies for human-elephant coexistence, two of these problem types focus on the needs of elephants, two on the needs of villagers, and one on the zones of spatial overlap in their activities that serve as the locations of CDIs.

Like the causes of CDIs, stakeholders' responses were often complex and nuanced. After coding their responses from the transcripts, we considered various ways to portray their stories and integrate them into a single narrative, represented by Figure 2.5. The goal of identifying a discrete set of problem types that could be addressed at local landscape scales in different landscape contexts (chapter 4) was central, as was the desire to retain the complexity of their stories while making the synthesis visually accessible and directly useful for developing management strategies in local contexts.

Consequently, our analytical framework shows all implied causal arrows flowing horizontally from left to right. In doing so, we have ignored the fact that there are interactions and feedback within each theme of drivers, dynamics, and problem types. For example, the driver of disruption of native fruit production impacts elephant foraging behaviors. Furthermore, the lack of arrows connecting categories within the primary themes led to the need for several instances of tightly linked categories among the themes. For example, disruption of native fruit production (driver), reduced native fruit availability (dynamic), and reduced reliability of fruit production (problem type). We debated extensively on how to address these issues. In the end, we decided that the framework shown best represented the commentaries and intentions of the interviewees and that the added complexity of attempting to describe or diagram interactions within themes made the framework too complex to serve its purpose of clarifying the causes of CDIs. If this framework were further developed, we recommend that these interactions and feedbacks within themes be further explored. With that caveat, we next explore the relationships identified through stakeholders' stories of the interactive relationships that lead to CDIs.

2.4.1. Multiple-use forest

Stakeholders connected multiple-use forest to four of the six drivers, primarily *logging* and *elephant foraging behaviors* (Figure 2.5). The activities of *logging* have initiated drivers of forest structural change, decreased elephant habitat safety, and reduced native fruit availability (Blake 2002, Poulsen et al. 2011). Forest structural changes from logging were described as alterations to forest structure and composition, particularly the reduced numbers of big trees and increased distance between them through selective harvest. Many of the most important timber trees that have been logged are important sources of fruit for forest elephants. There are recent efforts to restrict logging of the most important trees for elephants in Gabon, but so far, they include only a few species (Decretn°0137/PR/MEFEPA 2009). While the density of trees removed under Gabon's logging practices is low (1-2 trees/ha), loggers naturally target the giant trees that are also the most important individuals for elephants. Interviewees reported, "*The fruiting tree species of which animals consumed fruits were also the trees logged in the past"* (Professional, ID 21*)*. "*Logging concessions destroy elephant habitat and food sources* (Professional, ID 35).

Large fruit trees are often the anchors of elephant trail systems. Trail systems in turn, are the spatial foundation for *elephant foraging behaviors*. Established trails serve as an elephant herd's cognitive map of the results of their past foraging, increasing the efficiency of their movements as they seek fruits and other food resources (Fishlock et al. 2016, Presotto et al. 2019). Through their trail systems and the guidance of experienced, older elephants, cognitive maps seem to be transmitted from generation to generation (Fishlock et al. 2016). In this way, logging can change elephant foraging behavior at the landscape scale, leading them to roam widely as they search for reliable food sources. Over time, they create an updated trail system that serves their dietary needs throughout their seasonal rounds to maximize foraging efficiency. Because of reduced fruit availability in logged areas and, as described next, the disturbances of logging activities, elephants and their trail systems may be relocated into both protected areas and around villages, establishing new patterns of behavior that will be passed on from one generation to the next.

In multiple-use forest, interviewees most often linked the driver of *elephant foraging behavior* with the dynamic of decreased elephant habitat safety. In addition to adjusting their foraging behaviors to changes in fruit distribution, they must adjust to increased noise and danger. "*Logging noise pushed elephants away* (Professional, ID 16). *Indeed, I was involved in logging before I worked in conservation. You cannot imagine the noise made by chainsaw, engine, and bulldozer* (Professional, ID 31)". Furthermore, both noise and danger are brought into the forest with the use of guns during hunting and poaching.

Hunting and poaching are strongly associated with logging and other industrial extraction processes (Fay and Agnagna 1991, Blake 2002, Rakotonarivo et al. 2021) and affect elephant presence and behavior in both forest and savanna (Kolowski et al. 2010, Yackulic et al. 2011, Vanthomme et al. 2013, Breuer et al. 2016). Interviewees reported that elephants left the forest due to noise from guns used during hunting or poaching. "*There is a displacement of elephants as they move away from poaching areas* (Professional, ID 36)", causing elephants to leave their areas of established use and associated trail systems. "*...They leave their corridors when they are disturbed*" (Professional, ID 14). This process is self-perpetuating as the proliferation of new roads provides ongoing access, and those involved in extractive industries may themselves take advantage of the opportunities for gain. "*More, people who worked take advantage to hunt animals, I saw that personally. I think that this is the cause of elephant movement at 100%"* (Professional, ID 31). In these ways, both the processes and outcomes of logging stimulate new elephant foraging behaviors and reinforce them over time. As expanded upon below, these direct and indirect effects then contribute to increased CDIs as elephants displaced by logging may seek food and safety in protected areas and villages.

Through these three drivers and four dynamics, stakeholder commentaries described how human activities in multiple-use forest led to three problem types: decreased elephant security, reduced reliability of fruit production, and most importantly, regular human-elephant negative interactions. In this landscape context, then, we argue that multiple-use forest must be managed as part of a landscape-scale strategy to mitigate CDIs. Although logging creates intense disturbances to tropical forests (Hosonuma et al. 2012, Tyukavina et al. 2018), including the loss of fruiting trees and loud, disruptive activities, the short-term impacts could be managed to provide benefits to forest elephants in the long term through the creation of different-aged patches of secondary forest, so long as increased access for hunting and poaching can be controlled.

2.4.2. Protected areas

Stakeholders connected protected areas almost equally to four drivers: *conservation policies*, *disruption of native fruit production*, *elephant foraging behaviors,* and *village-elephant spatial overlap*. Hunting and poaching in protected areas were not noted for this landscape, although it is a major factor in other Gabonese national parks (Maisels et al. 2013, Poulsen et al. 2017).

Conservation policies in Gabon were intended to create a safe environment for elephants through the establishment of national parks. The government established these large, protected areas to conserve core portions of the Congo Basin rainforest for wildlife as both a complement and counterpart to trends toward logging for economic gain (Laurance et al. 2006, Lee et al. 2006, Eba'a Atyi et al. 2022). Extractive industries like logging and mining were excluded to retain habitat quality, and hunting wildlife was prohibited to create secure areas for wildlife to thrive. Outside the parks, hunting species of concern like elephants was highly restricted, and efforts were put in place to stop elephant poaching for ivory.

The effects of national park establishment, however, have propagated through the socio-ecological system in unintended ways. The expectation was that forest elephants would stay in these protected areas, but some interviews reported they spend most of their time in surrounding human land use areas, particularly village areas. "*In 1981-2, the ECOFAC* [conservation program] *began; from there, people could not go in the forest as they wanted; not even to hunt. At that time, animals* [elephants] *began to come close to people. Those elephants have multiplied* (Villager, ID 22*)".*

One of the reasons elephants are leaving their reserves may be the *disruption of native fruit production* by rapidly changing global climate. The collapse of fruit production is creating severe scarcity (Bush et al. 2020b) of a central component of forest elephants' diet (Tchamba and Seme 1993, White et al. 1993, Beirne et al. 2020, Djoko et al. 2022, Fai et al. 2022). Since 1982, a research station in what is now Lopé National Park has maintained a long-term forest fruit phenology dataset. The data showed that fruit production has been in rapid decline since at least

1986 (Bush et al. 2020b), when Lopé was a wildlife reserve, long before its establishment as a national park in 2002. As a result, elephants must search longer and roam further to find fruit.

Like the loss of fruit trees from logging, reduced fruit production which includes both fewer fruits in a tree and reduced numbers of years in which an individual tree produces any fruits changes *elephant foraging behaviors*. As has been shown for several important elephant fruit tree species such as *Sacoglottis gabonensis,* elephants track the variation of native fruit availability (Momont 2007, Mills et al. 2018, Beirne et al. 2020, Bush et al. 2020b), using trail systems that take them close to individual fruiting trees (chapter 3, (Short 1981, Blake 2002, Blake and Inkamba-Nkulu 2004). They also use their acute sense of smell to determine when fruits are ripe across long distances away (White et al. 1993, Plotnik et al. 2014), which applies not only to native fruits but to domestic fruits and some crops, such as banana plants (Villager, ID 34), potentially guiding them toward villages as they seek new food sources.

For these reasons and others described below, the establishment of protected areas has increased *village-elephant habitat spatial overlap*. Village areas offer elephants access to both food and shelter in Gabon (Blake et al. 2008, Kolowski et al. 2010, Vanthomme et al. 2013, Wall et al. 2021), especially those located in and adjacent to protected areas (Mills et al. 2018). One interviewee described this increased elephant presence as follows: "*In 1981-2, the ECOFAC began; from there, people could not go in the forest as they wanted, not even hunting. At that time, animals* [elephants] *began to come close to people; these elephants have multiplied (*Villager, ID 22)". Lahm (1996) reported that villagers associated CDIs with periods of reduced reliability of fruit production, which can explain forest elephants' presence near villages areas. "*These disturbed elephants are obliged to find refuge in nearby villages"* (Professional ID 12).

Although protected areas were created to provide elephants safe refuges with abundant resources, they have not fully met the needs of elephants nor protected the livelihoods of nearby villagers. For protected areas to serve their full potential and their central role in long-term wildlife conservation, we argue that resolving their unintended consequences, particularly the reduced reliability of fruit production, is crucial for both villagers and elephants.

2.4.3. Village Areas

As described above, displaced elephants from multiple-use forest and protected areas are under pressure to find reliable food sources that fulfill their year-round dietary needs and to seek safety from logging activities, hunting, and poaching. Village areas, which are the location of CDIs, appear to provide those needs. In that context, stakeholders connected village areas to five of the six drivers of landscape change, particularly to *conservation policies*, *elephant foraging behaviors,* and *village-elephant spatial overlap*.

Conservation policies intended to protect habitats and wildlife inside national parks have had large effects on villages inside or adjacent to the parks. Because villages were widely distributed across the landscape, some wound up inside the parks while others were located close to their boundaries. Those inside the parks can no longer hunt at all, while those outside parks can no longer hunt protected species, including elephants. Villagers may request that the forestry service kill a problem elephant, but the process is time-consuming and difficult.

Interviewees reported a new permanent forest elephant presence around village areas, particularly since the establishment of protected areas where elephant hunting is prohibited (Professional, ID 14). This increased safety made crops easily available to elephants when they faced increasing fruit scarcity and reduced safety in large parts of the regional landscape. Several researchers have suggested that the shortage of fruits in the forest may have encouraged elephants to leave protected areas to forage in surrounding human land-use areas, particularly around villages (Lahm 1993, Mills et al. 2018, Djoko et al. 2022). Interviews echoed this idea, for example, by saying, "I think they came here [to the village] when the forest did not produce fruit for them…" (Villager, ID 11). The increased presence of elephants around villages has happened when villagers' capacities to protect their crops have been reduced by both the prohibition of lethal force, and the impacts of rural exodus, as described below.

With greater access to crops, *elephant foraging behavio*rs have changed as well. They are intruding within village areas more often, especially those in and adjacent to protected areas (Nsonsi et al. 2017, Mills et al. 2018, Beirne et al. 2019, Ngama et al. 2019).*"In the past, elephants were hard to see, and now, without hunting, they are around villagers. The elephants are more and more. In the past, one elephant was coming, and it used to eat and go back. Today there are groups of more than six elephants* (Villager, ID 13).

Increased pressure by elephants seeking crops in conjunction with rural exodus, has made labor-intensive traditional crop protection methods less effective as elephants become used to them or find ways to overcome them. Traditional methods were managed by working-age youths and adults leaving the village for big cities. Newer methods of protection, such as permanent fencing, have proved problematic, for example, using ineffective fencing materials, to which elephants can quickly adapt (Shaffer et al. 2019) .

The inclusion of crops in elephants' diet is also fostered by their ongoing availability. Villagers convert nearby forest into plantations through slash-and-burn clearing each year (Angoué 1999), where they produce crops for 1-2 years, after which plantations return to secondary forest, a further source of herbaceous forage. Forest elephants may also seek out crops because of fruit scarcity and because they provide important nutritional value, particularly minerals in their diet (Chiyo and Cochrane 2005, Chiyo et al. 2005, Rode et al. 2006).

To help villagers protect their crops in the face of increasing elephant incursions, electric fences have been introduced in some villages in and adjacent to Lopé National Park. Electric fences have shown given promising results but may push elephants toward other villages lacking such fences. For all these reasons, villages in and adjacent to protected areas may be perceived by elephants as a source of security and food (Mills et al. 2018). Elephants grow bolder when they are pushed from the forest by lack or danger and drawn to village areas where crops are reliably available on a year-round basis.

Village-elephant habitat spatial overlap has increased under these combined forces. Villagers stated that it used to be rare to see elephants in village areas. Elephants used to stop to eat some crops when they passed by village areas, mostly in plantations that were some distance from housing sites (ID, 13). As a consequence, villagers used to have few interactions with forest elephants. Even hunters would have to walk around 50 km before seeing the elephant's footprint (Villager, ID 33). Their interactions with elephants were meaningful enough that they had ritual significance. They described how elephant hunters conducted traditional rituals to prepare a product that they would spread on the footprints of the elephant they had targeted before they pursued it. These interactions suggest that people and elephants once had their own places, with limited overlap in their use of the forest, potentially due to their hunting (Barnes 1996).

Now, village areas offer elephants access to both food and shelter in Gabon (Blake et al. 2008, Kolowski et al. 2010, Vanthomme et al. 2013, Wall et al. 2021), especially villages in and adjacent to protected areas (Nsonsi et al. 2017, Mills et al. 2018). Compounding the problem, villagers lack the ability to deter elephants using lethal force, as they once could: "*And the local* *population was weak against elephants. They could not do something to deter elephants from entering their plantation or garden…*" (Professional, ID 3).

Not surprisingly, village areas played a large role in stakeholders' accounts because they are the location of CDIs. But these conversations revealed clearly that drivers and dynamics generated elsewhere push elephants toward resource-rich village areas where people cannot repel them. Stakeholders linked village areas to all five problem types through the intermediaries of five of six drivers and three dynamics: the reduced capacity to protect crops, increased human-elephant interactions, and decreased elephant safety.

It is clear from these conversations that resolving CDIs in villages requires more than just resolving the problem of ineffective crop protection. It must also attend to the drivers produced by managing multiple-use forest and protected areas, which in turn lead to other contributing problem types, including decreased elephant security, reduced food production reliability, and regular human-elephant negative interactions. Perhaps the most challenging problem types identified to address is the feedback from CDIs to declining village socioeconomic conditions, driven by larger national and regional forces of rural exodus. The same can be said of the drivers of conservation policies and logging. Our purpose in this study, however, was primarily to distill how the effects of local, regional, and national forces affected CDIs at local landscape scales. In this vein, we identified key problem types related to the needs of both villagers and elephants that could be addressed through local land management as a first step toward fostering coexistence.

2.5. CONCLUSION

The causes and consequences of CDI are sufficiently complex that at times they seem intractable. In this study, we identified three primary landscape contexts in which six broadscale drivers have led to five dynamics that in turn contributed to five key problem types influencing CDIs. Two of these problem types specifically relate to unmet elephant needs, leading them to seek out village areas and their crops. Two of the problem types related to the lack of effective crop protection methods as well as to broader issues of socioeconomic change that have led to rural exodus. Village population decline has reduced the ability of people to protect their crops even further, creating an ongoing cycle of rural exodus and increasing CDIs. The fifth problem type, regular human-elephant negative interactions, has increased through the impacts of all five dynamics. Elephants have shifted their foraging activities to village areas in search of increasing scarce food resources and safety. With settlement in permanent villages, rural peoples' traditional methods of slash-and-burn crop production embedded within natural forest has created a self-reinforcing, socio-ecological conflict centered around their village with decreasing resources to counteract the problem.

Despite their antagonism, villagers and elephants have common needs for safety and food even though villagers are faced with an urgent dilemma, the need to protect their crops to feed their families. People also need to physically protect themselves and their families from elephants that enter their villages. These displaced forest elephants find refuge in village areas, particularly those in and adjacent to protected areas. In village areas, crops are available year-round and typically lack effective protection, making it easy for elephants, protected by law, to consume them without danger. It is thus imperative to identify management strategies that simultaneously satisfy villagers' and forest elephants' needs by sharing the land rather than simply trying to block elephants from crops.

The combined perspectives and experiences of villagers and conservation professionals provide a solid foundation for understanding forces behind the persistence and severity of forest elephant CDIs. Many of the specific findings may have relevance for CDIs by endangered African savanna elephants and Asian elephants, which occupy large areas of Africa and Asia. More importantly, similar efforts could produce both regionally differentiated knowledge and a framework for sharing experiences. As in Gabon, crop protection efforts across these two continents have been insufficient to protect impoverished and vulnerable village populations. This study provides a transferable approach to address CDIs by drawing on the landscape-specific experiences of local villagers and professionals to identify how the unmet needs of people and wildlife can be reconciled for the benefit of both.

CHAPTER 3: UNDERSTANDING FOREST ELEPHANT CROP DEPREDATION CONDITIONS WITHIN VILLAGES IN AND ADJACENT TO LOPÉ NATIONAL PARK, GABON

Contributions

This chapter is co-authored by Hervé R. Memiaghe, Emma Bush, Nelson Ting, Steeve Ngama, Christine Enright, Katherine Abernathy, Dennis Galvan, and Bart R. Johnson. It was written by H. R. Memiaghe under B. R. Johnson's guidance. H. R. Memiaghe, B. R. Johnson, N. Ting, and C. Enright developed the research design and methods. H. R. Memiaghe conducted stakeholder interviews and led field data collection. H.R. Memiaghe and B.R. Johnson analyzed data and results. E. Bush provided the long-term phenology data and contributed to its assessment. All authors discussed the results and contributed to revisions and editing.

3.1. INTRODUCTION

Forest elephant crop depredation incidents (CDIs) in Gabon threaten rural livelihoods, particularly in villages in and adjacent to national parks. Villagers can lose most of their crops—their primary food source and sometimes a source of income (Walker 2012, Terada et al. 2021)—because crop protection methods are ineffective or effective only in the short term (Davies et al. 2011, Shaffer et al. 2019, Kiffner et al. 2021). Because Gabon has the largest remaining population of critically endangered forest elephants (Gobush 2021b, Hart et al. 2021, Laguardia et al. 2021), protecting both villagers' livelihoods and elephants is imperative.

But what drives CDIs, and why do they persist despite intensive efforts to control them? In natural habitats, forest elephants forage widely for a variety of native fruits, particularly those of tree species such as *Baillonella toxisperma, Sacoglottis gabonens,* and *Irvingia gabonensis* (White 1992, White 1994, Momont 2007), but fruits are getting scarcer due logging (Hosonuma et al. 2012, Tyukavina et al. 2018) and changing climate conditions (Tutin and Fernandez 1993, Bush et al. 2020a). Native fruit scarcity could push elephants to adjust their foraging behaviors to include human-transformed land, including villages (Mills et al. 2018, Beirne et al. 2020). When this happens, CDIs can be exacerbated by the proximity of native fruit trees to crops, and the availability of crops when native fruits are not available (Chiyo et al. 2005, Fairet 2012, Mills et al. 2018, Ngama et al. 2019).

Understanding the spatial distribution of resources used by elephants within villages and associated forest areas may offer important insights into how to shift elephant foraging away from village areas, allowing villagers and elephants to coexist more peacefully. Our objective in this study was to assess CDI occurrence in relation to seasonal native fruit and crop availability by integrating local stakeholder perceptions, a mapped census of native fruit tree distribution along elephant trails, and long-term fruit phenology data.

3.2. STUDY AREA

The study was conducted in central Gabon at Lopé National Park and two villages, Kazamabika and Ramba, which are in and adjacent to the park, respectively, along its northeastern edge (Figure 3.1). Lopé is one of 13 national parks in Gabon, covered by Gabon's characteristic equatorial rainforest as well as inclusions of savanna, otherwise found only in Gabon's southwestern, southern, and southeastern areas (Walters et al. 2012). Lopé National Park has been recognized for its wildlife diversity, including forest elephants (*Loxodonta cyclotis*), mandrills (*Mandrillus sphinx*), and western lowland gorillas (*Gorilla gorilla gorilla*). The abundance of forest elephants and other wildlife led to the area's classification as a natural wildlife reserve in the 1930s (Tutin and Fernandez 1987); it became a national park in 2002 (Laurance et al. 2006). The region's diverse wildlife and vegetation have benefited not only

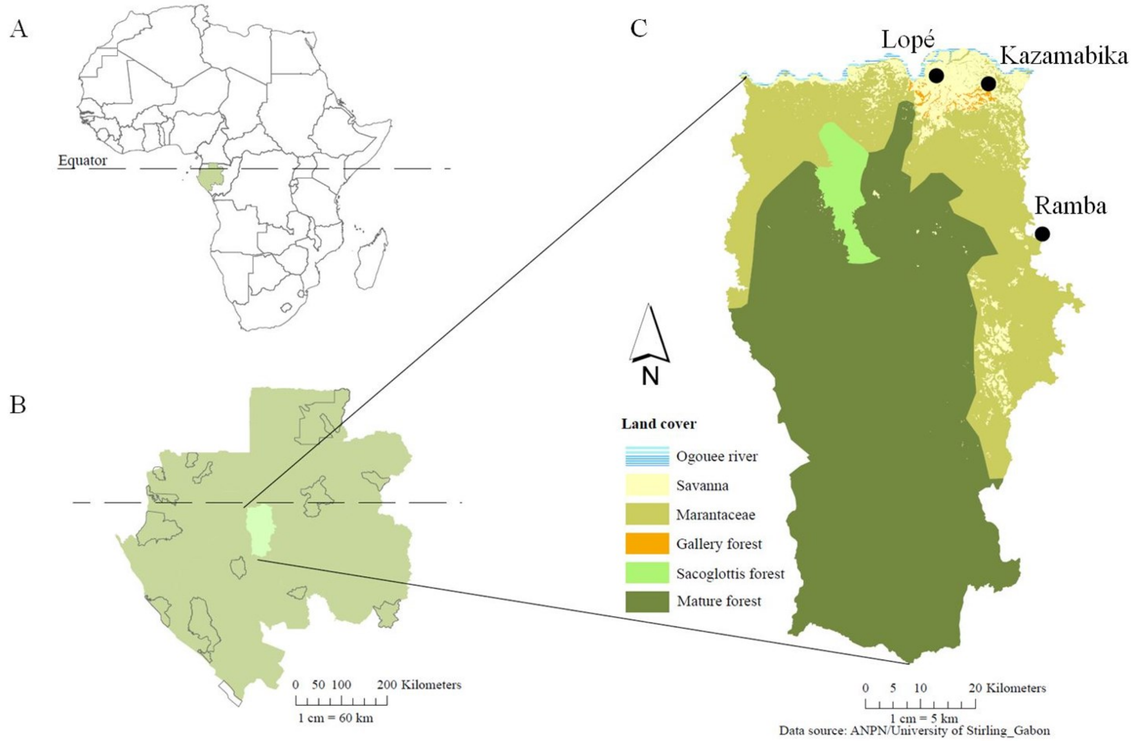

Figure 3.1. Location of case study villages near Lopé National Park, Gabon, Africa. (A) Location of Gabon in Equatorial Africa. (B) Gabon's 13 National Parks with Lopé highlighted. (C) Lopé National Park and key villages. Lopé is the region's principal village; Kazamabika and Ramba are the two smaller villages selected for this study.

elephants but also modern humans and their ancient ancestors, who have inhabited the area for around 400,000 years, based on archeological evidence (Oslisly and Peyrot 1992). Because of its ancient human history and biodiversity, Lopé was classified as a UNESCO World Heritage Site in 2007 (UNESCO 2010).

Land use practices changed dramatically when European colonization forced people to settle along the principal terrestrial and fluvial transportation routes instead of living as forest nomads (Lahm 1996, Morin-Rivat et al. 2017). These colonial settlements and more recent logging activities (Angoué 1999) contributed to the current village distribution in the northern part of Lopé, where villagers use the forest for subsistence agriculture, hunting, and gathering plants and fruits that wildlife such as elephants also consume. Traditional slash-and-burn agriculture also changed during the colonial period with the introduction of new crops, such as cassava, which lengthened the active cropping period from several months to one to two years before plots were abandoned (Vansina 1997). Subsistence crop fields, known in Gabonese French as "plantations," are established during the long dry season (June to September) through slash-and-burn practices that convert forest to short-term production areas for 1-2 years before they are abandoned and turn into secondary forest. This form of agriculture is variously referred to as slash and burn, shifting cultivation, and swidden agriculture, with no single, accepted term for the practice or the individual plots. We use the term "slash and burn" because it describes the practice of cutting and burning forest vegetation to prepare the plots, and retain the Gabonese use of the term "plantations" for the individual plots, while emphasizing that in Gabon the term holds no connotations of large-scale production of cash crops with wage labor or various forms of forced labor.

Elephants forage widely across this part of the park over seasonal cycles of native resource availability (Momont 2007). When they reach village areas, they naturally engage in crop depredation. Despite the use of various crop protection methods, CDIs persist in villages around Lopé (Walker 2012). Kazamabika and Ramba have different histories of settlement and experiences with CDIs. Kazamabika was settled in conjunction with logging expansion in the 1970s; by Okandé, Saké, and Makina peoples, and has had many CDIs (Angoué 1999, Walker 2010). In contrast, Ramba, also known as Massenguelani, was a Mitsogo tribal village, later joined by Babango people after their village flooded (Villager, ID 11). Historically, it had fewer CDIs than Kazamabika. Both villages have experienced increased CDIs since the establishment of the national park system in 2002 (Rakotonarivo et al. 2021).

The landscape of the northern part of the park is a mosaic of three main cover types based on vegetation structure and composition: semievergreen tropical rainforest (or "mature forest") (3165 km^2), savanna and forest-savanna mosaic (340 km^2); successional savanna-forest, including *Sacoglottis* and Marantaceae forests (1417 km^2); and small amounts of gallery forest, mostly located along streams and rivers (Figure 3.1C). All these vegetation types contain salt sites, called salines, where elephants eat soil for minerals (White et al. 1993), as well as seasonal or permanent water sources.

The dynamics of this vegetation mosaic, as well as the farming practices of villagers, are influenced by four seasons: a short dry season in January and February; the first rainy season from March to May; the long dry season from June to September; and the second rainy season from October to December (Figure 3.2). Lopé's semievergreen tropical rainforest is a mature forest with a closed canopy of overstory trees, including species from the families Burseraceae, Fabaceae, Myristicaceae, and Annonaceae; understory trees from the family Rubiaceae, and a sparse understory of herbaceous plants and shrubs (White 1992, White et al. 1993, Momont 2007). The diverse tree species produce fruits that attract numerous elephant herds, while the leaves of understory tree species provide herbaceous forage. In the past, around 2500 to 3000 km^2 of semievergreen tropical rainforest was selectively logged at low intensity (1-2 trees ha) (White et al. 1995), principally for one species, *Aucoumea klaineana* of the family Burseraceae (White 1992, Angoué 1999).

The savanna and forest-savanna mosaic occurs along the northern and eastern limits of the park. Savanna was established in the late Holocene era, with its long dry season of five to six months (Schwartz 1992, Delegue et al. 2001, Maley 2002, Ngomanda et al. 2009). Its establishment enabled the Bantu people to migrate from North Africa to Central Africa and occupy this region (Schwartz 1992). The Bantu, now considered local people, used to burn savanna to make hunting easier (Schwartz 1992, Oslisly and White 2000), which also prevented encroachment of the surrounding forest. The absence of fire leads to forest expansion along savanna edges and isolated forested patches in the middle of a savanna, known as "bosquet

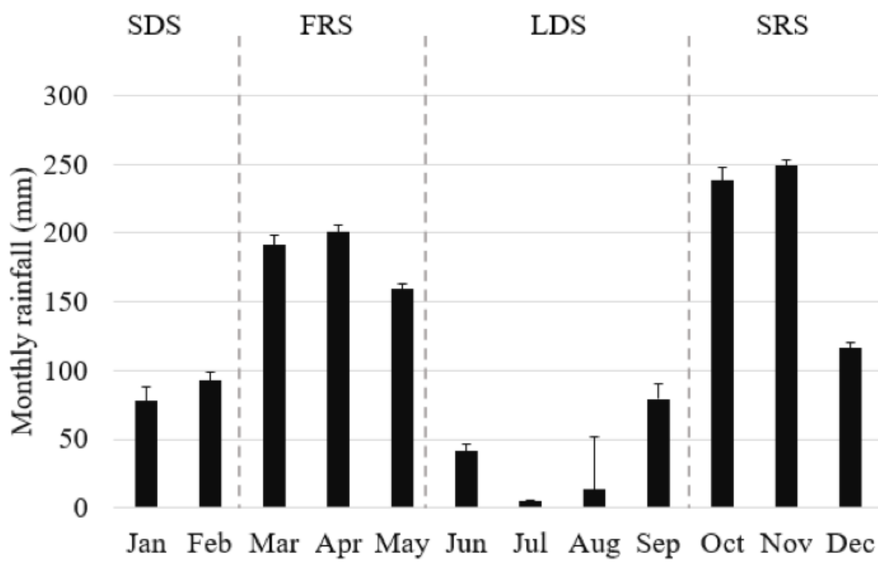

Figure 3.2. The four seasons at Lopé National Park based on 34 years of monitoring data. Seasons are expressed through the average rainfall and standard error in each month of each season: short dry season (SDS), first rainy season (FRS), long dry season (LDS), and second rainy season (SRS). The difference between "dry" and "rainy" seasons was based on 100 mm line base. Data derived from long-term precipitation monitoring at Lopé research station.

forests" (Ukizintambara et al. 2007). Today, the park service has introduced fire management throughout the park to mitigate forest encroachment (Jeffery et al. 2014, Walters et al. 2015, Moura et al. 2019).

Throughout the year, forest elephants also maintain forest and savanna through activities that include establishing trails, which reduces the spread of fire in the forest, dispersing fruit seeds in their dung, which helps establish new trees, and pulling down or otherwise consuming trees and other vegetation (Poulsen et al. 2018, Cardoso et al. 2020).

Successional savanna-forest is comprised of two main types, *Sacoglottis* and Marantaceae forests. *Sacoglottis* forest, found in the central northern portion of the park, is dominated by early successional species with *Sacoglottis gabonensis* (family Humiriceae) as the dominant tree (White 1992, White 1994). *Sacoglottis* produces fruits that attract many elephant herds (Momont 2007). The Marantaceae forest dominates the park's northwest and northeast areas, situated between mature forest and the savanna-forest mosaic (Momont 2007). This older stage of the successional savanna-forest also attracts many elephant herds. It has a more open canopy with trees of the families Leguminosae, Burseraceae, and Sterculiaceae, and is characterized by herbaceous plants of the Marantaceae and Zingiberaceae families (White 1992, White et al. 1995).

3.3. METHODS AND ANALYSIS

We used a combination of interviews, field studies, and long-term monitoring data to examine how various food resources' availability could influence forest elephant CDIs in Kazamabika and Ramba.

3.3.1. Interviews of local stakeholders

We used semi-structured interviews of thirty-seven interviewees (previously described in chapter 2) to explore their local perceptions of the seasonal variation of CDIs and crop and mango availability in the two villages (villagers) and across the entire park (professionals). Interviewees included villagers (n = 24) and professionals (n = 13). Villagers were equally represented from the two villages. Professionals included nine park agents, one researcher, and three forestry agents.

We assessed interview transcripts using qualitative content analysis in thematic and quantitative phases (chapter 2). In the first phase, the lead author used thematic analysis to determine (1) the main problems identified by villagers and professionals as drivers of CDIs in each selected village and across the entire park respectively, and (2) the percentage of interviewees reporting CDIs, or the availability of native fruits, crops, or mangoes as contributing to CDIs, in each season. Because participants offered their own responses to the questions posed, the percentages reported are based only on the issues raised by interviewees. Two analyses were conducted. One broke out only villager responses by individual village, and the second included all stakeholders to understand CDIs across Lopé National Park and the associated villages.

We expected to use a forestry service CDI report as a source of quantitative data on the timing, location, and crops consumed or damaged by elephants. The data would have been aligned with monthly native fruit phenology data (section 3.3.3) and analyzed statistically to compare the roles and potential interactions of native fruit availability. Prior to conducting stakeholder interviews, we collected 167 individual incident reports from 2016-2018 in 9 villages around Lopé National Park, 392 incident reports from 2013-2017 derived from annual summaries of all CDI incidences in 9 villages around Lopé National Park that broke out individual incidents into their constituent crop damage. Both sets of reports included Kazamabika and Ramba. After extensive assessments of the reports, we concluded that they were unusable for our purposes. They were not based on incident dates but on the dates when the reports were written; hence we could not match reported crop loss to specific months. Data were incomplete and often inconsistent. The CDI reports also offered no clear explanation for the absence of some villages during some years or the concentrated reporting in some years for one village or another for no apparent reason. Because of this, we shifted our attention to gleaning the best possible information about the number, timing, and location of CDIs and the factors driving them from our interviews.

3.3.2. Census of native fruit trees that attract elephants

We censused native fruit trees attractive to forest elephants within the two village areas and nearby forest sites. Domesticated mangoes were censused within village areas where they were planted by villagers. We selected the associated forest site for each village using three criteria. First, it must be inside the park where elephants are safe. Second, it must be close enough to the village to be expected to influence the behavior of elephants visiting that village. Our selected distance of 15 km represents two days travel for an elephant based on an average distance of 7.5 km/per day for GPS-tracked elephants in Lopé (Momont 2007). And third, local field assistants used their knowledge of the area to identify locations with relatively high levels of elephant activity, presumably because these locations provide concentrated native food resources to elephants (Figure 3.3).

In each of the four delineated study areas, teams censused native fruit trees in forests for ten days by following elephant trails to record all fruit tree species located less than 1 m from the side of a trail (Figure 3.4). Principal elephant trails were identified based on their relative openness and permanence due to frequent use and the presence of elephant smells and evidence of activity. Because fruit trees did not occur in savanna areas, trail segments followed through savanna were mapped but not included in the analysis. The village area censuses also recorded domestic mango trees situated among houses in the village center. Camera traps were deployed in the Kazamabika village center to document elephant foraging on mangos. Censuses were conducted with identical methods except for adjustments to the size of the area sampled, which focused on the spatial extents of active human use in the village areas versus expected elephant daily use in the associated forests. The villages were used as the staging area of each census, and

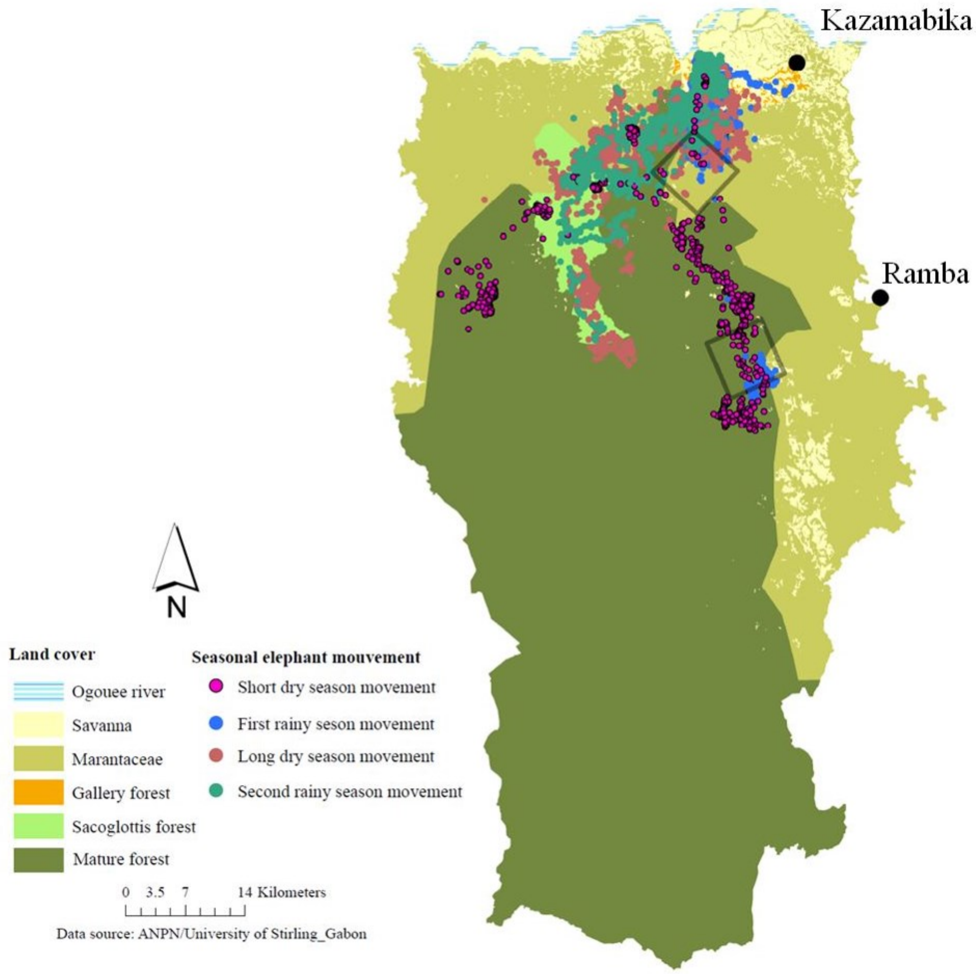

Figure 3.3. Location of the two selected villages and associated forest the sites (black squares) at 15 km from each village where elephants fruit trees were censused at Lopé National Park. Overlap of seasonal elephant movements tracked by GPS (Momont 2007) shown by season in relation to the two associated forest sites.

initial trail mapping began from there each day. Mapping was constrained to within 1.5 km of a village (i.e., roughly a 3 km diameter circle) because villagers described that as the maximum distance to establish plantations, thus defining the “village area.” In the associated forest sites, the local field team censused trees for ten days along principal trails and spur trails in a square area of 7 km per side using similar protocols.

This larger size for forest sites was selected to capture areas large enough for a typical 1-day elephant travel. The center of the site was used as a staging area, similar to the protocol for village sites. Each forest site was divided into four 3.5 km by 3.5 km quadrants to allow the team

Figure 3.4. View of forest elephant principal trails and nearby fruiting trees. A) Important fruit tree at a trail intersection. B) Fruiting tree close to one side of a trail. C) . Important fruit tree adjacent to trail. Most trails come very close to the fruiting trees that elephants are foraging.

to sample each quadrant for two days to ensure completion of the entire site and then use the last two days to return to quadrants with greater trail densities for more thorough sampling. At all four sites, we followed a principal trail until reaching an intersection, measuring and mapping all native fruit trees, fresh and old elephant dung, and the presence of salines. If the trail intersection was with a spur trail, we stopped to map and measure along it until encountering a distance of >100 m between fruit trees. At this point, we walked back to the intersection and continued along the original trail. In the village areas, we followed the original trail until a maximum distance of 1.5 km from the village. At that point, we selected another principal trail to follow back in the direction of the village. In the associated forest sites, we continued along the main trail until we approached the quadrant boundary and then looked for another principal trail to return to the center of the site.

For analysis, native tree species were further categorized as the eight most important and the twelve next most important trees to elephants, based on a ranking of the 20 most important tree species (Table B1). We selected these 20 species based on prior studies (White et al. 1993, White 1994, Momont 2007) and in consultation with research assistants involved in long-term phenology monitoring at Lopé National Park. Additional fruit tree species identified as attractive to elephants (White et al. 1993) were categorized as “other fruit” trees. The density (tree/km) of each category of native trees was calculated by dividing the number of trees along the associated trail system by the total length of trails using ArcGIS (ESRI, 2016, ArcGIS 10.5). The use of resource density along trails as the dependent variable allowed for comparisons across sites, or trail segments within sites, regardless of the total distance sampled over the ten days at each site. Mangoes were reported as the number of trees per village since they were scattered among houses rather than along trails.

3.3.3. Phenology of elephant fruit tree species

We acquired a phenology dataset of the 20 most important native fruiting tree species for forest elephants from a dataset of all fruiting tree species observed from 1984 to present in the vicinity of the Lopé National Park research station. We used data starting in 2003, by which time most of the selected 20 fruit tree species were included in the study. These data are currently managed by the Tropical African Phenology Group based at the University of Stirling in the UK, and the National Park Agency in Gabon (Tutin et al. 1991, Bush et al. 2017, Bush et al. 2020b), following their past work with Gabonese institutions (Bush et al. 2017, Bush et al. 2018).

We calculated the observed native fruiting score for each species by month for each year and then averaged it across the months of each season for each year. We determined the observed native fruit score by adjusting the fruit availability score (FAS) model expressed as FAS (species, month) = P*C based on ripe fruit scores, where P = proportion of fruit presence on the individual tree at the time of monitoring, and C= the mean of canopy coverage of fruit presence at the time of monitoring (Bush et al. 2020b). We then replaced the ripe fruit scores in the model with observed native fruits at the time of monitoring (OFTM), which added unripe to ripe fruit scores. The OFTM scores for each of the four seasons were obtained by adding OFTM scores for each species by days for each month per year. Each monthly total OFTM score was divided by the number of species observed, which was not always equal to 20 for each month (Table B2). We used the results of those divisions to determine the average OFTM for each season over each of the 18 years of data. The average OFTM for each season was then compiled into two nine-year periods (2003-2011 and 2012-2020) to align with interviewees' commentaries on key periods (Table B3). This nine-year period includes the six-year-minimum span required for valid measurement of tropical phenology variation (Bush et al. 2017).

3.4. RESULTS

3.4.1. Local interviewees

Villagers (12 interviewees per village) related CDIs to 18 local problems based on each village's situation and needs. These local problems fell into three of the five problem types previously identified as influencing CDIs (chapter 2). Two problem types were common to both villages, and one applied only to Ramba (Table 3.1).

At Kazamabika, villagers identified five issues contributing to *Ineffective crop protection*, including the absence of working-age youths and adults in the village, elephant adaptation to crop protection, and asserting that their electric fence pushed elephants to other parts of the village area. They identified three issues related to *Regular human-elephant negative* *interactions*, with increased elephant presence in village areas due to conservation ranked highest.

Table 3.1. Villager perception of problem types and local issues influencing CDIs at Kazamabika and Ramba. Twelve people were interviewed at each village (n=24 total).

Village	Problem types / local issues	Interviewees by village	
		No.	%
Kazamabika	Ineffective crop protection	10	83%
	Absence of working-age people in the village	5	42%
	Elephant adaption to crop protection	4	33%
	Electric fence pushes elephants to other village areas	3	25%
	Absence of elephant hunters	2	17%
	More elephants in village areas due to conservation	1	8%
	Regular negative human-elephant interactions	9	75%
	More elephants in village areas due to conservation	5	42%
	More elephants in village areas with natural food resources	3	25%
	Village food resources attract elephants	3	25%
Ramba	Ineffective crop protection	3	25%
	Electric fence in neighboring village pushes elephants into Ramba	3	25%
	Elephant adaption to crop protection	1	8%
	Regular negative human-elephant interactions	8	67%
	More elephants in village areas close to the river	4	33%
	More elephants in the village due to ineffective crop protection	3	25%
	Disturbance of elephant habitat	2	17%
	Absence of working-age people in the village	1	8%
	The proximity of plantations and native elephant food resources	1	8%
	Reduced reliability of fruit production	3	25%
	The lack of fruit in the forest turns the village into an elephant food source	3	25%

At Ramba, villagers identified two issues contributing to *Ineffective crop protection:* the increased presence of elephants due to an electric fence in the neighboring village (highest ranking) and elephant adaptation to crop protection. They identified five issues related to *Regular human-elephant negative interaction*. The three highest ranked were increased elephant presence in village areas close to the river, villages with ineffective crop protection, and disturbance of elephant habitat. They also identified one local issue related to the *Reduced reliability of fruit production*, which was that the village became a source of food for elephants when fruits were scarce in the forest.

3.4.2. Census of native fruit trees that attract elephants

Project logistics, including the 2020 COVID pandemic, prevented sampling the associated forest sites in the same year and season. The lead author and local field team conducted tree censuses in 2020 during the short dry season in the two village areas. The forest site around Kazamabika was sampled in 2020 during the long dry season, and the site around Ramba was sampled in 2021 during the short dry season. The field team's goal for each site was to sample 3 km of elephant trails/day for a total of 30 km over the 10 days of sampling. The actual distances achieved depended on factors such as the difficulty of terrain, type of vegetation encountered, and the density of resources being mapped and measured. At Ramba's associated forest site, 41 km of trails were mapped and measured compared to 24 km at Kazamabika. This difference was due to the higher density of fruit trees encountered and the need to follow elephant trails through areas of savanna, which did not contain any fruit trees and therefore were not included in the forest resource density calculations. Similarly, the 36 km of forested elephant trails mapped for the village area of Ramba, was roughly double the 15 km mapped at Kazamabika (Figure 3.5).

The abundance of native fruit trees varied between the two village areas, and to a lesser degree between each village and its associated forest site. Both areas around Kazamabika had greater density of native fruit trees along trails in all categories of importance than the comparable areas around Ramba. Summed across all fruit trees, densities in the Kazamabika areas were nearly seven times higher than the comparable areas at Ramba. Contrasts between the village area and associated forest site were more muted (Figure 3.6). The village area of Kazamabika had 11% lower density of native fruit trees than the associated forest site due to lower densities of the "next twelve" most important trees. The village area of Ramba had nearly

30% lower native fruit tree density than the associated forest site due to lower densities in all categories. Both villages had mango trees, with Kazamabika having four times as many as

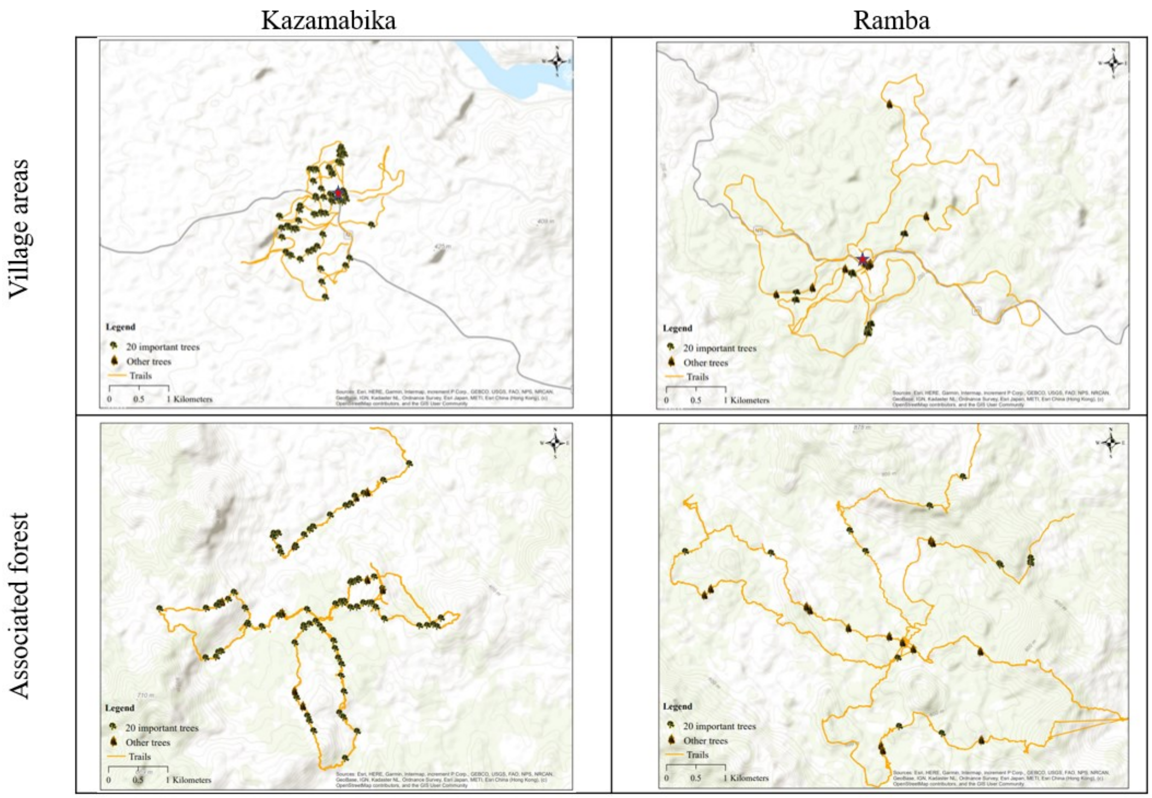

Figure 3.5. Maps of elephant fruit trees and trails within village areas and associated forest sites.

Ramba. Elephants were observed foraging on mangos in the early morning 11 times over eight days in Kazamabika using camera traps (Table B7). Because only the two village sites could be sampled during the same year and season, we could only compare evidence of elephant activity with native food resources between these two sites. This comparison provided some evidence that the village area with the highest presence of elephant food resources also has the most elephant activity.

Kazamabika, with much higher density of trees in active fruiting and much higher density of salines, had nearly 50% higher density of elephant dung along trails (Figure B3). However, the relative proportions of salines between the two villages were almost identical to the relative proportions of fruit trees, making it impossible to distinguish which was the likely driving factor. Our goal of using the censuses of all four sites to tease out these relationships was confounded by our inability to sample them in the same year and season. Moreover, our attempts to correlate elephant activity to resource density along individual trail segments within sites were unsuccessful because elephants do not necessarily deposit their dung near the immediate location

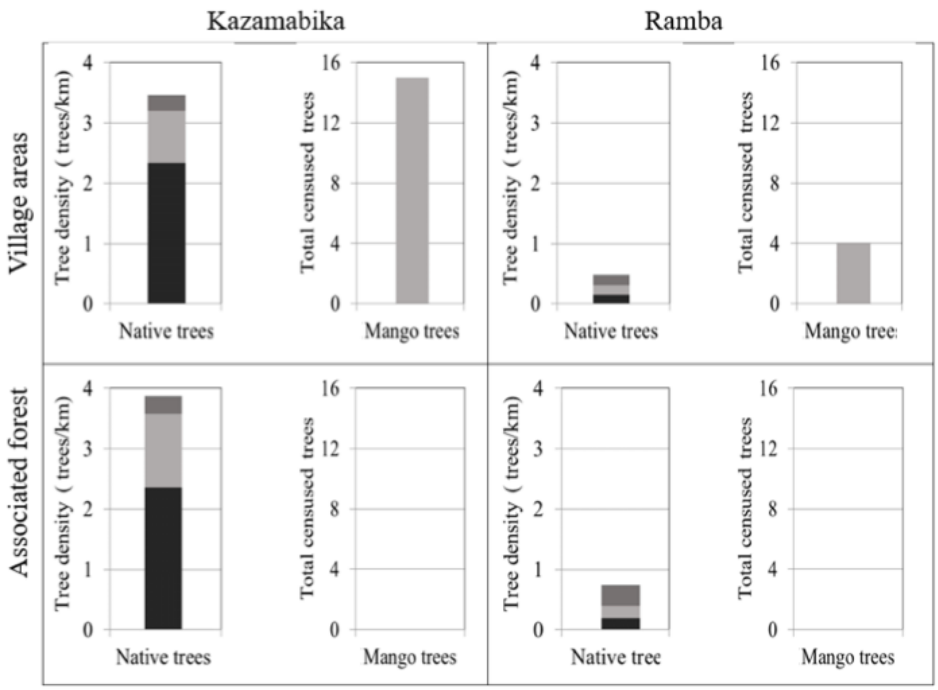

Figure 3.6. Censused native and mango trees in the two selected villages and associated forest sites at Lopé National Park. Black = eight most important native trees; light grey = 12 other important trees; Medium grey = other fruit trees.

of foraging and because our efforts to use trail width as a surrogate for elephant activity were ineffective - some trails were between rocks, and many were on clay or sandy soils, which made trail depth and width unreliable measurements of elephant use intensity.

3.4.3. Phenology of elephant fruit tree species

The fruit production of the 20 most important species declined by 2/3 from 2003-2009, followed by relative stability from 2010-2020 (Figure B1). A breakdown by species shows that the highest producing species showed the most dramatic declines (Figure B2). We grouped the productivity trends of the 20 most important fruit trees for elephants into four categories by the relative level of production in the first five years shown, rate of decline, and capacity for productive years in the last five years recorded. Overall trends of rapid decline are consistent with those of Bush et al. (2020b), who assessed results for a compiled, broader set of fruit tree species using the same dataset. Our species-by-species assessment shows that within that larger trend, some tree species with high (7 species) and moderate (4 species) production still show capacity for productive years, even if lower than in the early 2000s.

In comparison, three species that began the assessment period with relatively low production have shown near-complete loss of fruiting over the last two decades. Finally, four species showed modest or no decline, with some capacity for years with production close to that of the first five years of the assessment period, and two species with low production show increasing trends. We note that productivity (the y-axis) is measured by the proportion of the canopy with fruit. Because the analysis does not include the numbers or size of the fruit, we emphasize that low productivity does not necessarily mean a low volume of fruit produced.

3.4.4. Synthesis of seasonal variation of native fruit and crop availability during CDIs

Villagers and professionals indicated that CDIs, as well as crop and mango availability in village areas, varied across the alternating dry and rainy seasons (Figure 3.7 A-C). Similarly, native fruit availability varied across seasons over the two decades of phenology data. When averaged across the two most recent 9-year periods of data, fruit availability declined 30 % in the most recent period (Figure 3.7 D). Breaking the results out by season, the decrease was most pronounced in the long dry season (37%) and least during the short dry season (20%). We relied primarily on the recent decade’s fruit production for comparisons with CDIs and crop availability since it best coincides with interviewees' reports (Table B3).

This perception of high CDIs in the second rainy season coincides with the highest reported crop availability and the key mango season. In the second rainy season, as in the first, there was a similar balance of crop and fruit—both slightly lower in the second rainy season.

The first rainy season had the lowest production of the 20 most important fruit production compared to the long and short dry seasons that had similar fruit production, slightly higher than in the second rainy season (Table B4). Interviewees also related how their activities in plantations varied seasonally (Table B5) and their perception of the seasonal reasons for CDIs (Table B6).

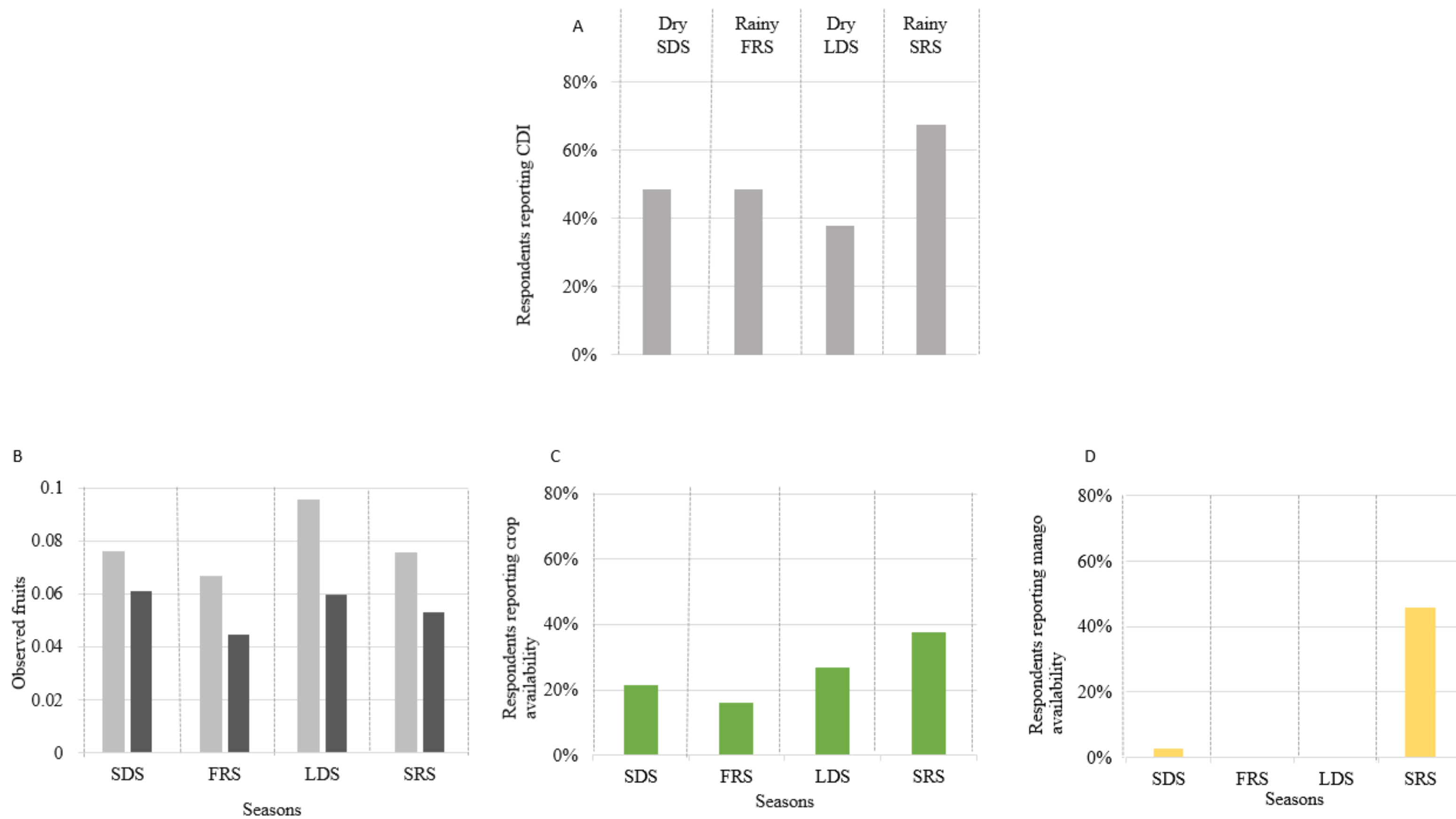

Figure 3.7. Seasonal variation of CDIs and elephant food sources by season. (A) CDIs (B) Crops. (C) Mangoes (D) Native fruit availability. A-C from respondent interviews. D from long-term data. Fruiting trees were assessed for two nine-year periods: 2003-2011 (grey) and 2012-2020 (black). Observed mature and immature fruits shown on a scale from 0-0.1, based on a maximum of 4 occupied quadrants of a tree canopy. Seasons: short dry season (SDS), first rainy season (FRS), long dry season (LDS), and second rainy season (SRS).

3.5. DISCUSSION

The causes of elephant crop depredation incidents (CDIs) are complex; both simple explanations and lasting solutions have proven elusive. We investigated a broad array of potential contributing factors in two villages located in and adjacent to Lopé National Park in Gabon, which holds some of the world's best-remaining forest elephant habitat. We used semi-structured stakeholder interviews, an elephant fruit tree census, and long-term fruit phenology data to explore the relationships between CDIs and the seasonal availability of crops and native fruit trees within and around two villages.

We view stakeholder reporting as extremely valuable and trustworthy but note that the semi-structured interview methodology we employed was designed primarily for qualitative, exploratory analysis rather than the statistical analysis we intended to apply to an integrated temporal data set of CDI reports and fruit phenology. With this caveat in mind, we explore the plausibility of various factors that may help explain CDI occurrence over time, in space, and by season. In the process, we first consider big-picture evidence of changes and differences in CDIs and then delve deeper into localized issues. We begin by considering the five key problem types identified by villagers and conservation professionals as contributing to CDIs (chapter 2), including the three types identified by villagers for the two case study villages (Table 3.1), and compare their assertions to other evidence that might support or argue against their perceptions. In doing so, we attempt to better convey how multiple issues may jointly impact CDIs. We start from coarse scales of time and landscape context and then focus on localized seasonal contexts, with an eye toward informing strategies to manage CDIs by satisfying both villagers' and elephants' needs to create conditions for coexistence.

3.5.1. Increase of CDIs over time

Forest elephants seem to have made crops a regular part of their diet (Naughton-Treves 1998, Chiyo et al. 2011, Gunn et al. 2014, Djoko et al. 2022). According to villagers from Kazamabika and Ramba, until recent decades, extreme levels of crop loss were uncommon, and people had many ways, such as killing elephants, guarding crops at night, and making fences with old cans or endura rooting sheets to protect their crops. However, land use changes, such as commercial logging, appear to have increased pressures for elephants to seek out crops, while the creation of the national park seems to have led to a further increase in elephant crop consumption at the same time that peoples' ability to prevent CDIs has declined due to village population loss and restrictions on the use of lethal force to protect their crops.

The worst CDIs currently appear within villages in and adjacent to protected areas such as Lopé National Park (Walker 2012). At Lopé, stakeholders specifically asserted that CDIs were increasing in villages as three interacting factors played out over the last 50 years: the harvest of large fruiting trees by logging concessions from the 1970s to 1990s, wildlife protections in the early 1980s, and conservation policies during the 2000s that prohibited killing problem elephants. Antihunting and poaching policies marked the 1980s, while the 2000s were marked by reinforcing these policies with the establishment of national parks, leaving local villagers with only far less effective ways to protect their crops (Table 3.1).

In the midst of these policy and land use changes, human activities in the landscape declined starting the 1990s with the departure of logging concessions from Lopé. Losses of jobs associated with the logging industry, combined with the reduced ability to hunt wildlife due to regular and intense patrols in the villages and across the park, led to the exodus of many rural people. Villages and the park became quieter and safer for elephants, allowing them to approach the villages more securely (Professional, ID 12, 35,44; Villager, ID 4) and increasing regular human-elephant negative interactions (Table 3.1). It was rare to see elephants before these changes; traditional elephant hunters had to go through a traditional ritual before going to hunt an elephant over 50 km from the village (Villager, ID 33). People used to walk between Lopé town and different parts of the forest without seeing elephants, while now elephants are found even around housing (Villager, ID 22).

Along with these land use and policy changes, elephants have faced rapidly declining native fruit production (Figure B1, B2; see also Bush et al. (2020b). Local stakeholders asserted that CDIs occur when there is native fruit scarcity in the forest due to irregular fruit production and implicated that changing climatic conditions were negatively affecting native tree species. For example, bush mango (*Irvingia gabonensis)*, one of the eight most important fruits for elephants, used to produce fruit twice per year but now may not produce even once per year, impacting both elephants and villagers, who also eat the fruits (Table B3: Professional, ID 32, Villager, ID 9). Bush mango fruit production has declined in other places in Gabon due to fruit overharvest by villagers and incidental damage from logging (Midoko Iponga et al. 2018b) and elsewhere in Africa (Udeagha et al. 2016).

Fruit tree phenology data from the Lopé research station showed that fruit production of the 20 most important fruit tree species declined by 2/3 from 2003 to 2009 and has remained low since then, fluctuating from year to year but never recovering from the prior decline (Figure B1). The assertion by stakeholders of a causal link between climate change and reduced fruit production is further supported by Bush et al. (2020b), who, based on the same phenology dataset, associated large declines in ripe fruit availability with recent declines of forest elephant body condition in Lopé National Park, while suggesting that climate change could underlie the declining fruiting. They documented a warming and drying trend in the park over this time period in a subsequent paper (Bush et al. 2020a). Native fruits are central to the forest elephant diet. Fruit reduction so severe that it has led to declines in body condition, along with the exodus of able-bodied villagers to protect crops, could have led elephants to add crops to their diet through the joint drivers of necessity and opportunity.

From the perspective of continued production of native fruits for elephants, it is daunting that all 11 species with high or moderate productivity in the early 2000s have experienced substantial declines but encouraging that each still shows some capacity for productive years. On the other end of the spectrum, four species of relatively low production have experienced little or no decline and some capacity for production, and two low-production species show increasing trends. Although the overall native fruit picture thus appears grim for elephants, there is some hope if species that show some capacity for continued years of good production and particularly those species that are increasing production, can be reestablished and even increased in the forest. We also note that many tropical canopy tree species are found only at low densities (Slik et al. 2013) due to natural enemies such as insects and pathogens so that efforts to increase the density of some species may be confronted with ecological limits that thwart such efforts (Levi et al. 2019, Comita and Stump 2020).

Importantly, ripe native fruits attract elephants across the forest, leading elephants to move long distances (Momont 2007, Mills et al. 2018). Elephants will move again once they have exhausted available fruits within a resource patch or may simply need to move more often and further when fruits have become scarce. In each case, movement, especially roaming longer distances and exploring broader areas if their existing trail systems no longer provide reliable resources, may increase the likelihood of encountering crops. When villages and associated plantations are embedded within forests of similar fruit tree densities to nearby protected areas (Figure 3.5, Figure 3.7), this could provide a particularly attractive habitat for elephant foraging by combining native with highly nutritional domestic food resources (Rode et al. 2006, McLennan and Ganzhorn 2017, Vogel et al. 2019, Bryson-Morrison et al. 2020). As they forage, elephants develop long-term trail systems that lead them efficiently toward reliable resources (Blake and Inkamba-Nkulu 2004), likely reinforcing patterns of visiting village areas with rich native and domestic food resources.

3.5.2. CDIs in relation to differences between villages and their landscape context

We assessed CDI conditions within two villages in and adjacent to the protected area of Lopé National Park to answer the question: "Do CDIs vary between the two villages, and if so, what factors might explain the differences?" Prior to installing the electric fence, Kazamabika villagers reported that CDIs were more of a problem than Ramba villagers (interview for chapter 2). Walker (2012) identified Kazamabika as one of the villages with the highest CDI index of villages in and adjacent to protected areas in Gabon. Ramba was not included in that study; we questioned professionals on the absence of Ramba from previous studies but received no clear answers. Ramba could have been omitted because villagers complained less about CDIs at that time. It is also possible that because Ramba is outside the park, hunting games by villagers in the surrounding forest may have frightened elephants away, whereas hunting is not allowed outside Kazamabika because it lies inside the park.

If the prevalence of native fruits around a village increased CDIs by drawing elephants toward it, one would expect greater numbers of CDIs in areas with higher density of native fruit trees (Figure 3.6). Ngama et al. (2019) showed that CDIs were high in plantations with fruit trees at the Mont de Cristal National Park in Gabon. The reports of higher CDIs at Kazamabika than

Ramba, and its seven times higher density of native fruit trees along village-area elephant trails, are consistent with this expectation. The higher density of elephant dung at Kazamabika than at Ramba during the short dry season (Figure B3), when domestic mangos are not ripe, adds weight to this argument, as does evidence of higher elephant presence with greater native fruit availability in both community lands and a national park (Djoko et al. 2022). It is also possible that the landscape around Kazamabika provides important habitat diversity for forest elephants because Kazamabika is located in forest-savanna mosaic where elephants have been observed mostly in the gallery and bosquet forest, and savanna (White et al. 1993, Momont 2007). Ramba and its associated forest are at higher elevations in steeper terrain, which is known to reduce elephant use (Ngama et al. 2019). Ramba also shows substantial evidence of past logging, as evidenced by many old logging roads and tree stumps observed during fieldwork, whereas no such evidence was seen around Kazamabika.

This spatial evidence lends credence to the idea that village areas with higher elephant resources may be exposed to greater numbers of CDIs. While the idea may seem common sense, this evidence helps begin to disentangle the complex questions of what is drawing elephants to certain areas over others, including whether CDIs are purely a function of crop availability or whether crop availability is simply one factor in a broad suite of ecological factors to which elephants are responding.

Comparing the habitat characteristics of each village to that of a nearby protected forest site with known elephant use suggests another factor that could increase CDIs. Both Kazamabika and Ramba are embedded in natural habitats used by elephants with similar fruit tree density along elephant trails to that of the village area (Figure 3.5, Figure 3.6). One stakeholder emphasized that there is no clear difference between the village and the forest (Professional, ID

45), which could bring elephants close to the villages because of habitat continuity, and the way that abandoned plantations around the villages create an elephant-friendly secondary forest with abundant forage. Although we cannot confirm that our sampling protocols allowed us to map all principal elephant trails in the four sites, it is notable that over the course of 10 days of sampling at each site, the length of trails mapped in the two village areas were 88% (Ramba) and 63% (Kazamabika) of those mapped in the two protected forests, despite the added time needed to map the somewhat higher densities of fruit trees in protected forest. This result suggests that elephant trail densities in the village areas are similar to densities in nearby protected forests, creating seamless continuity for elephant travel.

The evidence of greater elephant presence and more CDIs around village areas with greater native fruit resources also suggests how declining fruit production over time could contribute to increased CDIs by causing elephants with established trails and habitual use of both the nearby forest and village area to shift their attention toward crops. It also leads to questions that could be investigated further. Perhaps only Ramba villagers asserted that native fruit decline had increased CDIs because the relative scarcity of native fruits made their decline more impactful in that locale than in the forest around Kazamabika, with its seven times greater abundance of native fruit trees.

The outcomes of installing electric fences around plantations in several villages suggest that attempts to control CDIs by blocking elephants without addressing underlying causes may shift the location of the problem rather than resolve it. In those villages as well as CDIs on those without electric fences (Table 3.1). Due to its high levels of CDIs, Kazamabika was selected for the first electric fence installation in 2016, in collaboration with ANPN, the Gabon National Park Service. After a series of modifications and adjustments, the fence blocked elephant access to crops as intended. However, villagers reported that elephants had shifted their activities to the village center, mostly during the mango season, creating not only fruit losses but increased danger. Meanwhile, Two villagers and one professional reported that Ramba CDIs increased after electric fences were installed in three nearby villages, particularly the one closest to Ramba in 2018 (e.g., Villager, ID 40; Professional, ID 14). Even if villagers believe there is a net benefit to using an electric fence in their own village, doing so may create inequities across the larger landscape. This again suggests the CDIs must be addressed as complex ecological phenomena at landscape scales rather than as a local problem that simply requires more effective crop protection.

3.5.3. Factors influencing CDI variation by season

Do CDIs vary seasonally, and if so, do the numbers appear to respond to crop and native fruit availability or other seasonal factors? CDIs occur throughout the year (Figure 3.7A). This alone emphasizes that CDI reduction is needed across all seasons and provides further rationale for a detailed examination of whether the factors driving CDIs are the same throughout the year or whether nuanced seasonal processes may be at play. Given that the seasonal CDI numbers presented were not developed for statistical comparisons, it is impossible to assign confidence intervals to them. However, the reported differences between the highest and lowest seasonal incidents are striking, with 30% more stakeholders reporting CDIs in the second rainy season compared to the long dry season. The short dry and first rainy seasons were similar and intermediate to the other two seasons but closer to the long dry season.

The second rainy season thus stands out as most strikingly different from the others. It also is reported to have the highest crop and domestic mango availability (Figure 3.7 B-C), the greatest crop abundance and variety (Table B4), and intermediate native fruit availability (Figure 3.7 D), suggesting that crop availability and not just native fruit deficit is contributing to CDIs.

In contrast, in the long dry season, stakeholders reported the lowest CDIs and the second highest crop availability, while native fruit availability was tied for the highest in recent times and before then was the highest. Meanwhile, the second dry season and first rainy season have equal, intermediate reports of CDIs, while they show the two lowest scores of reported crop availability and both high and low native fruits. It is difficult to argue from these results that either crop or fruit availability or the interaction between them is a definitive factor controlling CDIs seasonally. Determining whether the connections are complex and interactive or simply tenuous requires further exploration of the different factors and their spatial contexts (Figure3.8).

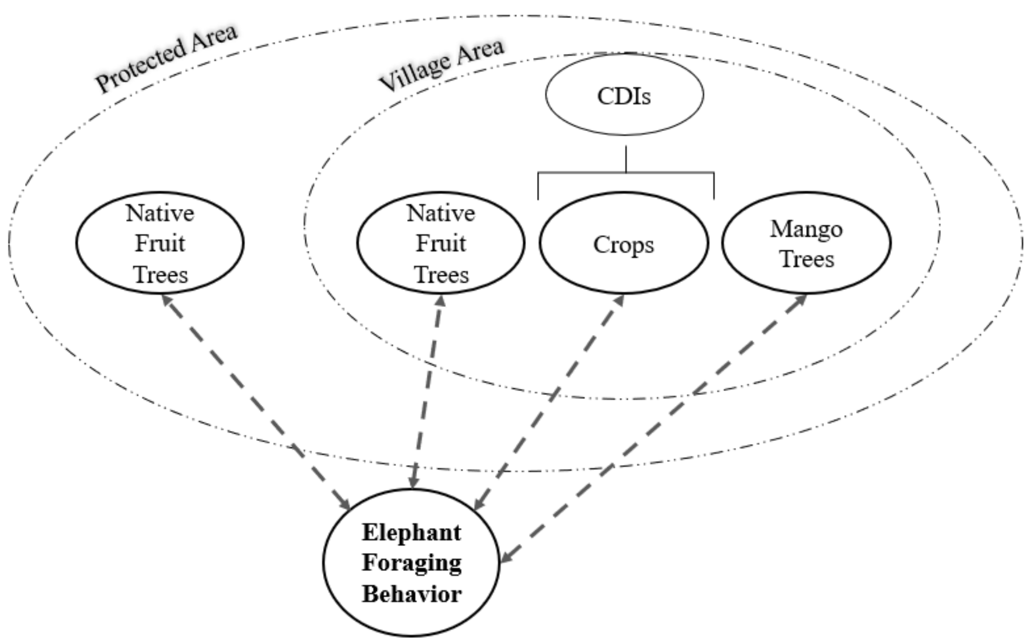

Figure 3.8. Spatial distribution and timing of native and domestic fruit (mango) and crop availability within village areas and adjacent protected areas may influence CDIs.

One factor warranting further investigation is the availability of domestic mangos. Taken across all seasons, only the central role of ripe mangoes during the second rainy season stands out as a striking, likely contributor to extremely high CDIs. Respondents reported that when domestic mango trees fruit (Table B4), many elephants leave the forest for villages (Table B6). Ngama et al. (2018) reported that forest elephants would not stop eating mangoes even when mixed with chili in efforts to deter elephant incursions into villages. During the ripe mango period, elephant herds and individuals move from one village to another as mango supplies are depleted.

Ripe mangoes have been reported to increase the number of forest elephants in other locations as well (Ngama et al. 2018, Meyer et al. 2022). Elephants then roam within village areas until the end of the mango season, which coincides with the period between the end of the second rainy season and the start of the short dry season. Villagers in our study reported that these elephants hid during the day in adjacent forest, waiting for nightfall to forage around mango trees, as reported in two other studies (Barnes et al. 2007, Kiffner et al. 2021). We also recorded elephant presence around mango trees from late afternoon to early morning during the second rainy season (Table B7). The overall decline of native fruits could be one reason that domestic mangos have become so important to elephants as a way to fulfill unmet dietary needs.

Plentiful crops are also available during the ripe mango period (Figure 3.7), potentially increasing CDIs because of elephants' constant activities and presence in and around the village. Mangos thus appear to draw elephants toward villages like a powerful magnet and then amplify CDIs as elephants stay within the village areas day and night. They essentially may be substituting domestic mangos for native fruit and then supplementing them with crops to satisfy their need for high quantities of herbaceous forage (White et al. 1993, Peter et al. 2001).

Except for mango production, there thus appears to be no potential "smoking gun" in our data to explain the annual variation of CDIs. Nuanced patterns among seasons suggest relationships that could warrant further study, particularly if more rigorous quantitative data on

CDIs and crop availability can be obtained. Alternatively, the patterns documented may point to the need for a more detailed understanding of not just when crops are available but the processes and timing of crop cultivation and growth in relation to native fruit availability and elephants' seasonal behaviors and movements. We explore these ideas next.

3.5.4. CDIs in relation to crop planting, growth, and harvest periods

Seasonal CDI variation could depend on relation to crop planting, growth, and harvest periods. The idea of crop availability itself may be an oversimplification that needs to be put into a broader context of villagers' annual round of activities through periods of crop planting, growth, and harvest (Figure 3.9). We next examine this annual cycle, one season after another, to see what can be learned.

During the *long dry season*, stakeholders reported the fewest CDIs despite moderate crop and relatively high fruit availability. However, another factor is that people spend more time in the plantations to both harvest crops and establish new plantations. People's increased presence and activities may discourage elephants from approaching. After crop harvest at the end of the dry season, villagers establish new plantations around their village, planting variety of crops after using slash-and-burn practices to clear the forest.

During the second rainy season, stakeholders reported the greatest number of CDIs. This is aligned with high crop availability, plentiful mangos, and intermediate native fruits. These factors alone suggest that high crop availability may increase CDIs, but other factors identified by stakeholders may also contribute. With the rains, diverse crops begin growing in the new plantations, but heavy rains reduce the number of days people can access their plantations. In the absence of regular weeding, many forest seedlings begin to establish, and the new plantations

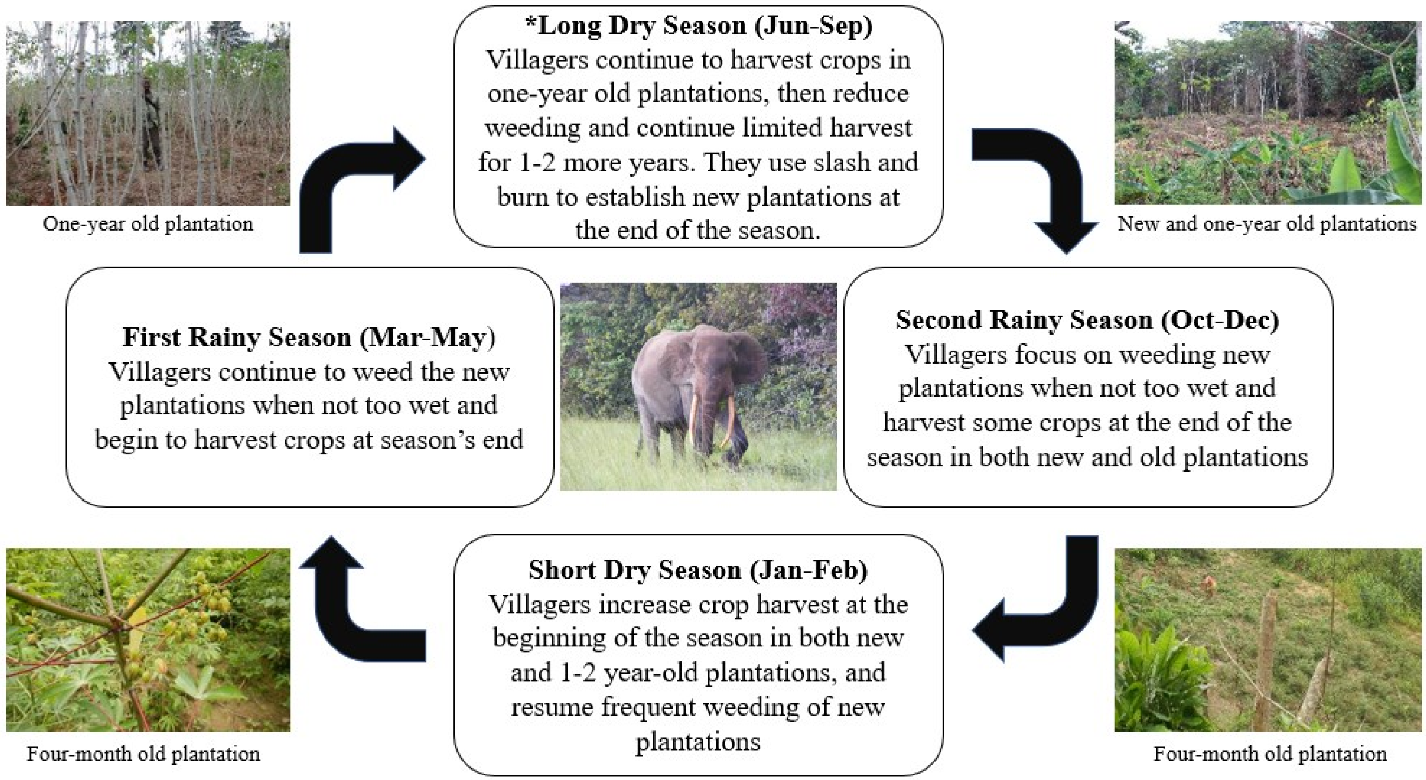

Figure 3.9. Annual plantation management cycle. Synthesis derived from descriptions of plantations management by 37 stakeholders, most of whom commented on only a single season (table B5.)

resemble secondary forest where elephants seek out the abundant herbaceous forage (Merz 1981, Barnes et al. 1991)

The combination of reduced human activity and increased weeds may thus contribute to the high reported CDIs. During the transition between the rainy and dry seasons, the reduction of rain again permits villagers to weed and harvest their crops, some of which begin to mature at the end of this season and the start of the next (Table B4 and Table B5). Angoué (1999) also noted the ripening and harvest of crops, such as peanuts, corn, and other vegetables that mature around three months during this period.

Stakeholders reported decreased but still intermediate numbers of CDIs in the *short dry season* in conjunction with reduced crop availability and increased native fruit availability compared to the previous season. This report is consistent with the hypothesis that CDIs would vary with the relative availability of crops and native fruit. Furthermore, similar to the beginning of the long dry season, people begin to renew their activities in both new and old plantations for weeding and crop harvest, potentially discouraging elephants from approaching. Stakeholders reported that most elephants left their villages to forage elsewhere during the *short dry season* (Villager, ID 10, 12). One possible reason for the reported decline of CDIs during the short dry season is that the lack of ripe crops leads elephants to leave the village area to look for native fruits in the forest. However, this may not have always been the situation. People used to plant more crops during this short dry season but discontinued the practice due to CDIs, except where crops are protected by an electric fence (Villager, ID 23).

During the first rainy season, stakeholders again reported intermediate levels of CDIs, coincident with both reduced crop and native fruit availability compared to the previous season. However, the rain again begins to limit peoples' activities in the plantations, and consequently, more weeds begin to grow. CDIs may also occur less often than in the second rainy season because of the reduced variety of crops, and because perennial crops such as cassava are still immature until the end of the first rainy season and the start of the long dry season. Elephants prefer to consume only mature cassava (Kamiss and Turkalo 1999, Chiyo et al. 2005), although a few elephants will eat immature plants (Kweku et al. 2010). Some elephants come back to eat mature cassavas when villagers also harvest them at the end of the first rainy season and beginning of the long dry season (Table B5).

Finally, one professional respondent, in a conversation following the interview, noted that during both rainy seasons, elephants may move from the flooded forest into the plantations (Professional, ID 8), Lopé National Park, Gabon, personal communication), which are located on higher ground, potentially increasing CDI's. CDIs may also vary due to seasonal reductions of accessible water, as some rivers and streams dry up in the long dry season. Water scarcity pushes elephants to concentrate around water sources across the forest (Buij et al. 2007, Mills et al. 2018, Beirne et al. 2020, Beirne et al. 2021), potentially limiting their movements in search of resources like crops.

This framing of CDIs a s influenced not only by the relative availability of crops and native fruit but by the seasonal patterns of people's activities in and around the plantations make the case that our assessment of CDIs in relation to resource availability by season (Figure 3.7) missed the more nuanced dynamics of the explanatory storytelling of people who live with these situations through the course of their daily lives and across many generations of lived experience. Because of this, we argue for further studies that take on the challenge of integrating ecological field studies with stakeholder engagement and using both qualitative and quantitative data.

3.5.5. Limitations

Our initial plan was to use forestry service CDI reports to assess the numbers, locations, and seasonal distribution of CDI over time and the types of crops damaged each season. We would then have aligned these results to the native fruit phenology data by year and season to assess the numbers of CDIs in relation to crop and native fruit availability. However, the CDI reports proved unreliable due to inconsistent reporting and apparent data gaps due to program administrative issues, villagers' likelihood of reporting CDIs across different seasons and crop types, and because the reports did not include the incident date but only the date that the forestry agent assessed the damage, which could have occurred long after the incident date. Given the value of such data for future analyses, we recommend a collaborative effort by researchers and government agencies to design and implement a CDI tracking system that can provide reliable data on the day, location, crops damaged (eaten or trampled), and extent of the damage for each incident and encourage villagers to report each incident. Given the complexity of the problem, we faced a variety of factors that confounded our ability to link disparate data sources into a single picture. For example, it was difficult to align field data collection across multiple sites in difficult terrain during a single season to make the full set of comparisons between village areas and associated forest sites that we had intended. The availability of long-term fruit phenology data was invaluable but it would be even more useful if the current metric of fruit availability could be translated into one that adjusts for the density and size of fruits and their nutritional value.

3.6. CONCLUSION

Integrating stakeholder interviews and ecological field data for the landscapes around two rural villages at Lopé National Park provided a coherent, if complex narrative about the causes of CDIs and why reducing them has proved so intractable. Our results indicate that neither crop nor native fruit availability, nor the interaction between them, is a definitive factor controlling CDIs. Instead, they suggest that these factors, along with the spatial and temporal distribution of elephant resources and human activities within mosaics of natural and managed landscapes, interact to influence elephant foraging behaviors, setting the stage for CDIs.

At broader spatial and temporal scales, land use and policy changes, including the settlement of nomadic slash-and-burn agriculturalists in permanent villages, the expansion of commercial logging and its decline, and the establishment of national parks, created a cascading set of effects that put villagers and elephants on a collision course. Reduction of native fruit production ¬ a central dimension of the forest elephant diet ¬ has increased the pressures on elephants to seek alternative food sources at the same time that villagers' traditional methods of crop protection – lethal force plus sufficient numbers of people to repel elephants have ebbed.

At local spatial scales, permanent village areas comprised of housing with planted domestic mangos surrounded by concentrated patches of active and abandoned plantations have been incorporated into well-established elephant trail systems, providing concentrations of native and domestic food resources that appear to have become critical to elephants with the decline of native fruits. At the same time, the seasonal associations identified by stakeholders between CDIs, native food resources for elephants, and the ebb and flow of people's activities in and around plantations suggest how seasonal ecological cycles create a set of nuanced, complex relationships between how people and elephants use the land. These relationships appear to partially explain the variation of CDIs across seasons and, by extension, across larger landscape scales and over time. Given that many of the dynamics described occur not just within seasons but across the transitions between seasons, and given the limitations of our study, we argue for further investigations that integrate ecological field studies with stakeholder engagement.

Although the situation is daunting, we see reason for hope that these understandings of how and why CDIs arise in the landscape through the lens of both human and elephant needs hold promise for developing solutions that promote more peaceful coexistence.

CHAPTER 4: A STRATEGIC FRAMEWORK AND TOOLBOX FOR HUMAN-ELEPHANT COEXISTENCE

Contributions

This chapter is co-authored by Hervé R. Memiaghe, Christine Enright, Steeve Ngama, Nelson Ting, Dennis Galvan, and Bart R. Johnson. It was written by H. R. Memiaghe under B. R. Johnson's guidance. H. R. Memiaghe and B. R. Johnson developed the research design and methods. All authors participated in developing the conceptual foundations of the paper and contributed to revisions.

4.1. INTRODUCTION

A practical conceptual framework for human-elephant coexistence could benefit villagers and African forest elephants, both of whom are threatened by crop depredation incidents (CDIs) (Nsonsi et al. 2017, Nsonsi et al. 2018). Village economies frequently depend on reliable food production from subsistence farming, and elephant CDIs threaten the basis of villagers' livelihood. Meanwhile, elephants may be killed or injured as a direct or indirect consequence of villagers' attempts to protect their crops (Lahm 1996, Mackenzie and Ahabyona 2012, Walker 2012, Nyirenda et al. 2018, Nyumba et al. 2020). Villagers use various crop protection methods, but most are only partially effective or work for only a short period of time before elephants surmount them. Historically, villagers killed problem elephants, an action now illegal because forest elephants are critically endangered from poaching and habitat loss (Maisels et al. 2013, Breuer et al. 2016, Poulsen et al. 2017, Turkalo et al. 2017). In some cases, villagers still kill problem elephants, a particularly contentious practice in villages near protected areas like national parks, where elephants may spend more time around villages than within the protected area (O'Connell-Rodwell et al. 2000, Nsonsi et al. 2018, Rakotonarivo et al. 2021, Terada et al. 2021).

What if the problem could be reframed from a focus on terminating conflict to a search for ways to foster coexistence? Building human-elephant coexistence requires satisfying the needs of both humans and elephants through intentionally designed and managed landscapes to share land peaceably (Morehouse and Boyce 2017, Frank and Glikman 2019, Tiller and Williams 2021). Frank (2016) points out that coexistence may be possible if both human and wildlife needs are satisfied, even while tolerating some wildlife crop consumption. A sustainable tradeoff might be achieved by satisfying top-priority human and wildlife needs while managing negative interactions to produce the least harm in a land-sharing environment (Morehouse and Boyce 2017, Tiller and Williams 2021). Identifying both species' needs is essential to determining management strategies that foster coexistence, which we refer to as "coexistence strategies," and the types of specific actions to put each strategy into practice.

A human-wildlife coexistence framework holds the potential to decrease crop depredation (Frank and Glikman 2019, Shaffer et al. 2019, Pooley et al. 2021) but needs successful implementation to demonstrate its feasibility. Land sharing through coexistence may require attending to broader issues such as ameliorating unfavorable socioeconomic conditions that exacerbate villagers' vulnerability to CDIs (Frank 2016, Van De Water and Matteson 2018, Frank and Glikman 2019), land management practices that degrade wildlife habitat and disrupt their foraging behaviors (Johns 1985, Dudley et al. 1992, Laurance 2010, Zakaria et al. 2016), and changing climate conditions that can impact food availability (Bush et al. 2020b, Sattar et al. 2021). Fostering coexistence could reduce the amplifying feedback loop between rural exodus and CDIs (chapter 2) (Angoué 1999, Fairet et al. 2014), while managing the land for keystone habitat engineers like elephants can help sustain key ecological processes, composition, and structure (Poulsen et al. 2018) that may make it more resilient to stressors such as climate change.

For coexistence to succeed, rural villagers should be involved as collaborative decision-makers to represent their needs and their knowledge (Lalaina et al. 2011, Satyal et al. 2019). Participatory planning approaches are essential to resolving landscape conflicts between biodiversity conservation and socioeconomic development (Slocombe 1993, Grumbine 1997, Johnson and Campbell 1999). Participatory engagement should begin in the initial planning stages, such as problem definition (Grumbine 1997), because how a problem is defined establishes whose interests its resolution will serve (Fischer 1993). If carried out throughout a planning process, participation can help ensure that all stakeholders, from local people to natural scientists and planners, contribute to the resolution of the conflict (Luz 2000). Participation is essential when working with traditional people who have both a long history of living in and interacting with local ecosystems, and who often have been marginalized in past decision-making (Larsen et al. 2000, Musavengane 2019).

While we can ask people what they need, it's not the same with elephants. A key concept for supporting elephants' needs while reducing CDIs is to align optimal foraging theory (Pyke 1984, Stephens and Krebs 1986), with more recent understandings from nutritional ecology (Raubenheimer et al. 2009). In particular, the latter replaces the former's emphasis on optimizing energy intake and output with recognizing animals' needs for nutrient balance in their diets. With this revision, foraging theory can offer an integrated understanding of elephant decisions around their dietary needs and preferences, including their selection of diverse resource patches in which they can balance their nutrient requirements (Turkalo and Fay 2001, Blake and Inkamba-Nkulu

2004, Rode et al. 2006) with their choice of when to leave one patch to seek another (Pyke 1984, Chiyo et al. 2011, Chiyo et al. 2012). Elephant behaviors are complex; their decision to leave a patch may be driven by resource depletion or by a perceived lack of security (Breuer et al. 2016, Beirne et al. 2021), and their movements along established trail systems vary in speed and distance when seeking new patches (Blake and Inkamba-Nkulu 2004, Von Gerhardt et al. 2014). Recent research builds our understanding of the ways in which elephant foraging behaviors are driven by the combined effects of food resource availability and their sense of safety as they move across the landscape (Mills et al. 2018, Beirne et al. 2020, Benitez and Queenborough 2021, Breuer et al. 2021, Fai et al. 2022). More effective than blocking elephants from crops may be applying knowledge of elephant behavior and cognition to help them meet their needs away from settlements (Mumby and Plotnik 2018). Understanding elephant foraging behavior in relation to year-round resource availability and nutrient balance thus may be central to building landscape-scale plans for coexistence that consider elephant and human needs across the large landscape mosaics that form the basis of elephant territories and human land use.

Coexistence is particularly crucial when villages are located within or adjacent to protected areas. Many such villages are associated with elephant populations that have become accustomed to crop availability over long periods (Webber et al. 2007, Von Gerhardt et al. 2014, Nsonsi et al. 2017, Kiffner et al. 2021, Eustace et al. 2022), leading to persistent and high levels of crop depredation (Hoare 2015). The proximity of nearby natural habitats, however, may provide the potential to alleviate the problem by making villages less suitable for elephants, in tandem with enhancing habitat quality in distant locations of the protected areas (Mumby and Plotnik 2018). Given the opportunity, forest elephants adapt their behaviors to reduce contact with humans (Vanleeuwe et al. 1997, Maisels 2004, Wrege et al. 2012).

When elephants spend time away from people, they benefit forest habitat by establishing trails and dispersing fruit tree seeds (Blake and Inkamba-Nkulu 2004, Blake et al. 2009, Campos-Arceiz and Blake 2011, Bunney et al. 2017). In turn, villagers use these trails to move around the forest and consume some of those trees' fruits (Mikolo Yobo and Kasumi 2014, 2015, Midoko Iponga et al. 2018a, Midoko Iponga et al. 2018b, Taedoumg et al. 2018, Fungo et al. 2019). Faced with persistent crop destruction, villagers may ignore these positive contributions of elephants and seek to eliminate them as pests (Remis and Robinson 2020). However, that situation might be mitigated if crop damage could be reduced by supporting these keystone mammals' needs in tandem with programs emphasizing how elephants benefit forests in ways that serve people's needs.

These ideas provide the foundation for proposing a conceptual framework for villager-forest elephant coexistence, informed by empirical studies. To make this framework broadly applicable, we linked three steps. The first was to identify problem types that exacerbate CDIs in relation to human and forest elephant needs (chapter 2). The second was to construct a set of conceptual coexistence strategies to address each problem type, while the third was to identify a suite of specific actions for each strategy from the literature and stakeholders. Together, these steps produced a coexistence planning framework supported by a toolbox of actions that can be selected to fit localized problem-solving. By bridging theory to application in localized contexts, the framework provides a means to test the feasibility of fostering human-elephant coexistence in real landscapes. By proposing this strategic framework and toolbox, the goal of this chapter is to promote participatory planning efforts and practical short and long-term steps to achieve peaceful human-elephant coexistence through actions that simultaneously serve the needs of both species.

4.2. METHODOLOGY

4.2.1. Study area

Gabon, a central African country located along the equator on the Atlantic coast, is recognized for its forest elephant population, which was recently estimated at 95,000 individuals—73% of all remaining African forest elephants (Thouless et al. 2016b, Laguardia et al. 2021). Gabon's success in this regard results from national policies that integrate sustainable forestry and biodiversity conservation. Sustainable forestry is driven by selective logging to minimize forest degradation. Biodiversity conservation has been prioritized since Gabon's constitution as a state in the 1980s by establishing natural reserves and prohibiting elephant hunting (Decret115/PR/MAEFDR 1981, McShane 1990). These reserves were expanded and turned into national parks that cover 10% of the country's area and 22% of its forests (Laguardia et al. 2021). Conservation success is also aided by Gabon's low human population density of 7.5 people/km^2, based on two million people over 270,000 km^2, with most people located in two coastal cities that provide job opportunities and public services such as schools and hospitals.

Lopé National Park, located near the center of Gabon and south of the equator, covers an area of around 4950 km^2 (Figure 4.1). It was one of Gabon's first protected areas and is a World Heritage site (IUCN 2007). The park is a mosaic of three leading land cover types: semi-evergreen tropical rainforest (3165 km^2), savanna and forest-savanna mosaic (340 km^2), and savanna-forest succession (1417 km^2), used by diverse wildlife, including big mammals like forest elephants (Momont 2007). Forest elephants use this heterogeneous mosaic to meet their seasonal cycles of fruit resource needs (Momont 2007) and salt by digging in some places called saline (White et al. 1993). This mosaic is also used by farmers to grow crops and to gather natural resources such as fruits, mainly in the northeastern part of the park, where Kazamabika and Ramba, the two case study villages for this research, are located (Angoué 1999). Kazamabika, located inside the park, is 10 km from the main town of Lopé. Both Lopé and Kazamabika have been significantly affected by

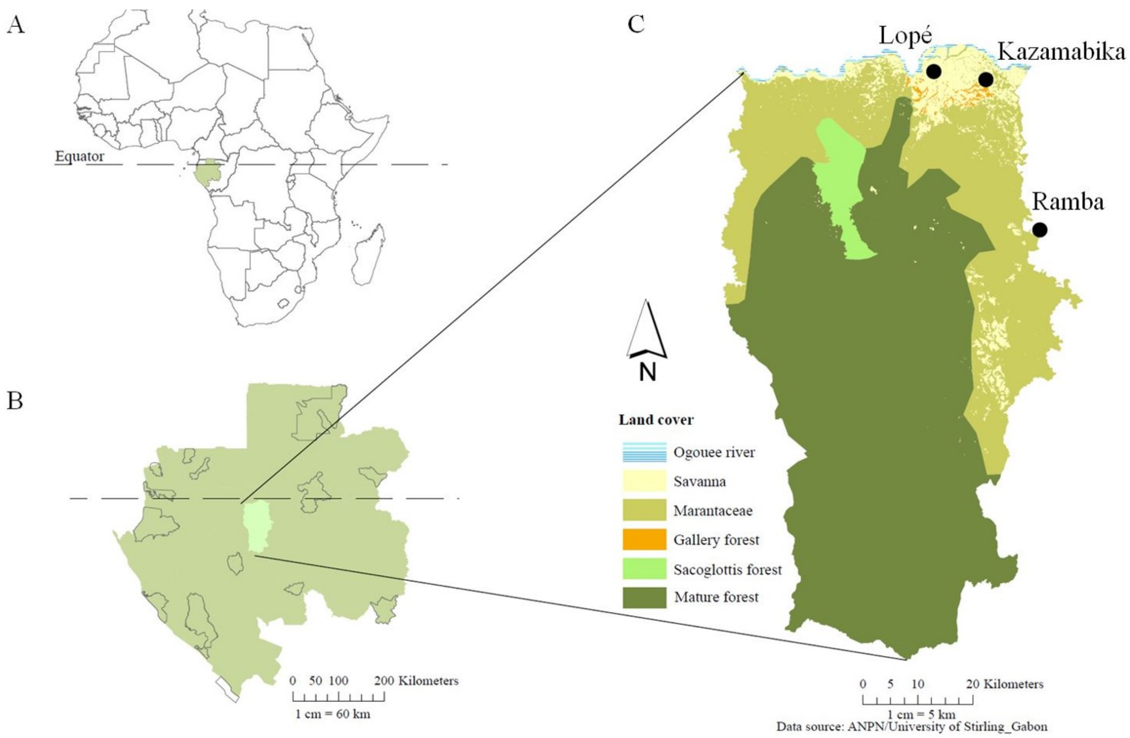

Figure 4.1. Location of case study villages near Lopé National Park, Gabon, Africa. (A) Location of Gabon in Equatorial Africa. (B) Gabon's 13 National Parks with Lopé highlighted. (C) Lopé National Park and key villages. Lopé is the region's principal village; Kazamabika and Ramba are the two smaller villages selected for this study.

elephant CDIs (Walker 2012). In 2016, Kazamabika erected Gabon's first electric fence, which was intended to resolve human-elephant conflicts by keeping the elephants out and allowing villagers to grow their crops safely. Meanwhile, Ramba is about 50 km from Lopé in the buffer zone in the eastern part of the park and is located near the river Offoué, a permanent water source. Its history of CDIs is less documented than that of Kazamabika. However, incidents seem to have increased with the establishment of the park and, more recently, with the installation of an electric fence in the closest neighboring village (chapter 3).

4.2.2. Coexistence framework development

The landscape management framework for human-elephant coexistence was built around five problem types (Table 4.1) identified from stakeholders' perceptions of CDI causes in Gabon and the two case study villages (chapters 2, 3).

Table 4.1. Problem types that can influence forest elephant crop depredation incidents. The impacts summarize stakeholder perceptions of these problem types (based on Chapter 2, Figure 2.5).

Problem types	**Impacts**
Decreased elephant security	Elephants leave their natural habitats because human activities create noise and reduce safety.
Reduced reliability of fruit production	Human activities such as logging reduce elephant fruiting trees and alter/fragment habitats. As a consequence, the efficacy of elephant trail systems and associated cognitive maps are also disrupted.
	Wild fruit production has decreased due to climate change. This can interact with episodic fruiting to make fruit availability less reliable. Elephants must find new food sources when fruits are not available.
Regular human-elephant negative interactions	Forest elephants regularly visit or stay within village areas for safety from poaching as well as for availability of crops. Villager land management practices create plantation-forest mosaics that allow elephants to access both crops and wild food in close proximity.
Ineffective crop protection	Many crop protection methods work only for a short period of time, while locally effective ones shift CDIs to other locations in the same village or other villages.
	Village youths and adults used to guard crops by chasing elephants but are now absent due to lack of local schools and jobs. Elderly villagers cannot effectively protect their crops, leaving crops more exposed to elephant depredation.
Village socioeconomic conditions	Reduced socioeconomic opportunities cause village exodus, reducing year-round population and increasing the proportion of the elderly.

First, based on the literature and stakeholder interviews (chapter 2), we reconceived each problem type into a coexistence strategy and identified the landscape contexts to which each strategy would be targeted. Next, as described below, we developed a set of actions for each coexistence strategy that could be deployed in key landscape contexts around individual villages (Figure 4.2).

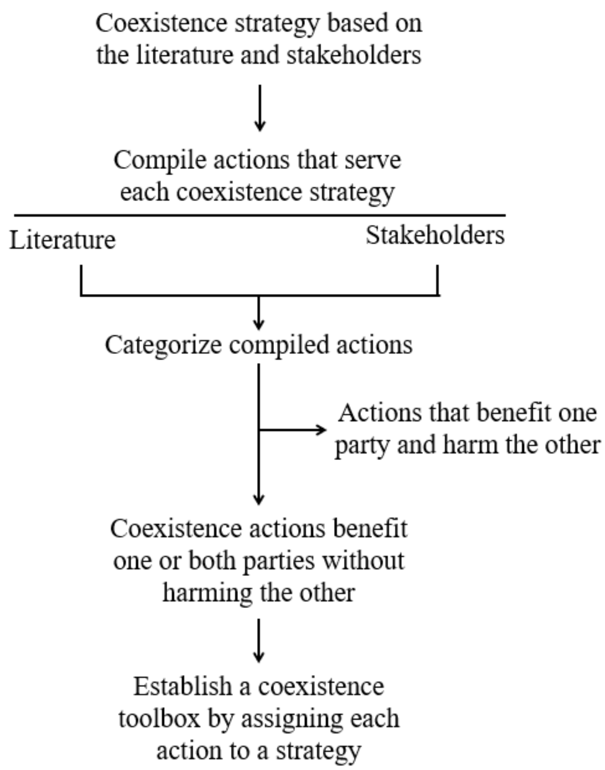

Figure 4.2. Methodology to elaborate coexistence toolbox that detailed actions in each coexistence strategy.

First, we reviewed the literature to identify actions that have been recommended or implemented to mitigate CDIs between humans and wildlife, particularly elephants. In a parallel process, we conducted follow-up interviews with participants previously interviewed about forest elephant CDIs in Gabon (chapter 2). Participants represented two groups: villagers from the two selected villages and conservation professionals, including park and forestry agents working in the national parks, and researchers working in national parks and other locations across Gabon. Twenty-six villagers (67%) and 13 professionals (33%) were interviewed for a total of 39 participants. The professionals included nine park agents, three researchers, and one forestry agent. Villagers were interviewed in person, individually. Conservation professionals were interviewed individually through phone calls due to COVID-19 travel restrictions.

Both villager and professional interviews included two phases. The first phase presented the initial results of CDI conditions from the previous interviews (chapter 2). In the second phase, which lasted 15 to 30 minutes depending on the depth of response, participants proposed actions to solve the multiple problem types.

Next, the compiled actions were categorized as those that benefited one party and harmed the other versus those that benefited one or both parties with no harm to the other. To do this, we rated each action using a decision matrix with columns for each party (villagers and elephants) and whether an action was expected to help satisfy that party's needs (indicated by "+"), harm that party (indicated by "–") or have no impact on them (indicated by "0"). The final step was to assemble a toolbox of actions organized under the five problem types and associated coexistence strategies to provide practical options for on-the-ground framework implementation and testing.

4.3. RESULTS

Our proposed landscape management framework for human-elephant coexistence (Figure 4.3) consists of five phases that can lead to a landscape management plan and its implementation within a participatory adaptive management cycle:

1. Assess the current CDI situation across all landscape contexts where CDIs occur or that otherwise contribute to the CDI problem.
2. Identify generalizable problem types associated with each landscape context.
3. Explore each strategy and associated actions to prioritize a feasible set of actions to implement that are deemed likely to address the CDI problem through the lens of coexistence.

4. Apply prioritized actions in each landscape context.
5. Monitor outcomes over time to periodically reassess the CDI situation and update the management plan.

A total of 76 actions were identified from the literature (41) and interviews (53), with 18 duplicates between the two sources (Table C1). Four actions were eliminated from the literature, three from interviews, and one from both sources because of their potentially negative impacts on elephants. After accounting for duplicate actions, the toolbox consists of 59 actions across the five coexistence strategies. Actions within each strategy were further grouped under sets of objectives that characterized differences in intended outcomes. Objectives were derived by examining each strategy to identify the higher-level intentions of its constituent actions. The primary purpose was to help planning participants identify additional actions that may not have been identified in this study (Table C2). An action toolbox that includes a list of sources for each action is provided for planners or researchers who want to further investigate different actions (Table C3), while selected examples are provided in Table 4.2 for the discussion. Each local problem related to CDIs that villagers identified at each of the two case study villages was each associated with a coexistence strategy (Table C4).

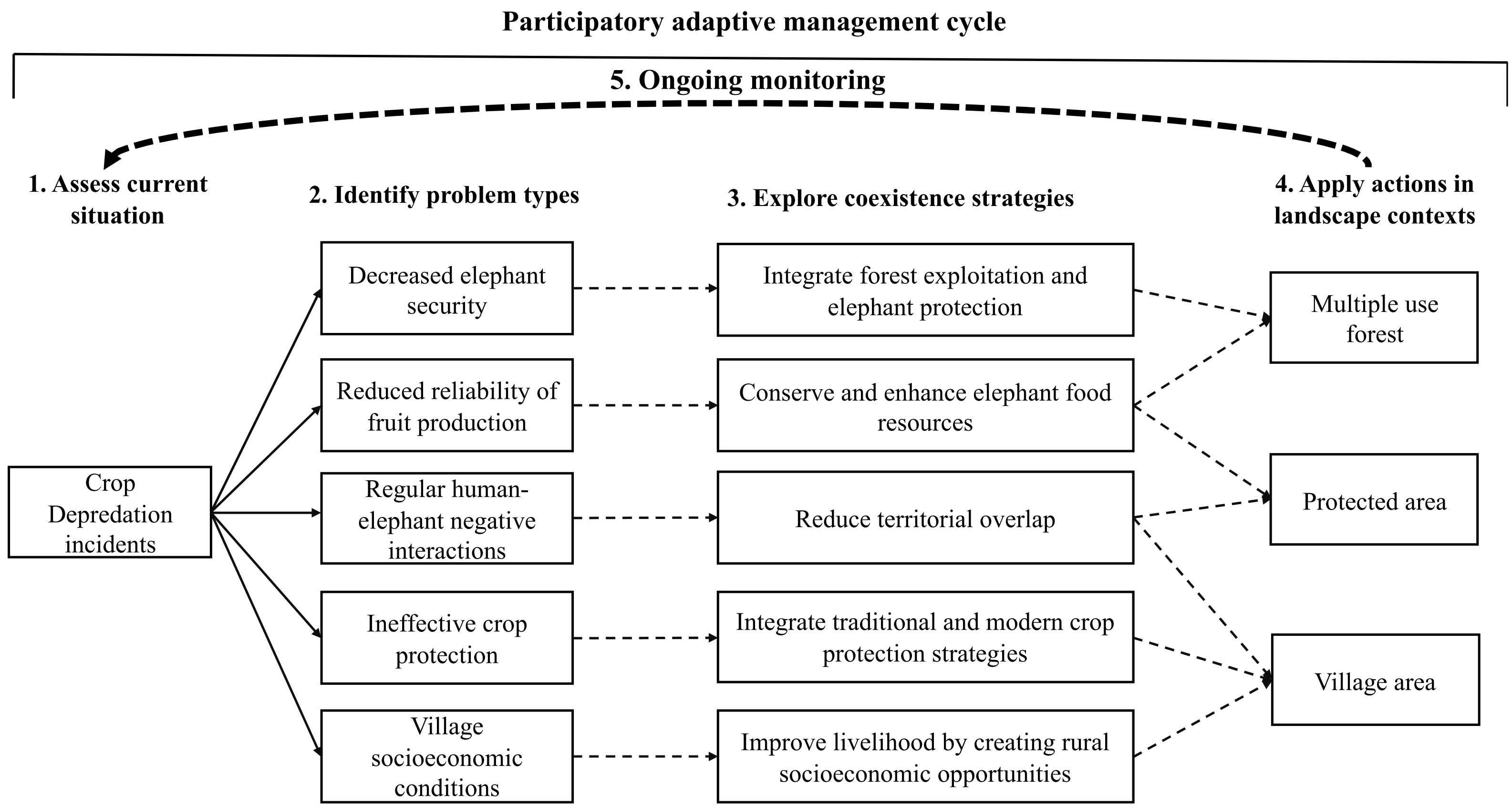

Figure 4.3. The human-elephant coexistence framework. Solid arrows show existing linkages (Chapter 2). Dashed arrows show proposed linkages to create an adaptive management cycle that fosters coexistence.

Table 4.2. Coexistence strategy toolbox derived from literature and stakeholder input.

	Problem types	Coexistence strategies	Examples of objectives with specific actions
Support elephants	Decreased elephant security	Integrate logging and elephant protection	Protect: Patrolling areas to reduce the secondary impacts of logging on forest elephants
			Integrate: Collaboration to integrate certified logging practices with elephant behavior research
			Conserve: Ecotourism as alternative to logging
	Reduced reliability of fruit production	Conserve and enhance elephant food resources	Conserve: Protect natural habitats to maintain fruit trees, other food resources, salines, baïs, and water sources used by elephants
			Enhance: Create elephant resource hotspots in areas of high elephant use far from villages, for example by selectively planting reliable fruiting tree species and enlarging baïs and water sources for year-round use.
Differentiate villager and elephant places	Regular human-elephant negative interactions	Reduce territorial overlap	Tolerate: Environmental education about elephants' ecological roles as keystone forest species and benefits to people; community forums about how villagers and elephants can coexist
			Integrate: Integrate spatial planning for people and elephants that deters elephants from reaching villages and encourages them to stay in the more distant forest, particularly around hotspots away from human land use
			Separate: Manage food resources in elephant forest sites (hotspots) and village areas (e.g., food waste) to separate elephant areas from people areas and create distance between them.
Support villagers	Ineffective crop protection	Integrate traditional and modern crop protection strategies	Repel: Increase village population to guard plantations at night, emphasizing traditional methods such as making noise, and introduce new methods such as drones that produce 'bee' noise, and bell alarms
			Deter: Modify the landscape by employing modern technologies such as electric fences, trenches, bio-fences, and solar light barriers;
			Adapt: Integrate multiple crop protection methods into adaptable plans that can respond to changing elephant behaviors
	Village socio-economic conditions	Improve rural livelihoods by creating socio-economic opportunities	Compensate: Efficient financial and material compensation to help villagers recover from CDIs
			Adjust: Reduce livelihood dependency on crops with alternative economic activities

4.4. DISCUSSION

The coexistence framework serves as an overarching structure through which cohesive planning can be conducted at the scale of an individual village within or near a national park or scaled to an entire national park like Lopé with its associated villages (Figure 4.3). The framework includes a toolbox of actions that can be selected and applied through collaborative decision-making among villagers and conservation professionals (Table 4.2 and Table C3). The goal of such projects is to implement a spatially integrated approach to mitigating elephant CDI impacts within a common framework. The framework integrates a comprehensive review of the literature with detailed investigations at two villages to provide a useful starting point for participatory engagement projects at a broader set of villages and national parks in Gabon and potentially elsewhere.

Although each village faces unique challenges that require prioritization of strategies and actions, we argue that crop depredation at each village should be approached holistically through an agreed-upon set of integrated actions that consider all problem types and their associated coexistence strategies. To this end, we recommend that the coexistence framework be used to produce action plans that satisfy seven criteria to support the participatory adaptive management cycle (Figure 4.3):

1. Individualized: tailored to the unique settings and needs of each village
2. Collaborative: uses participatory processes to develop a plan that has the support of both villagers and conservation professionals for an integrated set of actions supported by all parties

3. Comprehensive: addresses the full spectrum of problems that drive elephant CDIs in each location, including how multiple strategies work in concert to address the complexity of problem types and interactions

4. Strategic: recognize that long-term plans must begin with high-priority initial steps that can be agreed upon and achieved in the short term to build experience and trust among all parties

5. Cross-scalar: allows conservation agencies to apply a common framework across larger landscapes that reflect the land use needs of individual villages, the territories and movements of elephant herds, and the needs of an entire national park

6. Adaptive: implementation must be accompanied by well-conceived monitoring and assessment of outcomes so that successes and shortcomings can be assessed and adapted as needed over the longer term

7. Mutualistic: each strategy should support human and/or elephant needs without harm to the other.

The five coexistence strategies are not only conceptual but have spatial implications. Each can be applied in more than one landscape type, including multiple-use forest, protected areas, and village areas (Figure 4.3). Furthermore, actions in one place can affect CDIs in another. In the sections below, we explore each of the five coexistence strategies (Table 4.2) by first addressing the two designed to directly support elephants' needs, then the two designed to directly support villagers' needs. We conclude with the intermediate strategy, which spans the spatial domains of elephants and people by creating spatially distinct places that satisfy the needs of both. The number of actions identified under each strategy and objective, and their sources, is provided in Table C2.

4.4.1. Strategies to support elephants' needs

Elephants need both security and reliable food resources to forage effectively. These needs are addressed with two coexistence strategies: *Integrate logging and elephant protection*, and *Conserve and enhance elephant food resources.* These strategies attempt to mitigate how the joint impacts on native fruit production through logging and climate change can disrupt elephant foraging behaviors and movement patterns by reducing the efficacy of elephant trail systems and elephants' cognitive maps of landscape resources (Polansky et al. 2015, Mumby and Plotnik 2018, Presotto et al. 2019). These disruptions lead them to disperse and explore new locations and thus increase the likelihood that they encounter villages and plantations.

Integrate logging and elephant protection

The coexistence strategy of *Integrate logging and elephant protection* respond to decreased elephant security due to direct and indirect impacts of logging activities, including increased road density and loss of large fruiting trees (Maisels et al. 2013, Breuer et al. 2016, Poulsen et al. 2017). This coexistence strategy includes nine actions under three objectives: *protect, integrate, and conserve.*

Actions under the *Protect objective* focus on reducing the secondary impacts of logging on forest elephants, such the proliferation of logging roads that create both short- and long-term disruption of elephant activities and provide access for poachers. Patrolling in forest areas can increase elephant security (Clark et al. 2009, Stokes et al. 2010, Chibeya et al. 2021). While Gabon retains the largest known forest elephant populations in Africa (Laguardia et al. 2021), poaching for ivory remains the primary cause of population decline (Abernethy et al. 2013, Maisels et al. 2013, Breuer et al. 2016, Poulsen et al. 2017). Regular patrols in Gabon discourage local hunters as well as commercial poachers (Mangarella 2021, Tadoum et al. 2021). Most patrols occur in national parks, but many programs have been temporary and have not extended to regenerating secondary forest outside of parks where forest elephants like to forage (Merz 1986, Barnes et al. 1991).

Actions under the *Integrate* objective focus on improving certified logging practices through collaboration with elephant behavior researchers to maintain elephant security and their resource base (Mumby and Plotnik 2018), similar to recent innovations to protect lowland gorillas (Haurez et al. 2014, Morgan et al. 2019). In Gabon, integration applies anti-poaching policies in logging concessions outside of national parks (Wrege et al. 2017, Mangarella 2021) in response to the increasing footprint of logging concessions (Xue and Kiki 2018, Legault and Cochrane 2021).

Actions under the *Conserve* objective focus on alternative economic uses of the land that do not degrade elephant habitat, such as ecotourism. Ecotourism (Hodgson and Dixon 2000, Laurance et al. 2006) has long been promoted in Gabon as a key benefit of its national park system but must compete with well-established ecotourism programs in eastern and southern Africa. Gabon's ecotourism continues to warrant strategic rethinking and investment because it could not only protect elephants but also improve rural livelihoods, another strategy type. An additional benefit of *Conserve* actions is that they provide secondary economic benefits such as selling tropical forest carbon credits (Koh et al. 2021, Bomfim et al. 2022).

Conserve and Enhance elephant food resources

The coexistence strategy of *Conserve and Enhance elephant food resources* responds to fruit scarcity due to the loss of large fruiting trees from logging activities (Harris et al. 2021, Carvalho Jr. et al. 2022) and reduced fruit production due to climate change (Bush et al. 2020b). This strategy comprises three actions under 12 objectives of *Conserve* and *Enhance*.

Actions under the *Conserve objective* focus on maintaining fruit trees and other critical elephant resources such as salines and water sources in high-value habitat patches within logging concessions (Blake et al. 2007, Clark et al. 2009, Nsonsi et al. 2017, Kleinschroth et al. 2019, Beirne et al. 2020) and other types of exploited forest such as mining concessions and palm oil plantations. Another action is to exclude important native fruit trees from logging as Gabon already has done for *Baillonella toxisperma* and *Irvingia gabonensis* (Decretn°0137/PR/MEFEPA 2009). These policies require enforcement to prevent illegal logging (Laurance et al. 2006, Tegegne et al. 2016, Guan et al. 2018). Gabon's target of 100% sustainable logging (Laguardia et al. 2021) could reduce future habitat degradation but still leaves large areas of previously harvested forest in need of restoration and enhancement, as described next.

Actions under the *Enhance objective* focus on restoring and supporting basic food resources in degraded forests, as well as creating high-quality elephant food sources in areas far from villages (Mohandas et al. 2021). We refer to those areas as elephant resource hotspots that can be natural or designed areas with clusters of fruiting trees, baïs[2], salines, or water sources that can attract elephant herds and provide consistent foraging rewards. This is similar to but distinct from uses of the term elephant hotspot to indicate high elephant use (Wasser et al. 2015, Poulsen et al. 2017) or locations with high CDIs (Pozo et al. 2017). Hereafter, we refer to these

[2] The baï is an open canopy area that attracts wildlife such as forest elephants for food and minerals (Blake and Inkamba-Nkulu 2004).

sites more broadly as resource hotspots since they may also benefit other wildfire species. One of the most pressing food issues for forest elephants is the rapid decline of native fruit availability (Bush et al. 2020b), which is essential to their diet. Although the overall future of native fruit production appears grim for elephants, some important tree species show the capacity for continued years of good production, and a small number have stable or increasing production (chapter 3). Focusing on these species during resource hotspot development could be important, although efforts to increase the local density of some species may be confronted with ecological limits, since the abundance of many tropical tree species is held in check by the density-dependent transmission of disease.

The loss of native fruits, in combination with other land-use disruptions to elephant foraging behaviors, increases elephant movement (Tchamba and Seme 1993, White et al. 1993), potentially bringing them closer to human settlement. Hotspots that provide both safety and year-round stable food resources could serve these two primary needs in discrete areas far from villages, as discussed further below.

4.4.2. Strategies to support villagers

Protecting villagers from CDI impacts is not simple. Not only must CDIs be reduced, but village economies must be revitalized to create socioeconomic resilience. These needs can be addressed with two mutually supportive coexistence strategies: *Integrating traditional and modern crop protection strategies* and *Improving livelihoods by creating rural socioeconomic opportunities.*

Integrate traditional and modern crop protection strategies

The coexistence strategy of *Integrate traditional and modern crop protection strategies* responds to the persistence of crop depredation despite efforts to reduce them. The strategy includes 19 actions under three objectives: *repel, detect*, and *adapt*.

Actions under the *Repel objective* emphasize traditional methods that can be effective without harming elephants (supplement 2), such as making noise (Hsiao et al. 2013) and guarding crops (Hill 1998, Killion et al. 2021). Some methods are labor intensive, and sustained implementation would require addressing much larger societal issues. For example, working-age people have abandoned villages for the city, leaving only the elderly to guard crops (Fairet et al. 2014). Although village population loss appears to have been increased by CDIs in some areas, broader issues, such as the lack of rural employment and educational opportunities, are the biggest drivers. We later note several opportunities that could be explored in the Improve livelihoods strategy section. Even if enough able-bodied people are present, some actions, such as guarding crops at night, can expose villagers to malaria and interfere with family life, education, and other work commitments (Mackenzie and Ahabyona 2012, Hsiao et al. 2013).

Actions under the *Deter objective* focus on employing modern technologies to strengthen structures that prevent elephants from entering areas with crops (Montero-Botey et al. 2021, Vibha et al. 2021). Electric fences have proved effective at keeping elephants out of plantations, but fences require frequent and long-term maintenance. In Sri Lanka, electric fence maintenance costs have been reduced by families deploying mobile fences during crop growth and moving them to another location after harvest (Fernando et al. 2008, Fernando 2015). Even when successful in one village, elephants may simply move to other parts of the village or to a nearby village. For example, villagers at Kazamabika have largely resolved their CDI problem with an electric fence around an extensive plantation, but elephants have now shifted to foraging for mangoes inside the village center, creating further danger to themselves and villagers. Meanwhile, villagers at Ramba said their CDIs increased because an electric fence at a nearby village shifted elephants to Ramba. They have yet to find an adequate solution (Table C4) and are now asking for their own electric fence. Unless electric fences can be installed around every village, this solution may cause as many problems as it resolves. This *Deter* action could benefit elephants if mobile fences can be deployed for 1-2 years and then removed because abandoned plantations turn into secondary forest where elephants can forage.

Actions under the *Adapt objective* integrate multiple crop protection methods in adjustable plans that respond to changing elephant behaviors (Walker 2012, Tamrat et al. 2020, Killion et al. 2021) as elephants adapt to individual methods. Villagers at Ramba, where current methods are ineffective (Table C4), might test these *Adapt* actions for viability with forest elephants while they await the arrival of an electric fence.

Improve livelihoods by creating rural socioeconomic opportunities

The coexistence strategy of *improve livelihoods by creating rural socioeconomic opportunities* seeks to reduce villagers' vulnerability to CDIs, create greater capacity for villagers to respond proactively, and more broadly, to sustain the cultural value of village life and rural populations.

Maintaining rural populations is a key to effective crop protection and disrupting the feedback loop between increasing CDIs and decreasing village populations (Terada et al. 2021). Long-term economic improvements could encourage working-age youths and adults to stay in or return to their villages, and their presence can help reduce CDIs (Lahm 1996, Hsiao et al. 2013, Gunaryadi et al. 2017, Killion et al. 2021). This coexistence strategy is based on eight actions under two objectives: *Compensate* and *Adjust.*

Actions under the *Compensate* objective must respond quickly to indemnify villagers against CDI losses with financial and material resources that help them tolerate endangered elephant presence in their vicinity. For example, a community-based insurance program managed by the local community (Xu et al. 2019, Sherchan et al. 2021) could help to avoid the difficult, time-consuming procedures currently required in Gabon to file nationally managed CDI reports and receive compensation. Recovering from losses, however, is only one way to help sustain village economies, and such measures should be part of broader economic development.

Actions under the *Adjust objective* focus on creating opportunities to reduce livelihood dependency on subsistence crops with alternative economic activities, such as planting commercial crops (lemon grass and citronella that are unpalatable, to at least Asian elephants) (Gross et al. 2017) and ecotourism (Walker 2010, Barua et al. 2013). The idea of village microcredit associations has been promoted to help finance electric fences (Chang'a et al. 2016) but could be expanded to boost new business startups.

4.4.3. Differentiate villager and elephant places

The coexistence strategy of *Reduce territorial overlap* responds to regular human-elephant negative interactions—especially CDIs-that occur from the spatial overlap of plantations and elephant habitats (Eltringham 1990, Hoare 1999, Danquah et al. 2007). Historically, plantations were carved out of forest lands, managed and defended for a short period, and abandoned, leaving early successional forest that continued to provide elephants with diverse foods (Barnes et al. 1991, Lahm 1993, Barnes 1996). As people established more permanent villages, the plantation-forest mosaic became more spatially concentrated and centralized, creating long-term territorial overlap between villagers and elephants. This coexistence strategy is based on 11 actions under three objectives: *Tolerate, Integrate*, and *Separate*.

Actions under the *Tolerate* objective aim to increase villagers' awareness of the how to live with elephants through environmental education (Treves 2007). This is not new knowledge but rather a reminder of their traditional knowledge of the importance of this keystone forest animal in maintaining the forest and sustaining fruit tree species—which are also used by villagers—by dispersing their seeds (Noutcheu et al. 2016, Midoko Iponga et al. 2018b, Beirne et al. 2021). The persistence of CDIs and villagers' increasing anger calls for community forums where conflicts between elephant conservation and village life can be addressed through ongoing dialogue among villagers and conservationists. The cultivation of tolerance allows more time to explore peacefully how to prevent regular human-elephant negative interactions through coexistence.

Actions under the *Integrate* objective focus on preventing elephant-village overlap by integrating spatial planning for villagers' and elephants' land use (Selier et al. 2016, Killion et al. 2021). When Gabon's national parks were established; elephants were expected to stay within park boundaries. Instead, they continued to forage within village areas, in part because villages like those associated with Lopé National Park and their plantations are embedded within native forest. Expanded management plans cannot assume that protected areas alone will provide for elephants' needs. Such plans must integrate spatial planning that better delimits villagers' and elephants' places to determine effective actions to support the food sources of each. For example, forestry and park agents could work with villagers to map out future plantation sites and how to rotate mobile fences among them. Planning could include attention to avoiding major elephant travel corridors and high-quality natural habitat that is particularly attractive to elephants.

Actions under the *Separate objective* focus on creating greater differentiation between villagers' and elephants' places, reducing access to palatable crops in village areas through crop protection, growing unpalatable commercial crops, managing food waste, and enhancing elephant resource hotspots in distant protected areas as described above. To date, attempts to separate elephants from crops have focused on erecting barriers such as fences without providing alternative food sources to elephants (Adams et al. 2021, Montero-Botey et al. 2021, Vibha et al. 2021). At the extreme end of this strategy, government agencies in parts of Asia have gone so far as to build fences around parks and feed elephants to reduce regular human-elephant negative interactions (Pekor et al. 2019, Fernando et al. 2020). Both actions are impractical in Gabon. Fencing large expanses of Gabon's national parks would require enormous financial investments to build and maintain them, while feeding elephants is problematic because of already insufficient crop production. Instead, we propose that attracting elephants away from villages is a more promising approach to explore.

Implementation of resource hotspots may be a two-edged sword. Hotspot enhancement has never been tested to establish a suitable distance from villages so that elephants no longer forage nearby. Hotspot implementation is speculative and requires substantial investigation and testing. Design of a resource hotspot should be based on important fruiting tree species and other food resources that enable elephants to forage for as long as possible before needing to move to other areas. Providing diverse food resources, including fruits (Tchamba and Seme 1993, White et al. 1993, Beirne et al. 2020, Djoko et al. 2022), herbaceous forage (White et al. 1993, Fai et al. 2022), salines (White et al. 1993), and year-round water sources (Mills et al. 2018, Beirne et al. 2020) as well as a mosaic of forest and savanna (White et al. 1993, Momont 2007) could reduce the need for longer distance and exploratory movements by elephants (Mills et al. 2018).

Crops or domestic mango trees could also be planted in these hotspots, as has been done in US wildlife reserves for elk and waterfowl (Fish and Service 2013, Hinton et al. 2020, Mitchell et al. 2022). Elephants are drawn to crops, and are strongly attracted to domestic mangoes in villages (Ngama et al. 2018), which could help compensate for reductions in native fruiting trees due to climate change (chapter 3). Such hybrid natural-human landscapes, while possibly controversial, are worth exploring given the severity of the current CDI crisis, evidence of ancient human residence in these forests (Bahuchet 1972, 1978, Soengas López 2010), and the impacts of human-induced climate change. A hotspot strategy, however, will require much deeper knowledge of elephant foraging practices and decision making, so that resource hotspots can over time become the hubs of modified elephant trail networks that update and reconstruct connections between elephants' nutrient needs, social behaviors, and long-term cognitive maps in these dynamically changing landscapes.

Making coexistence an effective long-term strategy to mitigate CDIs and protect elephants requires testing the framework and toolkit spatially to determine if it can reduce the territorial overlap of elephant and villager land uses by integrating participatory assessments of villager needs with empirical assessment of elephant needs based on foraging theory, which provides a spatial framework for incorporating the conceptual

coexistence framework (Figure 4.4). A "push-pull" approach similar to that portrayed has been proposed to simultaneously draw elephants toward high-resource areas while removing elephant resources around settled areas (Gross et al. 2017, Djoko et al. 2022). Diagrams such as this could be useful discussion tools in participatory exercises between villagers and conservation professionals. For example, if mobile electric fences can be successfully deployed it may be better to position plantations further from the village center so that resultant patches of secondary forest are further away.

Interactions and feedback loops in complex socioenvironmental systems could lead to unintended consequences when novel strategies or actions are implemented (liu et al. 2007) to attempt to turn human-elephant conflict into coexistence. For example, the experience of Shell Gabon in the town of Gamba demonstrates how creating socioeconomic opportunities for villagers at first ameliorated CDIs but then amplified them.

With increased opportunities, Gamba's population grew. Agriculture expanded to include crops such as cassava, banana, corn, and peanut to feed the increased human population. The demand for food led to increased plantations and more CDIs (S. Ngama, agriculture research institute, Gabon, personal communication, 2022).

Enhancement of elephant resource hotspots also has the potential for unintended consequences. The objective of resource hotspots is to draw nearby elephants away from villages by providing them sufficient food in natural habitats, a system reinforced with *deter* actions around plantations. But hotspot enhancement has the potential to increase elephant density through intrinsic population growth or by drawing distant elephants toward a village if the distance between hotspot and village is not carefully aligned with elephants' movement dynamics in that area. For these reasons, the integration of strategies and specific actions must be approached critically in a holistic coexistence planning effort. Furthermore, implementation requires ongoing monitoring and assessment to support adaptive management that adjusts actions over time for mutually beneficial results (Grumbine 1997, Gillson et al. 2019).

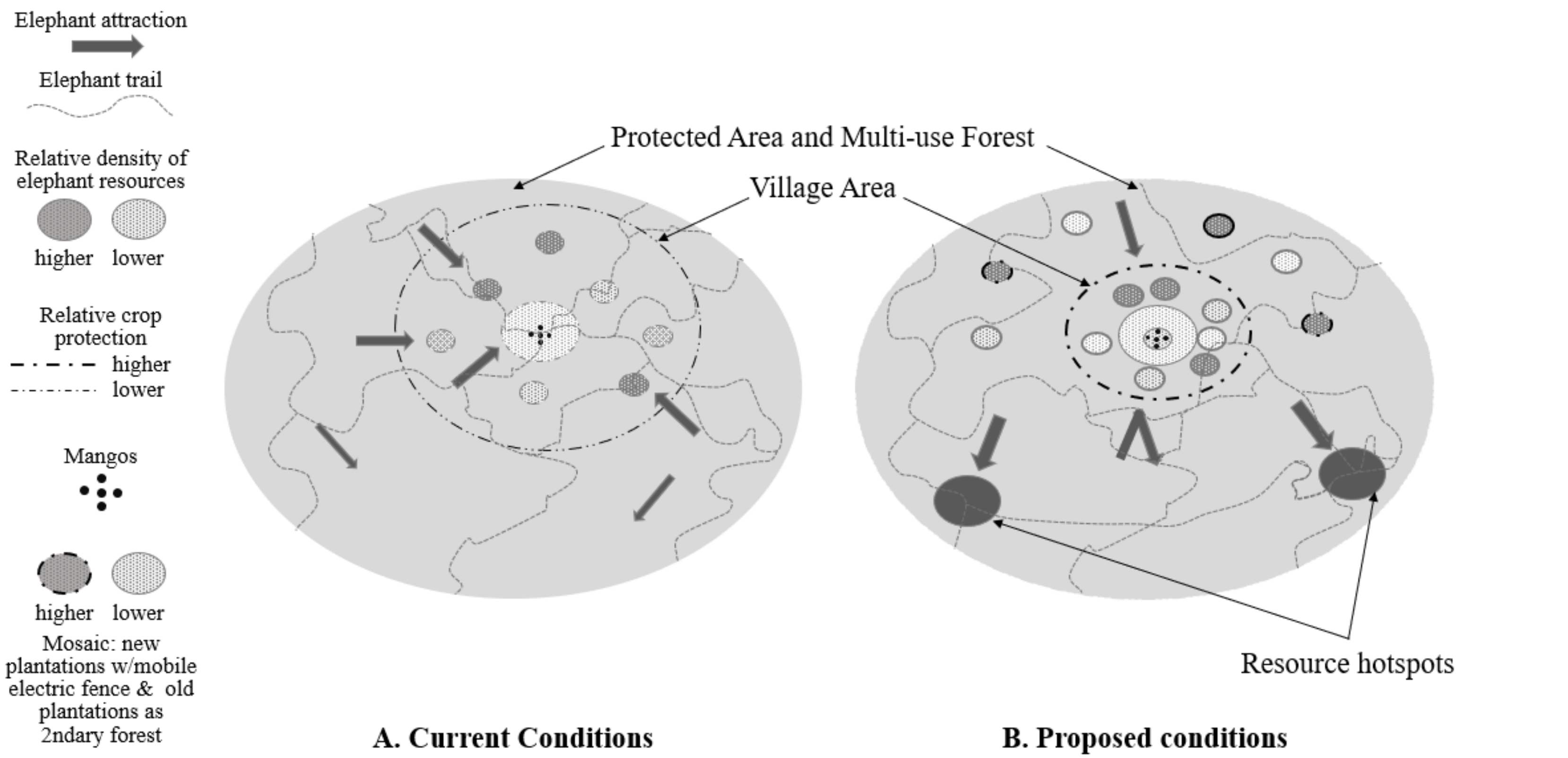

Figure 4.4. Current and proposed conditions to test human-elephant coexistence strategy in a village inside a protected area. A. Current Conditions. Extensive village area with village center and dispersed plantations of varying ages embedded within matrix of forest habitat draws elephants toward villages. B. Proposed conditions. Concentrated village area with more centralized, better defended plantations, and fewer elephant resources. Matrix of forest habitat includes enriched resource hotspots in protected areas to draw elephants away from village area.

4.4.4. Feasibility, Limitations and Urgency

One cannot be naïve about the challenges of resolving Gabon's human-elephant conflict through attempting to foster coexistence. The planning stages of the coexistence framework would be time-consuming and likely fraught with contentious discussions. Implementation of the actions, long-term monitoring, and adaptive management would be expensive and logistically challenging in both the short and long term. Even more daunting, many of the ideas suggested are novel and success is not guaranteed. Finally, the cost and feasibility of programs to support rural villages that are in decline due a host of socioeconomic issues in addition to elephant crop depredation raises a host of questions.

Given these challenges, why not just let rural exodus continue until there are no villages left and the CDI problem is gone? Even though many young people have moved to larger cities, they still return to the countryside during the holiday period of the long dry season to be connected to traditional life and gather with their families, spending time with their elders and reuniting with those who have dispersed to different locations. Furthermore, when they retire, many people want to return to the more relaxing village life, and supplement their retirement income with growing crops for consumption and sometimes for sale. Stable rural villages could also support other societal needs, for example, by serving as refuges during public health crises such as the COVID-19 pandemic (Kanu 2020).

The current situation is dire for both villagers and elephants. Solutions focused solely on preventing conflict have not met either party's needs. In addition to the challenges CDIs pose for villagers in and near to protected areas, it appears that maintaining viable elephant populations may require further active intervention due to the impacts of past logging and climate change on their food resources. For these reasons we argue that further exploration and development of an actional framework for coexistence is, in the long-term, the most promising approach forward, even if it can only be carried out in small steps.

4.5. CONCLUSION

Human-wildlife coexistence requires simultaneously managing human and wildlife needs. We developed a practical conceptual framework based on seven criteria to guide participatory planning efforts, and a toolbox of actions able to create conditions for human-elephant coexistence by managing the identified five key problem types in their unique landscape and sociocultural contexts, such as the Gabonese national park and associated villages of this study. The persistence of elephant CDIs and the threat they pose to rural villager livelihoods and forest elephant conservation is far from unique to Gabon. We argue that no one-size-fits-all set of strategies will work, and that human-elephant conflict planning efforts and plan implementation must be tailored to their local, national, and regional contexts. Such planning efforts are time-consuming and difficult to achieve. The seven criteria recommended to support a participatory adaptive management cycle (Figure 4.3) that planning efforts should be individualized, collaborative, comprehensive, strategic, cross-scalar, adaptive, and mutualistic are unlikely to make planning easier, but are intended to increase its likelihood of long-term success.

The coexistence framework itself is most likely to be directly transferable at its highest level: supporting elephant needs, supporting villager needs, and determining ways to differentiate elephant places from villager places in space and across their seasonal rounds of activities (chapter 3). The five problem types (chapter 2) and associated coexistence strategies (this chapter) seem likely to be substantially transferable but may be better used as a point of departure for initial conversations. The toolbox of actions is just that – a documentation of current knowledge from the literature and the villagers and conservation professionals in this research. If developed, disseminated and updated over time, it could provide a dynamic resource for coexistence planning efforts, just as intended by the recently released Human-Elephant Coexistence (HEC) Toolbox (https://ste-coexistence-toolbox.info/toolbox-index/), which links practical tools with implementation guidance. We note, however that their concept of coexistence appears to focus mostly on understanding elephant behaviors and protecting crops rather than on actively supporting the needs of both elephants and people within a single planning effort.

Our proposed coexistence framework and toolbox offer the first steps to implementing new conditions that mutually benefit elephants and villagers. Forest elephants would benefit from increased food availability and a sense of security while dispersing tree seeds, thus shaping the Congo Basin Forest and contributing to forest carbon sequestration (Berzaghi et al. 2021). Villagers could become better equipped to improve crop yields and stabilize their socioeconomic conditions, while workers who migrated to cities might find opportunities to return to village life and their cultural traditions and heritage. Some ideas represent best available knowledge, while others, like the enhancement of elephant resource hotspots, remain speculative but are beginning to garner interest.

While the Congo Basin Forest can benefit from its two land managers—villagers and forest elephants, coexistence will not be simple to achieve. It requires attention to the sociopolitical dimensions that exacerbate CDIs and threaten rural cultures by actively supporting greater equity in rural socioeconomic development. It also requires keen attention to the needs of elephants, which have too often been considered separately from the problem of CDIs. The stakes are high, since human-elephant coexistence may be critical to sustaining the diversity and resilience of the Congo Basin's equatorial rainforest, which is crucial in the fight against climate change, and to food source and the cultural heritages of its peoples.

CHAPTER 5: CONCLUSION

In this dissertation, we examined the nature of crop depredation incidents (CDIs) between elephants and villagers. This understanding permitted us to identify problem types that can be managed with suggested strategies and actions to reduce incidents and promote healthy coexistence for elephants and people.

Crop depredation incidents (CDIs) in villages near Gabon's Lopé National Park underscore the urgent need for strategies that can foster the coexistence between people and wildlife through landscape management that meets the needs of both. In human-transformed environments, management cannot focus on one population at the expense of the other (Frank 2016, Morehouse and Boyce 2017, Tiller and Williams 2021). This study's management approach offers numerous options that can produce numerous benefits, including sustainable human socioeconomic development and strengthening conservation initiatives of other species that use the same land.

This dissertation shows that establishing and maintaining conditions essential for human-elephant coexistence can offer new jobs to meet human and elephant needs. Working-age youths and adults have been leaving villages for cities, searching for jobs and educational opportunities. Yet Gabon's cities have few jobs, and unemployment is remarkably high (Fairet et al. 2014, Teye 2018, Awad 2019, Mueller and Thurlow 2019). Managing the environment to support human and wildlife needs would add significant diversity to the local employment sector. These jobs would be available in villages addressing land management; working-age youths and adults could return and build a life working in forest management but not only to work for conservation, logging, or mining when there are job opportunities.

Under current land management practices, forest elephants are difficult to view in their natural habitat. Coexistence practices could enhance ecotourism activities, which are still early stages since the establishment of national parks 20 years ago in Gabon, with forest elephants as the cornerstone species. to grow around specific sites with stable resource hotspots, allowing visitors to observe forest elephants across seasons and years in a specific site in their natural or semi-natural habitats. Ecotourism could offer villagers more job opportunities and provides a marketplace for their various traditional and cultural products (Avomo Ndong 2018). It would generate more direct income for villages and permit their involvement in elephant protection and land management that keeps food available for these elephants

5.1. Recreating coexistence for human-wildlife land sharing

The persistence of CDIs correlates with land use change and changing climate resulting in forest elephant inclusion of crops in their diet with the potential acceleration of native fruit scarcity. Given the detailed evidence presented here, we conclude that actions must be taken to reduce CDIs and manage land so elephant populations and village communities can coexist and thrive. To achieve this urgent goal, this dissertation proposed the development of a landscape management framework for coexistence with its five steps. These steps begin to identify problems affecting villagers and elephants to extract their needs to be managed simultaneously to satisfy both or one without harming another. This management should be monitored long-term to adjust and adapt to foster coexistence conditions as proposed in this framework.

5.2. Deteriorated past human-wildlife coexistence

Humans and elephants have coexisted in the past because they mark and protect their places, including some overlap. Humans knew to protect their areas from wildlife that tried to stay away, and wildlife avoided humans or adapted their foraging behavior to reach crops.

However, this coexistence has deteriorated over time with changes in human land use which did not consider the impact on villagers' relationship with the surrounding wildlife. Land use changed in regions like Gabon from nomadic to temporary villages, which could serve the needs of wildlife such as forest elephants (Lahm 1993, Barnes 1996). Temporary villages led to less direct interaction with wildlife, which could have kept their distance or consumed crops at night (Kiffner et al. 2021). These permanent villages obliged people to have permanent areas for plantations, creating a mosaic of plantations and natural resources, including regenerated forests representing old plantations or open gaps due to timber harvest. Today, villagers carry on subsistence farming with plantations through slash-and-burn field clearing on regenerated forest land. Forest elephants forage across this landscape, particularly in regenerated forest, causing CDIs. Plantations, initially established some distance away from housing (Lahm 1996, Angoué 1999), today are within the village areas, becoming more gardens than plantations. Also, the expansion of elephant populations within forests has happened with the reduction of hunting through conservation efforts. These changes, along with a decrease in native fruit availability due to changing climate, could have pushed more elephants to consume and trample crops. Forest elephants have been consuming crops for a long time; however, this consumption was previously not seen as a big problem because they ate only part of the crops, or they could spend only a little time there to reduce the risk of being killed.

5.3. Recommendations and limitations

The identification of factors influencing CDIs should be conducted at each of the landscape and site scales to identify problem types, which are: regular human-elephant negative interactions, ineffective crop protection, reduced reliable native fruit, decreased elephant security, and village socioeconomic conditions (chapter 2), causing CDIs in landscape contexts that can include multiple-use forest forests, protected areas, village areas, or combinations of them. In the case of protected areas with adjacent villages, as in this research, understanding the problems that cause CDIs is crucial for the survival of both villagers and forest elephants. The forest elephant is the least studied among the three existing elephant species (Benitez and Queenborough 2021, Breuer et al. 2021, Hart et al. 2021, Meyer et al. 2022), particularly in understanding and identifying foraging behavior and decision-making. This understanding will help researchers to identify problem types influencing these elephants' interaction with humans at each site to determine appropriate strategies and actions from the proposed toolbox to satisfy both elephants' and villagers' needs.

To understand CDI variations and food resource availability, including crops and native and domestic food consumed by elephants, researchers should include a multiyear census of food availability within the village area and in distinct habitats to inform understanding of crop and other food availability at the time of CDIs. Forest elephants' foraging behavior should also be further observed and documented to determine which elephants or herds are consuming crops and other domestic food sources, and why they are turning to human food resources, which endangers them, rather than safely foraging in the forests to avoid further negative interactions.

Developing the actions toolbox is the first step toward achieving practical coexistence. The contents and use of this kit should be developed through the participatory engagement of all stakeholders, including landowners, conservation practitioners, and villagers, to create plans that suit each group and allow them to engage in long-term management. While this research was mostly based on stakeholder perceptions, future phases should be based on participatory engagement with a collaboration between conservation professionals and villagers at Lopé National Park to address CDIs. This practical conceptual framework and kit can be used elsewhere to manage human-wildlife negative interaction to create mutually beneficial coexistence.

Coexistence that is created by improving crop protection and socioeconomic conditions to maintain people areas and wildlife security and food availability to enhance their conservation by managing identified local problem types with stakeholder contribution through the landscape and changing climate.

CHAPTER 2: APPENDIX A

Table A1. Questionnaire

The preliminary: identification and historical profile

Participant Number	Elder/ Adult	Female/man	Affected by CDIS	Date	Village	Voice record number

Main question:

Can you tell how the number of people in your family changes in your house across seasons and years?

(Pouvez-vous me dire comment le nombre de personnes de votre famille change dans votre maison à travers les saisons et années ?)

Sub-questions:

How many people live in your house during each season around? Please mention the number of people living in actually and the change through seasons and years

(Combien de personnes vivent en moyenne dans votre maison pendant chaque saison ? Svp, mentionnez le nombre qui vivent avec vous actuellement et les changements à travers les saisons et années)

Importance of elephants *for the forest and people*

Main question:

Before, we begin to talk about your conflict with elephants, are there any benefits to having them in the forest around you? How do you know that?

(Avant que nous commencions à parler du conflit, est-ce-qu'il y a des bénéfices à avoir les éléphants dans la forêt autour de vous ? comment s'avez-vous cela ?

Sub-questions

Are they useful for your plantations or soil qualities around you? Why or why not?

(Est-ce qu'ils sont utiles pour vos plantations ou la qualité du sol autour de vous ? Pourquoi ou pourquoi pas ?

What about the forest you use as a source of food and medicine? Why or Why not?

(Et au sujet de la forêt que vous utilisez pour la nourriture et médecine ? Pourquoi ou pourquoi pas ?)

The context of crop depredation incidents (CDIs) across space and time

Main question:

Do you know about what year did crop-raiding become a problem for you? What are the reasons? How do you live with it?

(Est-ce que vous connaissez l'année à laquelle les destructions des cultures sont devenues un problème pour vous? Qu'elles sont les raisons ? Comment vivez-vous avec cela ?)

Sub-questions;

C.1. Do you know when/where the elephant problem started around the Lopé area?

(Est-ce que vous connaissez quand/ ou le problème avec les éléphants à débuter autour de la Lopé?)

C.2. What year did elephants begin to destroy your crops?

(En quelle année les éléphants ont 'il commencé à détruire vos cultures?

C.3. What year did crop raiding become a problem in your village? why? (En quelle année les attaque des cultures sont-elles devenues un problème dans votre village ? Pourquoi ?

C.4. Do you see an increase, a decrease, or no changes in CDIs across locations, seasons or years? Can you describe the reasons? (Est-ce que vous voyez une augmentation, diminution, ou pas de changement de ces attaques à travers les lieux, les saisons, années ? Pouvez-vous donner les raisons)

C.5. Do you think that some years/ seasons or space are better or worse? Can you tell the reasons? (Pensez-vous que certaines années/saisons sont mieux/ grave? Pouvez-vous donner les raisons?)

C.6. Do you know the number? Can you indicate the number of CDIs approximately per year/season on the diagram below? Do you know the reasons? (Est-ce que vous connaissez le nombre ? Pouvez-vous indiquer approximativement le nombre d'attaque par année/ saison sur le diagramme ci-dessous ? Est-ce que vous connaissez les raisons ?)

C.7. If you estimate the losses in percentage, what percentage of loss allows you to still have what to eat only or both eat and sell?

(Si vous estimez les pertes en pourcentage, quel est le pourcentage de perde qui vous permet de toujours avoir que quoi manger ou manger et ventre ?)

C.8. What do you think can be the causes of elephant crop depredation? Why? (e.g., population size and fruit availability)

(D'après vous, qu'elles sont les causes de ces attaques des éléphants ? Pourquoi ? (Exemple, la taille de la population and la disponibilité des fruits)

C.9. Do you think that the elephant population has increased here in Lopé?

(Pensez-vous que la population des éléphants a augmenté ici à la Lope ?)

Changes in resources used by elephants across space and time and reasons for them

Main question:

Do you see any changes in the forest resources (fruits, water, and etc) that maybe increase CDIs recently or in the past?Why are these changes occurring? (Voyez-vous des changements dans la ressources (fruits, eau et etc) des éléphants en forêt qui pourront être la cause de la croissance des attaques ? Pourquoi y a t'il ces changements ?

Sub-questions :

D.1. Do you think that there is enough food and resources for elephants in the forest? Why or Why not? (Pensez-vous qu'il y a assez de nourriture et ressources pour les éléphants en forêt ? Pourquoi ou pourquoi pas ?)

D.2. Are you able to know what natural food or resource do elephants consume ? Can you explain your answer (Pouvez-vous connaitre les aliments et ressources que consomment les elephants ? Pouvez vous expliquez votre reponse)

D.3. Do you think that these natural food and resource (water,mineral, salt) are available around the plantations and villages? Why or why not? (Pensez-vous que cette nourriture et ressource (eau, mineral, sel) sont disponible autour des planatations et villages ? Pourquoi ou pourquoi pas ?)

D.4. Can you know what natural food and resource elephants eat in these natural patches around plantations and villages? Can you explain your answer? (Pouvez-vous connaitre ce que les éléphanants consomment dans ces sites autour des plantation et villages)

D.5. Have you already seen a time when this food or resource are available, but elephants are not present? Can you explain your answer?
(Avez-vous déjà vu une période pendant laquelle cette nourriture et ressource sont disponible, mais les éléphanants sont absent ?)

D.6. Do you experience CDIs when resources and crops are available? If yes, can you tell when, where,and what crops are eaten, damage or not?

(Avez-vous vécu les attaques quand les ressources et les culture sont disponible? Si oui pouvez-vous dire quand, ou et quelles cultures sont impactées ?)

D.7. Have you ever seen the elephants that have been raiding crops eating natural foods around plantation or village? If yes, What can you tell about this rencontre? (Avez-vous déjà vu les éléphanants qui attaquent les cultures manger autour des plantations ou villages ? Que pouvez vous dire sur cette rencontre ?)

Table a2. Stakeholder perception of drivers and subdrivers. The number of interviewees shown for a driver may be less than the total of those shown for its subdrivers because some interviewees comments fell into multiple subdrivers.

Drivers/subdrivers	Villagers (n= 24)		Professionals (n= 22)		Total (n= 46)	
	No	%	No	%	No	%
Elephant foraging behavior	16	67%	16	73%	32	70%
Elephant hunting and poaching	1	4%	11	50%	12	26%
Elephants crop preferences	5	21%	6	27%	11	24%
Fences push elephants to other sites	7	29%	1	5%	8	17%
Irregular native fruit production	5	21%	1	5%	6	13%
Elephant adaption to crop protection	4	17%	1	5%	5	11%
Safety/food availability for elephants	1	4%	4	18%	5	11%
Elephant food source expansion	1	4%	0	0%	1	2%
Presence of bush within the village areas	0	0%	1	5%	1	2%
Logging	6	25%	18	82%	24	52%
Logging	6	25%	17	77%	23	50%
Land transformation	0	0%	4	18%	4	9%
Other land use	0	0%	2	9%	2	4%
Mining	0	0%	1	5%	1	2%
Conservation policies	7	29%	12	55%	19	41%
Elephant hunting prohibition	6	25%	10	45%	16	35%
Establishment of park	4	17%	5	23%	9	20%
Village-elephant spatial overlap	7	29%	10	45%	17	37%
Village location	9	38%	4	18%	13	28%
Plantation expansion	0	0%	6	27%	6	13%
Rural exodus	5	21%	7	32%	12	26%
Village depopulation	4	17%	6	27%	10	22%
Absence of elephant hunters	2	8%	0	0%	2	4%
Shortage of time and labor	0	0%	1	5%	1	2%
Disruption of native fruit production	0	0%	7	32%	7	15%
Climate change	0	0%	7	32%	7	15%

Table A3. Respondents' quotes expressing each of the six drivers.

Drivers	Respondent's quotes
Logging	*There are less natural fruiting trees in the forest due to past logging* (Villager, ID 13). *Fruiting trees that elephants like were logged in the past* (Villager, ID 19). *Logging reduced big trees in the forest* (Villager, ID 24*). Past logging activities reduced fruiting in the trees that elephants like* (professional, id 3*). Yes, we can talk about logging activities having negative impacts on resource availability until recent times. This logging activity has changed with the protection of some species* (Professional, ID 12). *The problem is that we have logging concessions almost everywhere* (Professional, ID 45).
Conservation policies	*We used to kill elephants and this hunting keeps them away from crops. Since the presidential prohibition of elephant killing, I observed that more elephants were coming* (Villager, ID 19*). In 1981-2, the ecotax* [conservation program] *began; from there, people could not go in the forest as they wanted; not even to hunt. At that time, animals* [elephants] *began to come close to people. Those elephants have multiplied* (Villager, ID 22*). And the local population was weak against elephants. They could not do something to deter elephants from entering their plantation or garden* (Professional, ID 3*). Go to the village to ask about this conflict. They* [villagers] *will always tell you that since they have prohibited the kill of elephants, the elephants feel like it is their place here* (Professional, ID 12*).*
Disruption of native fruit production	*Today, I can tell you that the fruiting trees do not produce every time any more with all the same change due to the change in the climate or in the cycle in animal mind, the animal know for a long time that at this period and at this site it will find this this in maturity or today with does small change, it is not that and when it is think that it will find and does not find , eh ben, it look for other places it can come close to people where it will find what it can eat, it is a little bit my experience in this point. It is not just because those animal want to go, their environment is not the same, the climate change that do the le fructification change or they have a schedule that was established long time ago, this program , they can include that anymore, they need to be used to the new program and the fact that their house is destroy every day, it is true that we said that the Gabon is cover to 80 by primary forest, you observed well in is it not always true, we go there every day but when see, it is true that from the top we see the canopy but let see below, below the canopy do no represent anything*. (Professional, ID 21*)*
Elephant foraging behaviors	Everything that was planted, elephants were eating (Villager, ID 13). They come and stay around areas where they are safe and can find food (Villager, ID 7). They eat and keep the location (Villager, ID 16). They try to go to the fence , they are charge by electricity, they come back and oblige to eat food behind the house, There, it should have been a trail between the forest and the economic road, but as it is the village, they are obliged to cross it. You can see as elephant cross to look for the way to go. When they find domestic fruiting tree, they obliged to come and destroy everything. There is not a place where the elephant did not go and devastated everything (Villager, ID 22)
Village-elephant spatial overlap	*"From my experience, the population is here, their crops are here, and the elephants are here.* (Professional, ID 3*). In the savanna area, gallery forests are used by villager and are elephant corridor. For plantation, people cut tree which include elephant tree. The transformation of larger areas of forest or savanna push elephant nearby village (*Professional, ID 12*). There are almost located in the same part of the park* (Professional, ID 29*), there is not clear difference between forest and* village (Professional, ID 45*)*
Rural exodus: villagers and professionals:	These villages are empty, because the people were unable to produce their crops (Villager, ID 22). We used to have many people here and activities with logging concessions making much noise in the past. So, it was rare to see elephants and buffalo here, whereas now there are a lot. I saw that progressively with the reduction of activities with the departure of the logging concession, this area became quieter. This situation encouraged elephants to come more to the village (Professional, ID 25). When the population is decreasing in the villages, the elephants seem to come in. …villages and camps with different hunting activities kept elephants away. With fewer villagers and hunters in the forest, elephants have more space. So, you can see that when there are more people, the plantation can be protected (Professional, ID 38).

APPENDIX A

Table A4. Stakeholder perception of dynamics and subdynamics. The number of interviewees shown for a dynamic may be less than the total of those shown for its subdynamics because some interviewees comments fell into multiple subdrivers.

Dynamic/subdynamics	Villagers (n= 24)		Professionals (n= 22)		Total (n= 46)	
	No.	%	No.	%	No.	%
Increased human-elephant interactions	17	71%	19	86%	36	78%
Safe site for elephants	3	13%	11	50%	14	30%
Inclusion of crop in elephant diet	6	25%	6	27%	12	26%
Protected forest elephants	4	17%	3	14%	7	15%
Decreased native fruit production	5	21%	1	5%	6	13%
Elephant habitat conversion to village areas	2	8%	2	9%	4	9%
Forest become unsafe for elephants	1	4%	3	14%	4	9%
Reduced number of people in the villages	1	4%	3	14%	4	9%
Villagers and elephants occupy same areas	2	8%	1	5%	3	7%
Degraded forest habitat	1	4%	1	5%	2	4%
Partial/ineffective crop protection	1	4%	0	0%	1	2%
Reduced capacity to protect crops	13	54%	10	45%	23	50%
Altered social dynamics	5	21%	8	36%	13	28%
Partial/ineffective crop protection	8	33%	1	5%	9	20%
Elephant expansion in the forest	0	0%	2	9%	3	7%
Inclusion of crops in elephant diet	2	8%	1	5%	3	7%
Forest structural changes	4	17%	13	59%	17	37%
Village areas converted to elephant habitat	4	17%	8	36%	12	26%
Degraded forest habitat	0	0%	7	32%	3	7%
Road establishment	0	0%	2	9%	2	4%
Reduced native fruit availability	4	17%	11	50%	15	33%
Reduced number of native fruiting trees	4	17%	10	45%	14	30%
Decreased native fruit production	0	0%	7	32%	7	15%
Decreased elephant safety in native habitat	1	4%	11	50%	12	26%
Forest become unsafe for elephants	1	4%	9	41%	10	22%
Increased noise around elephants	0	0%	3	14%	3	7%

Table a5. Respondents' quotes expressing each of the five dynamics.

Dynamics	Respondent's quotes
Forest structural changes	*Logging reduced the number of big trees in the forest.* (Villager, ID 24, 7*). Moreover, like the moabi [wild fruiting tree], these species were sources of proteins for elephants. If you exploited all the moabi in one area, when the elephants come back and find out that there is no fruit to eat, they would look for protein elsewhere* (Researcher, ID 12). *The fruiting tree species of which animals consumed fruits were also the trees logged in the past* (Professional, ID 21).
Decreased elephant safety	*Poaching pressure pushes elephants away (villager, id 7). There is delocalization of elephants that move away from poaching areas (Professional, ID 36). When they are hunted or poached, elephants depart* (Professional ID 20).
Reduced native fruit availability	*For many years, we did not have some wild fruits. For instance, we have not eaten chocolate [Gabonese chocolate made from bush mango] for many years. The bush mango tree has not produced many fruits anymore. If two or three trees produce fruit, the elephants are already there ahead of us to consume what they can find under these trees. When we want to go and collect some fruits, we do not find anything because they have already eaten fruits from these trees that do not produce a lot. For more than ten years, we have not eaten chocolate [Gabonese chocolate] made from bush mango trees that no longer produce enough (villager, id 9). I think they came here [to the village] when the forest did not produce fruit for them* (Villager, ID 11*). And today, I can tell you that the fruiting trees do not produce any more (Professional*, ID 1). *There are indeed seasons where we see many trees with flowers. However, sometimes these flowers do not produce fruit; thus, the climate plays a role, but we know if there is high flower production will have a lot of fruit* (Professional, ID 3).
Increase human- elephant interactions:	*In the past, elephants were difficult to see in the dense forest. Now they are around villagers more and more* (villager, ID 13*). The elephants began to come into the village after the grandparents' death, and these grandparents used to kill them [elephants] (villager, id 4). In the past, one elephant was coming; it used to eat and go back. Today, there are six individual elephants who come.* (Villager, ID 33). *Moreover, the issue is regular for villages in or around the park as elephants are permanent (*Park agent, ID 29*). I saw that [increase of elephants] progressively with the reduction of activities due to the logging concession departure; this area became quieter. This situation encourages elephants to come more often into the village (Professional*, ID 25).
Reduced capacity to protect crop	*We built small camps to stay in [in order to] protect plantations before the electric fence was established here* (Villager, ID 24*). We tried traditionally built and adapted fences, but they worked for only a short- time. Empty cans did not work; elephants were not threatened by that; they played with them* (Villager, ID 10*). The local population protected their plantations by killing those animals. It is illegal, but people do that because they are desperate…there is no reliable technique, no concrete solution, no practices that help reduce the devastation to their plantations (Professional*, ID 27).

APPENDIX A

Table A6. Stakeholder perception of problem types and subproblems. The number of interviewees shown for a problem type may be less than the total of those shown for its subproblems because some interviewees comments fell into multiple subdrivers.

Problem types/subproblems	Villagers (n= 24)		Professionals (n= 22)		Total (n= 46)	
	No	%	No	%	No	%
Regular human-elephant negative interactions	17	71%	18	82%	35	76%
More elephants in village areas	17	71%	5	23%	22	48%
Village with food sources that attract elephants	6	25%	7	32%	13	28%
Disturbance of elephant safety in the forest	1	4%	12	55%	13	28%
Proximity of crop field and native resource	1	4%	4	18%	6	13%
Absence of people in the village	0	0%	3	14%	3	7%
Native fruit scarcity	1	4%	1	5%	2	4%
Increased human insecurity	1	4%	0	0%	1	2%
Ineffective crop protection	13	54%	12	55%	25	54%
More elephants in village areas	1	4%	10	45%	14	30%
Absence of people in the village	6	25%	2	9%	8	17%
Partial crop protection across villages	5	21%	1	5%	6	13%
Elephant adaption to crop protection	5	21%	1	5%	6	13%
Reduced reliability of fruit production	7	29%	14	64%	21	46%
Native fruit scarcity	7	29%	9	41%	21	46%
Disturbance of elephant habitat	1	4%	7	32%	11	24%
Decreased elephant security	2	8%	10	45%	16	35%
Unsafe forest	1	4%	11	50%	18	39%
Illegal elephant killing	0	0%	2	9%	2	4%
Village socioeconomic conditions	1	4%	3	14%	4	9%
Absence of people in the village	1	4%	3	14%	4	9%

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Table A7. Respondents' quotes expressing each of the problem types.

Problem types	Respondents' quotes
Decreased elephant security:	*I observed that when the forest was exploited in one area, the elephants were able to move to other areas very quickly to silent sites* (Villager, ID 40*). Indeed, I was involved in logging before I worked in conservation. You cannot imagine the noise made by chainsaw, engine, and bulldozer* (Professional, ID 31*). We began to observe elephants near the villages when logging concessions began to be established in the forest around villages. There was an increase in elephant presence in the village when engine noises disturbed them. If elephants are disturbed, they will turn to areas with the crops to feed themselves. They leave their corridors when they are disturbed* (Professional, ID 14). *In Pana, we showed that elephants were leaving the forest to [go to] the village and town. After the analysis, I think that the elephant was leaving the forest because of Congolese gold miners, who used to enter the forest illegally. Suppose I talk again about situations in Pana. In that case, I can say that there was no elephant issue there before miners' activities. I am certain? About that because I am from the Birougou park* (Professional, ID 41). *Logging concessions destroy elephant habitat and food sources* (Professional, ID 35*)*
Reduced reliability of fruit production :	*When we [villagers] were at Massenguelani [old village], the elephants used to eat bush mango trees, Detarium trees in the forest. These are the fruits that they follow the most in the forest. Today they are eating everything* (villager, ID 40*). I can imagine that they come here when there is no food production in their forest* (villager, ID 30*). I think they [elephants] came here when the forest did not produce fruit for them. It is the same for us; sometimes [things are] hard or [there's] some complication with the crop, so they [the elephants] come here. It is like us; we planted, but sometimes we do not harvest a lot; we have a decrease of crops, so it could be the same in the forest. Then it is when they [elephants] see there is no food in the forest that they come in the village* (Villager, ID 11). *Many tree species that produce elephants' preferred fruit were logged in the past. When I am looking at the forest, there are fewer "elephant fruiting trees" because these tree species, like moabi [important tree species], were logged in the past, but not like now with their exclusion from logging. Instead, one species pushes elephants to forage toward Soforga [old logging concession]; it is Ossugua. If it had been logged, we will be in the same case as moabi and others. We cut moabi and other species; these were their food* (Professional, ID 44*).*
Regular human-elephant negative interactions	*They multiplied, increased, and called others (V*illager, ID 4*). They come and stay around areas where they are safe and can find food (villager, id 7). In 1981-2, the Ecofac began; from there, people could not go in the forest as they wanted, not even hunting. At that time, animals [elephants] began to come close to people; these elephants have multiplied* (Villager, ID 22*). This area began to be more and more quiet. This situation encouraged elephants to come more to the village (Professional*, ID 25). *It has become silent here compared to ivindo [another park in Gabon], where there is still logging with Rouger [concession]. There are still activities around it [Lope], and that is why these elephants of Lopé treat it like a refuge* (Professional, ID *3). Elephants could join the village as a refuge, go where there is safety, and follow where there is food, so the alimentation attracts them* (Professional, ID 25*).*
Ineffective crop protection	*We made a fence with empty cans, but it did not work for a long time (villager, id 46). The technique they used was to shoot guns toward the sky or injure one elephant. People used to have time to grow and harvest crops and do other plantations* (villager, ID 44*). The elephants came to destroy the first plants. We tried traditional and adaptive fences, but it was just for a short period, with empty old cans. It did not work; elephants were not threatened by it; they were playing with it. It was hard for us* (villager, ID 33*). And, when the elephants left the forest and arrived in plantations and villages, people could not support the restriction on hunting this pachyderm* (Professional, ID 21*).*
Village socioeconomic conditions	*Young people left the village for job and better live, leaving only old people. Young people were the protectors and hunter of elephants, exodus came also with protecting elephant in middle 1980's* (Professional, ID 20). *They come to the village. One time, I stayed alone in the village; they came and even broken one kitchen* (Villager, ID 40*)*

Table A8. Stakeholder perception of landscape context and drivers.

Landscape context	Drivers	Number of respondents
Mutiple-use forest	Conservation policies	1
	Disruption of native fruit production	2
	Elephant foraging interests	11
	Logging	23
Protected areas	Conservation policies	3
	Disruption of native fruit production	7
	Elephant foraging interests	6
	Village-elephant spatial overlap	2
Village areas	Conservation policies	18
	Elephant foraging interests	25
	Logging	2
	Village dynamic	12
	Village-elephant spatial overlap	15

Table A9. Stakeholder perception of drivers causing dynamics.

Drivers	Dynamics	Number of respondents
Conservation policies	Increased human-elephant interactions	12
	Reduced capacity to protect crops	12
Disruption of native fruit production	Reduced native fruit availability	7
Elephant foraging interests	Decrease of elephant habitat safety	8
	Increased human-elephant interactions	20
	Reduced capacity to protect crops	12
Logging	Decrease of elephant safety	9
	Forest physical changes	7
	Increased human-elephant interactions	2
	Reduced native fruit availability	14
Village dynamic	Increased human-elephant interactions	5
	Reduced capacity to protect crops	7
Village-elephant spatial overlap	Forest physical changes	12
	Increased human-elephant interactions	6

CHAPTER 3: APPENDIX B

Table B1. Twenty most important elephant tree species, in two groups derived from previous studies and local field assistants

Fruiting tree species	Families	Fruit tree categories
Baillonella toxisperma	Sapotaceae	8 most important fruit tree species
Bobgunnia fistuloides	Fabaceae	
Detarium macrocarpum	Fabaceae	
Duboscia macrocarpa	Malvaceae	
Irvingia gabonensis	Irvigiaceae	
Nauclea diderrichii	Rubiaceae	
Sacoglottis gabonensis	Humiriaceae	
Uapaca guineensis	Phyllanthaceae	
Antidesma vogelianum	Euphorbiaceae	12 next most important fruit tree species
Chrysophyllus africanum	Sapotaceae	
Klainedoxa gabonensis	Irvigiaceae	
Mammea africana	Calophyllaceae	
Massularia acuminata	Rubiceae	
Myrianthus arboreus	Urticaceae	
Omphalocarpum procerum	Sapotaceae	
Panda oleosa	Pandaceae	
Pentadesma butyracea	Clusiaceae	
Psidium guineense	Myrtaceae	
Tetrapleura tetraptera	Fabaceae	
Uvariastrum pierreanum	Annonaceae	

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Table B2. Number of important fruiting tree species observed each month by year at Lopé National Park.

Years	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	11	13	12	15	14	11	15	13	16	16	10	13
2004	12	14	15	12	16	19	15	18	19	15	14	14
2005	16	18	16	18	18	19	16	19	17	18	19	19
2006	15	18	19	20	18	17	17	17	17	17	18	18
2007	19	19	17	17	17	20	19	19	20	18	15	14
2008	19	17	18	18	16	17	17	18	17	17	8	19
2009	19	18	20	19	16	17	16	17	13	19	16	15
2011	18	18	19	20	18	18	20	16	18	18	19	15
2012	19	17	19	17	18	17	16	18	15	20	14	15
2013	17	20	19	17	18	18	19	20	18	18	18	18
2014	20	17	17	17	19	16	19	18	17	19	18	17
2015	18	18	16	20	17	19	18	20	20	19	20	19
2016	18	20	18	18	17	18	18	18	14	17	18	17
2017	17	18	17	18	18	19	17	18	16	16	15	18
2019	15	17	17	18	19	16	16	19	16	18	18	17

Table B3. Stakeholder perceptions of native fruit production variation documented in 2020.

ID	Stakeholders	Reference periods	Stakeholder quotes
38	Professionals	Around 10 years ago	*During the past 10 to 11 years, the issue [CDIs] was regular in areas where* I worked [Park].
32		Around 10 years ago	*There were periods when you had two productions, without going far, the* [bush] *mango tree produce two times, the big production and small. Today they do not do that. It was like the forest when I was working at Ivindo* [around 10 years ago]; *every time I went to Louangue, every year we had an abundance of noisette* [native fruit], *but in my last years at Ivindo you found that the "noisitiers"* [native fruit tree] were producing every 2 or 3 years.
39	Villagers	Less than 5 years ago	*So since our last walk around the village* [2018], *I have seen the elephant numbers increase here [Ramba] with the fence in the neighboring village. This increase was intense in 2019 because they even degraded the cemetery.*
24		Less than 10 years ago	*It is between 2016 and now that they have been coming to eat everything in the village as the eclectic fence pushed them around housing. The electric fence protected crop field that elephants used to come from time to time depredate, mostly between 2012 and 2015*
9		Around 10 years ago	*How many year we do not have food. For instead we eat also the chocolate [Bush mango], but how many years we have eat chocolate... It is less than 10 year, it is even small, it is more that 10 years that we have the chocolate here.*

Table B4. Seasonal variation of crop and mango availability through stakeholder perceptions.

Seasons	Crops/ mangoes	Villagers (n=24)		Professionals (n=13)		Total respondents (n=37)	
		No.	%	No.	%	No.	%
Short dry season	Banana	2	8%	0	0%	2	5%
	Cassava	4	17%	0	0%	4	11%
	Maize	5	21%	1	8%	6	16%
	Mango	0	0%	1	8%	1	3%
	Other vegetables	3	13%	0	0%	3	8%
	Peanut	7	29%	1	8%	8	22%
First rainy season	Banana	3	13%	0	0%	3	8%
	Cassava	5	21%	1	8%	6	16%
	Other vegetables	1	4%	0	0%	1	3%
Long dry season	Banana	3	13%	0	0%	3	8%
	Cassava	6	25%	1	8%	7	19%
	Maize	1	4%	0	0%	1	3%
	Pineapple	3	13%	0	0%	3	8%
	Taro	2	8%	0	0%	2	5%
Second rainy season	Banana	5	21%	0	0%	5	14%
	Cassava	4	17%	0	0%	4	11%
	Maize	6	25%	2	15%	8	22%
	Mango	10	42%	7	54%	17	46%
	Other vegetables	4	17%	1	8%	5	14%
	Peanut	8	33%	1	8%	9	24%

Table B5. Perception of seasonal villager activities in plantations.

Seasons	Villagers' activities in plantations	Total respondents (n=37)	
		No.	%
Short dry season	Villagers harvest some crops at the beginning of the season and continue to maintain plantations	8	22%
First rainy season	Villagers maintain plantations by clearing weeds and harvest crops at the season's end	8	22%
Long dry season	Villagers harvest crops and then establish new plantations at the end of the season	11	30%
Second rainy season	Villagers maintain plantations during this season and harvest crops at the end	12	32%

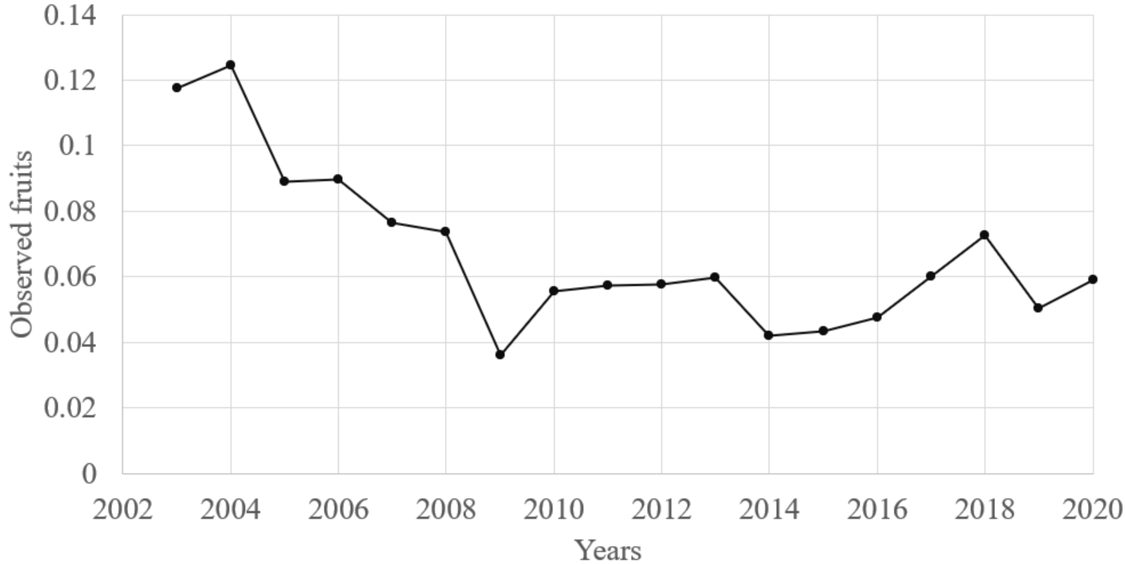
Table B6. Stakeholder perception of seasonal reasons for forest elephant crop depredation.

Seasons	Reason for elephant presence within village areas	Villagers (n=24)		Professionals (n=13)		Total respondents (n=37)	
		No.	%	No.	%	No.	%
Short dry season	Lack of native fruits	1	4%	0	0%	1	3%
	Crop available within the village areas	2	8%	2	15%	4	11%
First rainy season	Lack of native fruits	1	4%	2	15%	3	8%
	Crop available within the village areas	5	21%	1	8%	6	16%
	Native fruit availability within the village areas	3	13%	2	15%	5	14%
Long dry season	Lack of native fruits	0	0%	1	8%	1	3%
	Crop available within the village areas	2	8%	1	8%	3	8%
Second rainy season	Mango presence	12	50%	5	38%	17	46%
	Crop available within the village areas	2	8%	1	8%	3	8%

Table B7. Elephant gender and time spent around mango trees recorded with camera traps at Kazamabika in 2021. The two bolded cells indicate the earliest and latest times that elephants arrived to forage and departure.

Date	Hour	Time of day	Individual	Video ID
11/9/2020	**17:43:36**	**5:40 PM**	**Female and baby**	**1109004**
11/9/2020	17:45:01	5:45 PM	Young male	1109005
11/9/2020	18:55:49	6:55 PM	Single male	1109008
11/9/2020	20:11:27	8:10 PM	Single male	1109021
11/11/2020	18:30:14	6:30 PM	A female with two kids	1110010
11/11/202	19:00:02	7:00 PM	MALE	1110013
11/11/2020	19:31:46	7:30 PM	Young male	1110023
11/11/2020	20:03:22	8:00 PM	Male	1110025
11/11/2020	21:21:04	9:21 PM	Male	1110032
11/17/2020	5:19:00	5:20 AM	Male	1110856
11/17/2020	**5:58:00**	**6:00 AM**	**Male**	**1110857**

Figure B1. Decline of fruit availability across the 20 important native fruit trees at Lope National Park over 18 years from 2003-2020.



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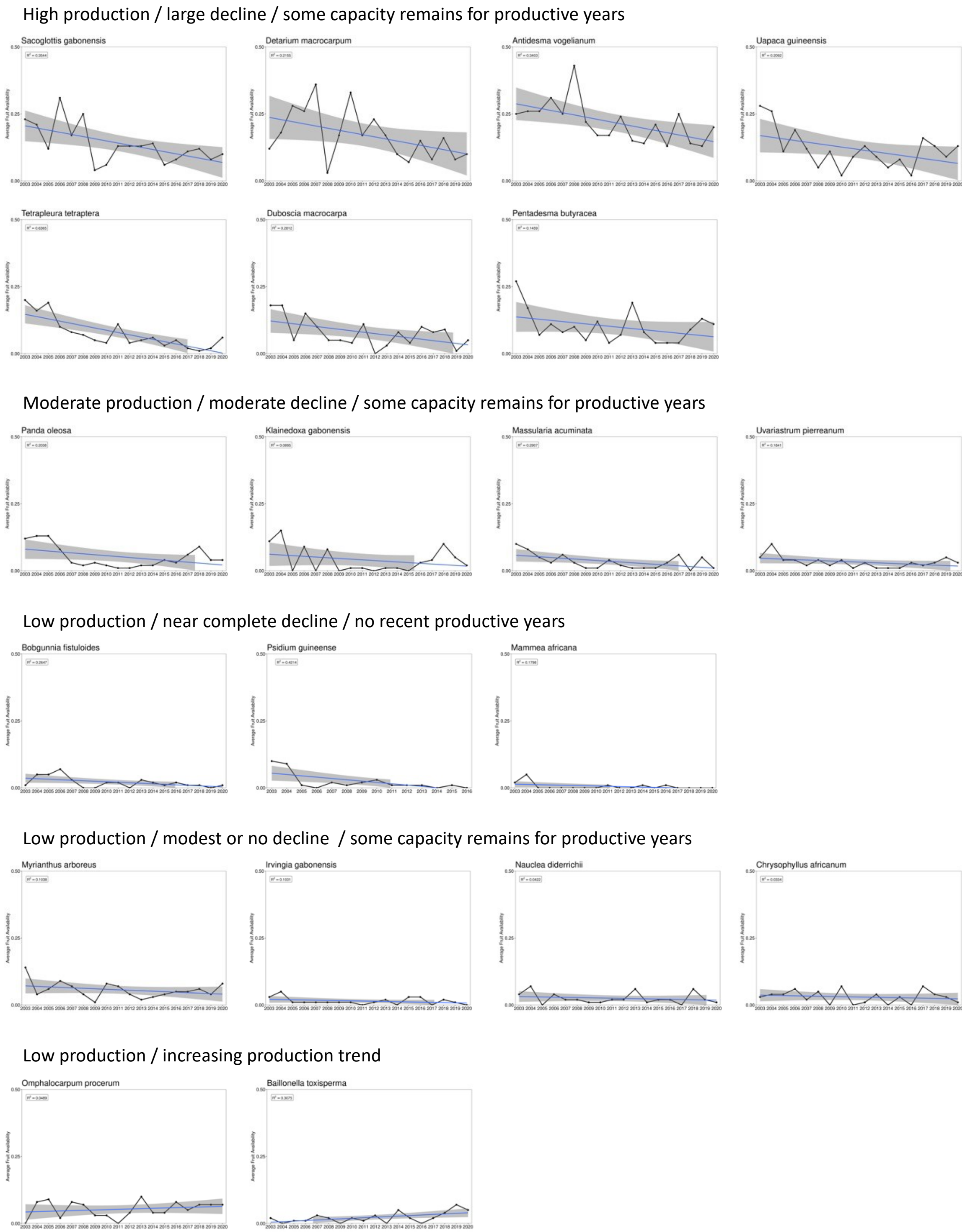

Figure B2. Trends in observed natural fruits of the 20 most important fruit tree species for elephants from 2003 to 2020. Species are organized into groups based overall fruit availability scores and trends over time. Y axis is the mean observed fruit score based on combining immature and mature fruit scores. X axis represents year.

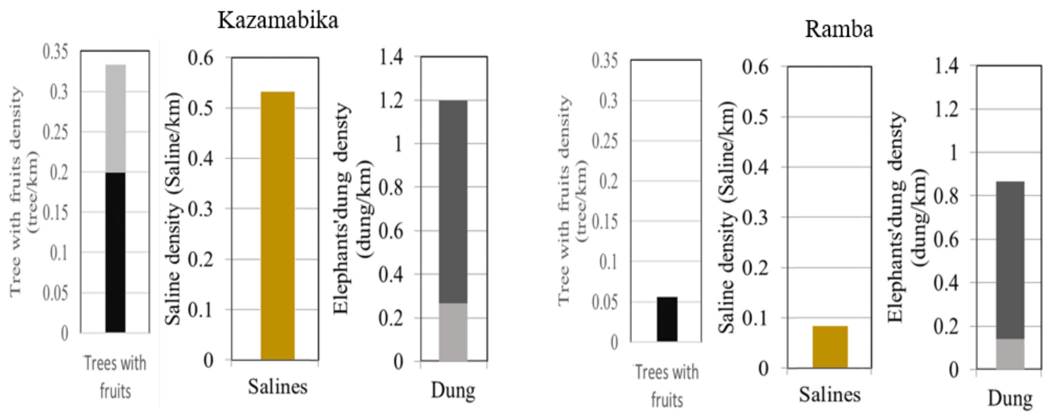

Figure B3. Censused native fruits, salines, and elephant dung along trails within villages areas at Kazamabika and Ramba after the mango period. Dark grey shows the density of trees in active fruiting for the eight most important native species, light grey shows the density of trees in active fruiting for the 12 next most important species. In the dung graph, the grey is young dung less than three days and black is old dung more than three days old.

CHAPTER 4: APPENDIX C

Apppendix C

Table C1. Compiled actions gathered through literature and stakeholders. The effect of these strategies on people or elephants was characterized as satisfying with the sign "+", harming with "– ", and no impact with "0."

Objectives/ Strategy	Actions	Benefit human	Benefit elephant	Literatures	Stakeholders
Decrease of elephant security / Integrate forest exploitation and elephant habitat protection					
Conserve	Ecotourism as alternative to logging	(+)	(+)	[1, 2]	No
	Combine research and ecotourism around elephants	(0)	(+)		Yes
Protect	Protection of intact forest landscape (IFL) through Forest Stewardship Council	(0)	(+)	[3, 4]	Yes
	Patrolling areas with high elephant population	(0)	(+)	[3, 5, 6]	Yes
	Used new technology like satellite	(0)	(+)	[7]	No
	Patrolling of elephant habitat	(0)	(+)		Yes
	Protect elephant habitat	(0)	(+)		Yes
Integrate	Collaboration of certified logging and research for tropical forest conservation and wildlife management	(0)	(+)	[5, 8-10]	No
	Increase monitoring of sustainable forest exploitation implementation	(0)	(+)		Yes
	Speed the increase of sustainable forest exploitation practice	(0)	(+)		Yes
	Sustainable forest exploitation implementation	(0)	(+)		Yes
Reduced reliability of fruit production / Conserve and enhance elephant food resources					
Conserve	Maintain fruiting trees in protected areas and logging concession	(+)	(+)	[11]	Yes
	Sustainable forest exploitation implementation	(0)	(+)		Yes

	Increase monitoring of sustainable forest exploitation implementation	(0)	(+)		Yes
	Increase sustainable forest exploitation implementation	(0)	(+)		Yes
	Ban logging of elephant fruit trees	(0)	(+)		
	Change logged fruit tree species	(0)	(+)		Yes
	Encourage international behavior change to improve climate	(+)	(+)		Yes
	Protect elephants remained food resources	(0)	(+)		Yes
Enhance	Feeding elephant	(+)	(+)	[12]	No
	Manage habitat to maintain water and plant favorable wild food for elephants	(+)	(+)	[13, 14]	Yes
	Adapt fruiting trees to seasonal/climate change	(+)	(+)		Yes
	Plant elephant wild fruit tree species	(+)	(+)	[14]	Yes
	Replant important fruiting species logged in the past	(+)	(+)		Yes
	Restore logging areas with elephant fruit tree species	(+)	(+)		Yes
Regular human-elephant negative interactions / Reduce territorial overlap					
Tolerate	Environmental education	(0)	(0)	[15]	Yes
Integrate	Integrate spatial planning for rural communities, conservation, and forest exploitation. Unfractured development	(+)	(+)	[16-18]	Yes
	Integrate management for local development and conservation	(+)	(+)	[19, 20]	No
	Community-based intervention method and landscape-scale management habitat management	(+)	(+)	[6, 21, 22]	No
	Planning to avoid plantations nearby elephant habitat	(+)	(0)	[23]	Yes
	Introduce plantation planning	(+)	(+)		Yes

	Participatory planning	(+)	(+)		Yes
	Control elephant population	(+)	(-)		Yes
Separate	Plant non-unattractive crops for elephants	(+)	(0)	[12, 24, 25]	No
	Fences around the parks	(+)	(0)	[26]	Yes
	Elephant crop hotspot	(+)	(+)		Yes
	Elephant wild food hotspot	(0)	(+)	[14, 24]	Yes
Separate	Village protection	(+)	(0)		Yes
	Village waste management	(+)	(0)		Yes
Ineffective crop protection / Integrate traditional and modern crop protection strategies					
Repel	Bell. Alarm	(+)	(0)	[27]	Yes
	Spotlight	(+)	(0)	[21, 23, 27]	No
	Guard plantation, mostly at night	(+)	(0)	[20, 23, 27-29]	Yes
Repel	Make noise to repulse elephants	(+)	(0)		Yes
	Hurt elephant	(+)	(-)		Yes
	Kill elephant	(+)	(-)		Yes
	Use of bees to repel elephants	(+)	(-)	[30, 31]	Yes
	Disruptive darling (o anesthetize the animal and apply concentrated chili wax (>150 000 Scoville units) on sensitive parts of his body (avoiding the eyes)	(+)	(-)	[32]	No
	Repellent wild animal: protein bill, chili	(+)	(-)	[20, 28, 33, 34]	No

Deter	Technologic (acoustic and image action) and Spatial analysis	(+)	(0)	[13]	No
	Trenches	(+)	(0)	[22]	No
	Virtual automated fence with drones with bees song	(+)	(0)	[35]	No
	Solar light barriers	(+)	(0)	[36]	No
	Electric fence, solar fence	(+)	(0)	[11, 21, 22, 27, 28, 30, 37-47]	Yes
	Seasonal electric fence	(+)	(+)	[48, 49]	No
	Biofences, vegetation fences	(+)	(0)	[11, 21, 22, 27, 28, 30, 37-47]	No
	Deter elephant	(+)	(0)		Yes
	Fences around village areas	(+)	(0)		Yes
	Use fish net fences	(+)	(0)		Yes
	Use of traditional fence	(+)	(0)		Yes
	Village protection	(+)	(0)		Yes
	Chili-oil fence, Wire mesh, Barbed-wire, beehive fence	(+)	(-)	[11, 21, 22, 27, 28, 30, 37-47]	No
Adapt	Combine crop protection methods	(+)	(0)	[20, 50, 51]	Yes
	Combine traditional and modern methods	(+)	(0)		Yes
	Improve crop protection method	(+)	(0)		Yes
	Plant crops in the village areas	(+)	(0)		Yes

Village socioeconomic conditions / Improve livelihood by creating rural socioeconomic opportunities					
Compensate	Regular financial and material compensation	(+)	(+)		Yes
	Community-based insurance scheme	(+)	(+)	[52]	No
	Income to provide habitat for wildlife	(+)	(+)	[53, 54]	No
	Compensate for crop loss	(+)	(0)	[37, 55]	Yes
Adjust	Reduce livelihood dependency to crop with alternative economic opportunities like ecotourism	(+)	(0)	[56, 57]	Yes
	Village micro-credit association	(+)	(0)	[39]	No
	Get income from unattractive crops to elephant/ alternative livelihood	(+)	(0)	[24]	No
	The socioeconomic benefit of compensation with money from tourism	(+)	(0)	[20, 56, 58]	No
	Improve livelihood by creating rural socioeconomic opportunities	(+)	(0)		Yes
	Improve the socioeconomic condition of villages	(+)	(0)		Yes
	Income from Beehive	(+)	(-)	[11, 42, 59]	No

Table C2. Summary of the number of actions in each coexistence strategy with their objectives from literature and by stakeholders. The subtotal and total actions per coexistence strategy are the bold numbers.

Problem types	**Coexistence strategies**	**Objectives**	**Number of actions**			
			Literature	**Stakeholder**	**Common**	**Total**
Decrease of elephant security	Integrate forest exploitation and elephant habitat protection	Conserve	1	1	0	2
		Protect	3	2	2	3
		Integrate	1	3	0	4
Subtotal			**5**	**6**	**2**	**9**
Reduced reliability of fruit production	Conserve and enhance elephant food resources	Conserve	1	7	1	7
		Enhance	2	4	1	5
Subtotal			**3**	**10**	**2**	**12**
Ineffective crop protection	Integrating traditional and modern crop methods	Repel	3	3	2	4
		Deter	7	6	1	12
		Adapt	1	3	1	3
Subtotal			**11**	**12**	**4**	**19**
Regular human-elephant negative interactions	Reduce territorial overlap	Tolerate	1	1	1	1
		Integrate	4	2	2	4
		Separate	2	5	1	6
Subtotal			**7**	**8**	**4**	**11**

Appendix C

Problem types	Coexistence strategies	Objectives	Number of actions			
			Literature	**Stakeholder**	**Common**	**Total**
Village socioeconomic condition	Improve livelihood by creating rural socioeconomic opportunities	compensate	3	1	1	3
		Adjust	4	2	1	5
Subtotal			**7**	**3**	**2**	**8**
Total			**33**	**41**	**14**	**59**

Table C3. Coexistence framework toolbox of strategies and actions. The effect of these strategies on people or elephants was characterized as satisfying with the sign "+" and no impact with "0."

Objectives/ Strategy	**Actions**	**Benefit human**	**Benefit elephant**
Integrate Forest exploitation and elephant habitat protection			
Conserve	Ecotourism as alternative to logging	(+)	(+)
	Combine research and ecotourism around elephants	(0)	(+)
Protect	Protection of intact forest landscape (IFL) through Forest Stewardship Council,	(0)	(+)
	Patrolling areas with the high elephant population	(0)	(+)
	Used new technology like satellite	(0)	(+)
Integrate	Collaboration of certified logging and research for tropical forest conservation and wildlife management	(0)	(+)
	Increase monitoring of sustainable forest exploitation implementation	(0)	(+)
	Speed the increase of sustainable forest exploitation practice	(0)	(+)
	Sustainable forest exploitation implementation	(0)	(+)
Reduced reliability of fruit production/Conserve and enhance elephant food resources			
Conserve	Maintain fruiting trees in protected areas and logging concession	(+)	(+)
	Sustainable forest exploitation implementation	(0)	(+)
	Increase monitoring of sustainable forest exploitation implementation	(0)	(+)
	Increase sustainable forest exploitation implementation	(0)	(+)
	Change logged fruit tree species	(0)	(+)

Objectives/ Strategy	Actions	Benefit human	Benefit elephant
	Encourage international behavior change to improve climate	(+)	(+)
	Protect elephants remained food resources	(0)	(+)
Enhance	Feeding elephant	(+)	(+)
	Manage habitat to maintain water and plant favorable wild food for elephant	(+)	(+)
	Adapt fruiting trees to seasonal/climate change	(+)	(+)
	Replant important fruiting species logged in the past	(+)	(+)
	Restore logging areas with elephant fruit tree species	(+)	(+)
Regular human-elephant negative interactions/Reduce territorial overlap			
Tolerate	Environmental education	(+)	(0)
Integrate	Integrate spatial planning for rural communities, conservation, and forest exploitation. Unfractured development	(+)	(+)
	Integrate management for local development and conservation	(+)	(+)
	Community-based intervention method and landscape-scale management habitat management	(+)	(+)
	Planning to avoid plantations nearby elephant habitat	(+)	(0)
Separate	Plant non-unattractive crops for elephant	(+)	(0)
	Fences around the parks	(+)	(0)
	Elephant crop hotspot	(+)	(+)
	Elephant wild food hotspot	(0)	(+)
	Village protection	(+)	(0)
	Village waste management	(+)	(0)

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Objectives/ Strategy	Actions	Benefit human	Benefit elephant
Ineffective crop protection/Integrate traditional and modern crop protection strategies			
Repel	Bell. alarm	(+)	(0)
	Spotlight	(+)	(0)
	Guard	(+)	(0)
	Grouping villages	(+)	(0)
Deter	Technologic (acoustic and image action) and Spatial analysis	(+)	(0)
	Trenches	(+)	(0)
	Virtual automated fence with drones with bees' song	(+)	(0)
	Solar light barriers,	(+)	(0)
	Electric fence, solar fence	(+)	(0)
	Seasonal electric fence	(+)	(+)
	Biofences, vegetation fences	(+)	(0)
	Deter elephant	(+)	(0)
	Fences around village areas	(+)	(0)
	Use fish net fences	(+)	(0)
	Use of traditional fence	(+)	(0)
	Village protection	(+)	(0)
Adapt	Combine crop protection methods	(+)	(0)
	Improve crop protection method	(+)	(0)

Objectives/ Strategy	**Actions**	**Benefit human**	**Benefit elephant**
	Plant crops in the village areas	(+)	(0)
Village socioeconomic conditions/Improve livelihood by creating rural socioeconomic opportunities			
Compensate	Community-based insurance scheme	(+)	(+)
	Income to provide habitat for wildlife	(+)	(+)
	Compensate for crop loss	(+)	(0)
Adjust	Reduce livelihood dependency to crop with alternative economic opportunities like ecotourism	(+)	(0)
	Village micro-credit association	(+)	(0)
	Get income from unattractive crops to elephant/ alternative livelihood	(+)	(0)
	Socioeconomic benefit with compensation with money from tourism	(+)	(0)
	Improve socioeconomic condition of villages	(+)	(0)

Appendix C

Table C4. Case study to manage CDIs in two selected villages at Lopé National Park. Local problem types were identified and prioritized and then aligned to their associated coexistence strategies from Table 2 in the main results.

Village	Local problems at each village	Coexistence strategies
Kazamabika	Absence of youths and adults in the village	Integrate traditional and modern crop strategies
	Elephant adaptation to crop protection	
	More elephants in village areas because of conservation	
	Absence of elephant hunters	
	Electric fences shift elephant activities to housing areas, increasing threats to people	
	More elephants in village areas because of conservation in nearby protected areas	Reduce territorial overlap
	More elephants in village areas because of the village location which have resources such as native fruit trees, water that attract many elephant	
	Village contain food resources such crop, mango trees that attract elephants	
Ramba	Villages serve as sources of food when there is a lack of fruit in the forest	Conserve and enhance elephant food resources
	Villagers ineffectively use old cans and endura metal roofing as crop protection	Integrate traditional and modern crop strategies
	Elephant adaptation to crop protection	
	Village replaces elephant habitat because build its habitat or along corridor	Reduce territorial overlap
	More elephants in village areas because of the village location which have resources such native fruit trees, water that attract many elephants	
	Village contain food resources such crop, mango trees that attract elephants	
	More elephants in village areas because of electric fences in the neighboring village	
	The proximity of crop fields and elephant resources in natural habitats	

Appendix C

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