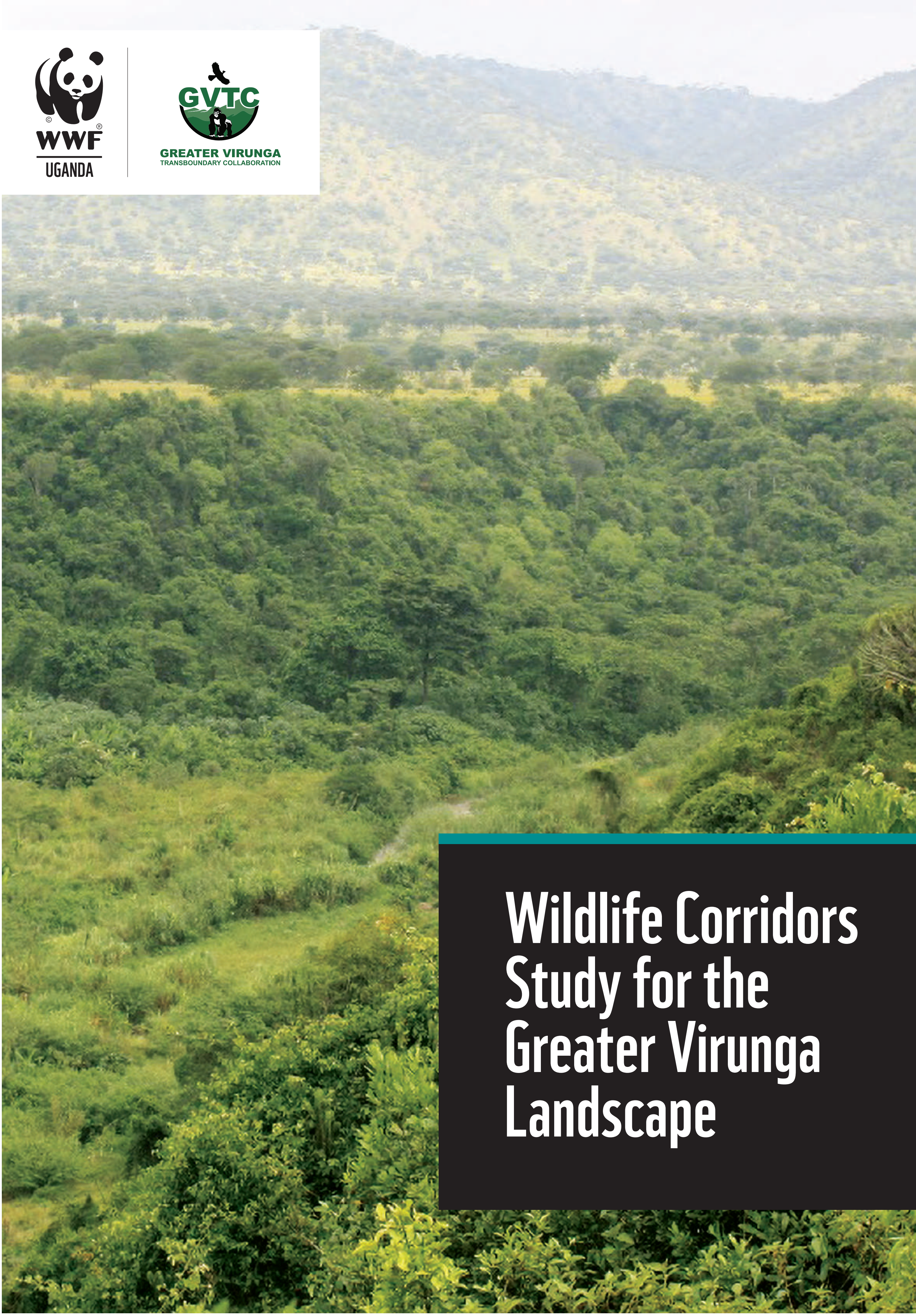
WWF UGANDA

GVTC GREATER VIRUNGA TRANSBOUNDARY COLLABORATION



Wildlife Corridors Study for the Greater Virunga Landscape

In Collaboration with;

International Gorilla Conservation Programme

UWA

Jane Goodall Institute

ICCN INSTITUT CONGOLAIS POUR LA CONSERVATION DE LA NATURE

Wildlife Conservation Society

RDB RWANDA DEVELOPMENT BOARD

Executive Summary

This report summarizes the findings of a study on the status and functional connectivity of corridors within the Greater Virunga Landscape (GVL), focusing on the four target species (i.e., elephants, lions, chimpanzees, mountain Gorillas). We assessed the status and functional connectivity of 20 corridors (5 savanna, 13 forest, 2 forest - savanna ecotone) using a combination of methods, including literature review, ecological and socio-economic surveys, species occurrence and/ movement data, and threat data from GVL partners, landcover and land use mapping, and suitability modeling.

Of the 20 corridors assessed, seven are transboundary (ie., Bwera, Ishasha, Virunga – Semliki, Bwindi – Sarambwe, Volcanoes - Mgahinga, Virunga - Mgahinga, Volcanoes - Virunga), while the remaining corridors provide ecological connectivity between and within protected areas in the GVL partner countries (Uganda, DRC). These include: five corridors that provide ecological connectivity between protected areas in Uganda (Dura, Kalinzu – Kasyoha Kitomi, Kyambura – Kasyoha Kitomi, Kyambura gorge - Kasyoha-Kitomi), four corridors that link habitats within the same protected area in Uganda (Katwe, Muhokya, Kasenyi in Queen Elizabeth National Park; "The Neck" in Bwindi Impenetrable National Park); four corridors that link habitats within Virunga National Park in the Democratic Republic of Congo (Virunga north, Virunga central, Virunga south, Mikeno), and the corridor that links the Greater Virunga Landscape to Toro – Semliki Wildlife Reserve.

Elephants were the most widely distributed species in the Greater Virunga Landscape potentially utilizing all the assessed corridors, except the Kalinzu - Kasyoha Kitomi corridor. Lions were majorly ranging in the northern, and Ishasha sectors of Queen Elizabeth National Park (QENP), and the southern sector of Virunga National Park (VNP), and they primarily utilized four corridors. These include: the Ishasha corridor (connecting southern QENP and VNP), Kisenyi corridor (connecting southern and northern sectors of QENP), Bwera corridor (connecting northern QENP and VNP) and the Muhokya corridor (connecting Kasenyi to Dura sectors within QENP). Chimpanzee corridor habitat use was documented and predicted for six corridors including: Virunga – Semuliki corridor (linking northern VNP and Semuliki NP), Kyambura Wildlife Reserve and Kashyoha Kitomi Forest Reserve, Kyambura gorge and Kashoyha Kitomi Forest Reserve, Kalinzu and kasyoha kitomi Forest Reserves, and within the Bwindi – Sarambwe ecosystem. We documented and predicted corridor habitat use for mountain gorillas between Bwindi Impenetrable National Park and Sarambwe Nature Reserve, and between the northern and southern sectors of Bwindi Impenetrable National Park, and within the Virunga massif among the three protected areas (Volcanoes - Mgahinga, Virunga - Mgahinga, Volcanoes – Virunga).

The populations of the four target species were documented to be increasing for elephants, mountain gorillas, stable for chimpanzees, and declining for lions within the Greater Virunga Landscape. The major threats affecting the abundance and distribution of the target species across the assessed corridors are habitat degradation and poaching. The 2025 landcover and use map for the Greater Virunga Landscape showed that 47% (8) of the identified corridors are impacted by habitat loss and degradation. Habitat loss and degradation was primarily observed and documented in Virunga National Park, and Kasyoha kitomi Forest Reserve, and the Kyambura gorge_KK corridors. Habitat loss and degradation increase the resistance to movement and use of the corridors by the target species, and risk of human wildlife conflict. Poaching was documented to be highly prevalent along the Ishasha corridor, Muhokya corridor; Kyambura – Kashyoha Kitoma corridor, Bwera corridor, Virunga north and south corridors considering the 2000 – 2012 ranger monitoring data. However, the analysis of recent ranger monitoring data (2014 – 2022) for the Queen Elizabeth Protected Area showed a decreasing trend in poaching from 605 incidences in 2019 to 178 incidences in 2022. The decline in the number of poaching signs observed could be attributed to deterrence effort by law enforcement or weaker reporting, and/ the effect of electric fence that was constructed starting in 2019/2020.

Human-wildlife incidences were dominated by elephants across all the assessed corridors in the Greater Virunga Landscape. While human wildlife incidents by lions, chimpanzees, and mountain gorillas were localized to Muhokya and Ishasha corridors, and Kalinzu_KK, Kyambura gorge_KK, and Kyambura_KK corridors, and Virunga Massif and Bwindi-Sarabwe ecosystems respectively. The human wildlife conflict profiles reflected distinct ecological gradients across the surveyed corridors from forest - agriculture mosaics to open savanna systems - emphasizing the need for corridor-specific mitigation approaches. Generally, the communities living near the corridor sites preferred the implementation of compensation schemes (e.g., direct payment for livestock loss), followed by community-based conservation projects (e.g., community wildlife scouts, land use planning) and alternative livelihoods (e.g., bee hives) respectively as mechanisms of minimizing the cost borne out of human – wildlife conflicts. The implementation of compensation schemes and community-based projects as mechanisms for minimizing the cost of living near corridor sites were positively correlated (> 0.7), indicating that collective action among community members in the design and implementation of mitigation measures is important for their long-term success. Preference of compensation schemes across the surveyed corridors – showed that economic losses that are incurred due to depredation and crop raiding are experienced at household level, and that compensation directly addresses these economic losses.

The duration of implementing human – wildlife conflict interventions analysis revealed that most interventions had a mean duration score of 3.2 ± 1.1 years, with long-standing initiatives concentrated in corridor sites where both government and communities have sustained collaboration. Older, long-running efforts such as trenching (fencing) and community guarding HWC mitigation measures dominated Bwera, Muhokya, and Kalinzu sites, where implementation has exceeded six years. In contrast, Ishasha showed a shorter implementation history, with interventions still in their early phases – which reflected either recently implemented measures or contexts where earlier efforts were discontinued. The coexistence of long-term community-led initiatives (e.g., “community guarding” and “revenue sharing”) with state infrastructure investments highlighted an emerging hybrid model of sustained conflict mitigation, balancing top-down and bottom-up governance approaches. This spatial heterogeneity underscored how institutional continuity, community participation, and resource allocation jointly influence the persistence of wildlife-conflict mitigation strategies across the surveyed sites.

Physical barriers (e.g., electric fence, trenching) were the most preferred intervention to mitigate human wildlife conflicts in the Greater Virunga Landscape. Respondents showed a consistent belief that human-wildlife conflict interventions by government are more sustainable, followed by community-based interventions, with minimal preference to interventions initiated by non-governmental organizations. As such, the limited recognition of NGO-led efforts may reflect shorter project cycles or less visibility at household level.

In terms of governance, corridors in the GVL are primarily administered through a network of country-protected area authorities under the framework of the Greater Virunga Transboundary Collaboration (GVTC) - which aims to strengthen transboundary conservation through coordinated landscape planning, knowledge transfer, benefit sharing, ecological research and monitoring. The member countries of Uganda, Rwanda and the Democratic Republic of Congo are represented by the Uganda Wildlife Authority (UWA), Institute Congolais pour la Conservation de la Nature (ICCN), and the Rwanda Development Board (RDB) respectively. Twenty four percent of the corridors (4) within the GVL are transboundary and are co-governed by ICCN and UWA, fifty three percent of the corridors (9) are located within protected areas and are governed by the country specific protected area authorities (UWA or ICCN). The remaining corridors (4) are governed under hybrid system that involves Uganda Wildlife Authority, National Forestry Authority, and/or local communities. Therefore, effectiveness of corridor governance in the GVL is dependent on the harmonization of the land use goals of the different government agencies. For example, under the National Forestry Authority Collaborative Forest Management, local communities planted eucalyptus and pine in some parts of the corridors which potentially affected their functionality.

To enhance wildlife corridor management and conservation within the Greater Virunga Landscape, we recommend the following measures to managers and policymakers. These include: strengthening law enforcement to prevent encroachment (habitat loss and degradation) and poaching, habitat restoration and community engagements for corridors located outside protected areas, promoting the construction of electric fences, compensation schemes, and community initiated projects as mechanisms of mitigating human-wildlife conflicts; reviewing effects of collaborative forest management on corridor sites, and examining the potential of expanding the size of the narrow corridor sites.

Conclusion

Using literature review, an ecological and socio-economic survey, landcover and land use mapping, species distribution and threat data from GVL partners (WCS & JGI), and long-term species occurrence and threat data from the Uganda Wildlife Authority collected under the ranger based monitoring system, and habitat suitability modeling – we established that the status of 75% (15) of the corridors within the Greater Virunga Landscape in relation to habitat condition as unmodified (natural), and that these corridors were functional providing ecological connectivity between and within protected areas for the target species. The remaining corridors (5) that are potentially dysfunctional were primarily affected by habitat loss and degradation specifically in Virunga National Park (i.e., Virunga north, Virunga central, Virunga south - DRC), the Kasyoha-Kitomi Forest Reserve (Uganda), and in the community area along Kyambura river (Uganda).

As such, this study highlights the importance of corridors in the GVL in terms of increasing ecological connectivity between and within protected areas for the target species, and how to enhance their management and conservation.

Acknowledgements

We would like to extend our appreciation to organizations and individuals who contributed their time and data towards the successful completion of this study on assessing the status and functional connectivity of corridors within the Greater Virunga Landscape.

First and foremost, we would like to thank the Uganda Wildlife Authority (UWA) for sharing their long-term species sightings and threat data collected under the ranger-based monitoring program, and for granting us permission to conduct research within the protected areas. Next, we would like to express our gratitude to the Wildlife Conservation Society, Uganda Program, and The Jane Goodall Institute for providing access to their data on target species distributions and threats within the Greater Virunga Landscape.

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List of Acronyms and Abbreviations

GVL	Greater Virunga Landscape
GVTC	Greater Virunga Transboundary Collaboration
UWA	Uganda Wildlife Authority
ICCN	Institute Congolais pour la Conservation de la Nature
RDB	Rwanda Development Board
NFA	National Forestry Authority
QENP	Queen Elizabeth National Park
QECA	Queen Elizabeth Conservation Area
VNP	Virunga National Park
KK	Kasyoha Kitomi Forest Reserve
WCS	Wildlife Conservation Society
WWF	World Wide Fund for Nature
JGI	Jane Goodall Institute
PA	Protected Area
OECMS	Other Effective Area-Based Conservation Measures
CFM	Collaborative Forest Management

1. Introduction

Wildlife corridors play a vital role in maintaining ecological connectivity and ensuring the long-term survival of wildlife populations by linking protected areas and other critical habitats. They facilitate dispersal, gene flow, and seasonal migration, enabling species to access essential resources such as food and water, while also buffering against the effects of climate change (Beier & Noss, 1998). The need for functional connectivity is especially urgent in regions experiencing rapid habitat fragmentation and land-use change driven by human activities. The Greater Virunga Landscape (GVL) is one of Africa's most biologically significant ecosystems, encompassing parts of Uganda, Rwanda, and the Democratic Republic of Congo (DRC). It contains eight national parks and numerous game and forest reserves, including three UNESCO World Heritage Sites -Virunga, Bwindi Impenetrable, and Rwenzori Mountains National Parks, alongside Ramsar and Man and the Biosphere Reserves. This exceptional diversity supports globally important populations of large mammals such as African elephants, lions, chimpanzees, and the endangered mountain gorilla, as well as over 400 bird species, many of which are Albertine Rift endemics (Plumptre et al., 2016). The ecological and socio-economic value of the GVL is immense, including ecosystem services, tourism income, and livelihood resources to millions of people in the region.

Despite this importance, the GVL faces mounting threats from poaching, agricultural expansion, settlement encroachment, industrial development, and extractive activities including oil exploration and mining. These pressures have led to increasing fragmentation of natural habitats and the disruption of traditional wildlife movement routes (Nellemann et al., 2014; WWF, 2018). The resulting loss of connectivity between protected areas not only threatens wildlife populations but also reduces the resilience of the entire ecosystem to environmental and climatic change.

Within Uganda's portion of the GVL, the Wildlife Conservation Society (WCS) and Uganda Wildlife Authority (UWA) identified seven major wildlife corridors (here defined as areas that maintain ecological connectivity between and within protected areas, often narrow (bottle necks) within a human dominated landscape) in the Queen Elizabeth Conservation Area (QECA) in 2008 - four savanna corridors (Ishasha, Bwera, Dura, and Muhokya) and three forest corridors (Kyambura–Kasyoha-Kitomi, Kyambura Gorge – Kasyoha Kitomi, and Kasyoha Kitomi -Kalinzu–Maramagambo; Figure 1). While these corridors were identified and assessed in 2008, their status and functional connectivity are unknown (WCS, 2008; UWA, 2012). As such, updated assessments of these corridors are needed to understand their status and functional connectivity, and to identify potential new corridors within the Greater Virunga Landscape - to guide future restoration and management actions.

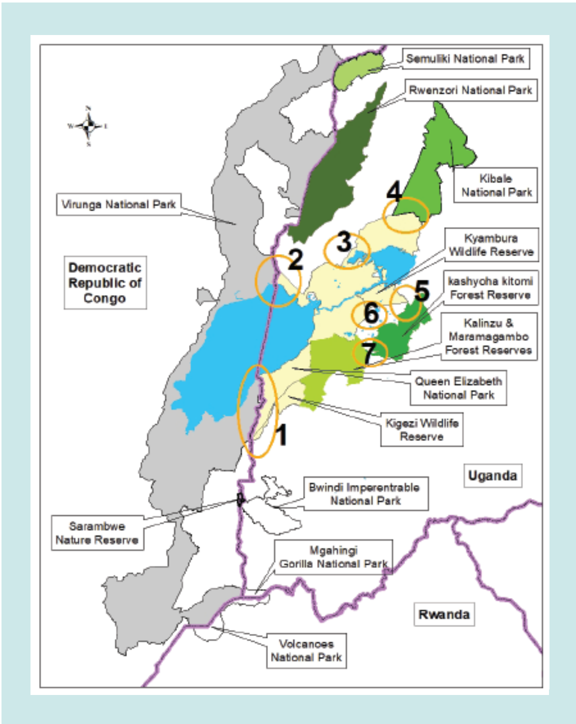


Figure 1: Study area showing known wildlife corridors within the Greater Virunga Landscape from an earlier study. Potential new corridors that were identified during this study are shown in the results section.

1 = The Ishasha corridor (savanna) linking southern Queen Elizabeth National Park (Uganda) to Virunga National Park (DRC)

2 = The Bwera corridor (savanna) linking northern Queen Elizabeth National Park (Uganda) to Virunga NP (DRC)

3 = The Muhokya corridor (savanna) within northern Queen Elizabeth National Park (Uganda)

4 = The Dura corridor (savanna) linking northern Queen Elizabeth National Park to Kibale National Park (Uganda)

5 = Kyambura – Kasyoha Kitomi corridor (Uganda)

6 = Kyambura Gorge corridor (forest) linking Kyambura Wildlife Reserve and Kasyoha-Kitomi Forest Reserve (Uganda)

7 = Kasyoha Kitomi – Kalinzu Maramagambo corridor (forest; Uganda)

1.1 Corridor Governance

The governance of wildlife corridors within the GVL is complex and multi-level. Most areas fall under state or public governance, with UWA (Uganda), ICCN (DRC), and RDB (Rwanda) holding statutory authority for protected area management. These institutions collaborate under the Greater Virunga Transboundary Collaboration (GVTC) Treaty, which provides a legal framework for joint planning, monitoring, and enforcement across international boundaries (GVTC, 2015). In Uganda, Collaborative Forest Management (CFM) arrangements under the National Forestry Authority (NFA) enable local communities and Indigenous Peoples to participate in the management of forest reserves such as Kasyoha-Kitomi and Kalinzu, thereby enhancing stewardship, benefit-sharing, and compliance with forest management plans (NFA, 2019; WWF, 2018). Meanwhile, in the DRC, the partnership between ICCN and the Virunga Foundation represents a state–private co-management model that integrates conservation management with sustainable development initiatives (Virunga Foundation, 2014).

Recent analyses confirm that corridor functionality is closely linked to governance effectiveness. Savanna corridors such as Ishasha and Bwera are primarily governed by state authorities but rely heavily on transboundary coordination under the GVTC framework for effective management. Forest corridors, including Kyambura–Kasyoha-Kitomi and Kasyoha-Kitomi–Kalinzu–Maramagambo, are characterized by hybrid governance systems involving UWA, NFA, and local communities through CFM mechanisms. These collaborative structures have proven vital for maintaining ecological connectivity and mitigating human–wildlife conflicts (WWF, 2018; GVTC, 2015). In contrast, the co-managed sectors of Virunga National Park highlight how public–private partnerships can bolster enforcement capacity, attract sustainable financing, and align conservation with livelihood programs (Virunga Foundation, 2014).

Assessing and strengthening the governance frameworks are crucial for the implementation of the Greater Virunga Transboundary Strategic Action Plan (2024–2033). This assessment will combine spatial mapping, ecological field surveys, and institutional analysis to provide an evidence-based understanding of corridor conditions, connectivity, and management effectiveness.

The results will guide priority interventions, foster institutional collaboration, and contribute to the long-term ecological integrity and socio-economic resilience of the Greater Virunga Landscape.

1.2 History and design of corridors

The history and design of wildlife corridors in the GVL reflects more than two decades of transboundary ecological planning and institutional innovation aimed at maintaining landscape connectivity across Uganda, Rwanda, and the Democratic Republic of Congo (DRC). The concept of ecological corridors in this region emerged during early landscape conservation initiatives led by the Wildlife Conservation Society (WCS) and the Uganda Wildlife Authority (UWA), which recognized the ecological and genetic risks facing wide ranging species within isolated protected areas (Plumptre et al., 2007). The foundational corridor mapping exercise in 2008 identified seven critical wildlife corridors in the Queen Elizabeth Conservation Area (QECA), including four savanna linkages (Ishasha, Bwera, Muhokya, and Dura) and three forest linkages (Kyambura–Kasyoha-Kitomi, Kyambura Gorge, and Kasyoha-Kitomi–Kalinzu–Maramagambo) (WCS, 2008). These corridors were delineated using species movement data, vegetation structure, and land-use patterns to optimize ecological flow between key protected areas such as Queen Elizabeth National Park (QENP), Kibale National Park, and Virunga National Park (VNP).

The design of these corridors followed a dual typology, savanna and forest, reflecting the heterogeneity of the GVL. Savanna corridors were conceptualized primarily for the dispersal of large-bodied mammals such as elephants, lions, and buffaloes, whose movements historically traversed low-lying plains between protected areas. In contrast, forest corridors were designed to sustain primates, forest elephants, and other forest-dwelling species dependent on canopy continuity for migration and foraging. Mapping relied heavily on telemetry data, ranger-based monitoring, and spatial analysis of barriers such as cultivation zones, settlements, and road infrastructure (WCS, 2008; Beier & Noss, 1998). The design criteria emphasized both ecological connectivity and socio-economic feasibility, ensuring that corridor delineation considered human and land-use realities.

The GVL's corridor planning evolved from localized ecological mapping to a landscape-scale, transboundary framework. The GVTC Treaty, signed in 2015, institutionalized joint conservation planning and governance across the three countries. The treaty formalized shared mechanisms for biodiversity monitoring, law enforcement, and corridor management involving the UWA, ICCN, and RDB (GVTC, 2015). This institutional development represented a paradigm shift from protected area isolation toward cooperative, multi-country ecosystem management. It also integrated social and governance components, acknowledging that corridor functionality depends on the alignment of policy, land tenure, and community participation frameworks (IISD, 2023).

Recent work under the Greater Virunga Transboundary Strategic Action Plan (2024–2033) and related ecological monitoring projects demonstrates that corridor design in the GVL must now accommodate rapid landscape transformation and climate variability.

Studies show that key species, including elephants and great apes, are exhibiting range contractions and altitudinal shifts, underscoring the need to design corridors that remain functional under changing climatic conditions *(Ayebare et al., 2013; Plumptre et al., 2017; Ayebare et al., 2018)*. Furthermore, there is growing recognition that governance type strongly influences corridor sustainability. Forest corridors such as Kyambura–Kasyoha-Kitomi and Kasyoha-Kitomi–Kalinzu–Maramagambo are managed under hybrid arrangements combining UWA, the National Forestry Authority, and local community participation through Collaborative Forest Management.

Meanwhile, in DRC's Virunga National Park, a state–private partnership between ICCN and the Virunga Foundation enhances enforcement and integrates livelihood development within corridor management *(Virunga Foundation, 2014; NFA, 2019)*.

The design history of GVL corridors can therefore be described in three volutionary phases. The first phase (pre-2010) focused on identifying physical linkages between protected areas through empirical ecological data and species tracking between protected areas in Uganda and the Democratic Republic of Congo. The second phase (2010–2015) emphasized institutionalization of transboundary cooperation, culminating in the GVTC Treaty. The third and ongoing phase (post-2015) integrates governance, climate resilience, and community-based conservation into corridor design. This adaptive, evidence-based approach reflects the GVL's shift toward a networked conservation model that balances ecological imperatives with socio-political realities across borders.

1.3 Ecological theory and wildlife corridors

The metapopulation theory, and the equilibrium theory of Island Biogeography *(MacArthur and Wilson, 1963)* describe the importance of wildlife corridors in conservation science. The metapopulation theory, views local populations as spatially structured assemblages of breeding populations whose long-term persistence is maintained by colonization and extinction events – thus influencing local population dynamics (*Hanski & Simberloff, 1997; Levin 1969; Wegmann et al., 2014)*. While the equilibrium theory of Island Biogeography describes how species richness on islands is a function of colonization and extinction rates, size of the island and distance from the mainland (Brown., & Lomolino,1989; MacArthur, & Wilson, 1963). Together, these theories show that corridors reduce ecological isolation between and within protected areas – through enhancing colonization and reducing local extinctions. Additionally, the theories provide a way of thinking about the importance of fragmented habitats to conservation. For example, equilibrium theory of Island Biogeography predicts species richness among habitat patches in relation to their area and distance from other patches, while the metapopulation theory predicts the importance of a viable population of a species within some patches that enables recolonization of other patches within a landscape (Van Aarde, & Jackson, 2007; Olivier et al., 2009; Matthews, 2021).

1.4 Landscape species concept and corridor identification

Landscape species *(umbrella /keystone/ flagship)* are species that require large home ranges for their survival *(e.g., lions, elephants, gorillas)*, and significantly influence the structure and functioning of ecosystems *(Plumptre et al., 2007; Caro, 2003)*. The landscape species concept has been used to achieve a broad set of conservation goals that address threats of multiple species *(Khosravi and Hemami, 2019; Sanderson et al., 2002)*. As such, assessing the status and functional connectivity of corridors based on the landscape species concept ensures that sites that are ecologically complementary to other species in terms of increasing ecological connectivity are identified.

1.5 Human dimensions of wildlife corridors

Globally, habitat loss and degradation is among the top five threats to the conservation of biodiversity (*Bellard, et al., 2022)*. Habitat loss and degradation has been most prevalent outside protected areas, affecting the structure and functional connectivity of wildlife corridors *(Green et al, 2018; Riggio et al., 2019; Elisa et al., 2024)*. Consequently, habitat loss and degradation outside protected areas minimizes the effectiveness of wildlife corridors and increases human wildlife conflict *(Songhurst et al., 2016; Elisa et al., 2024)*. Human–wildlife conflict occurs when the needs of wildlife and humans negatively affect each other *(Madden, 2004)*. Most wildlife corridors are narrow tracts of land within a human dominated landscape, leading to an increase in human wildlife conflicts.

1.6 Study Objectives

The main objective of the study is to assess the status and functional connectivity of wildlife corridors in the Greater Virunga Landscape to guide partners and stakeholders to design and implement viable management and conservation actions.

The primary species of focus are lions (*Panthera leo*), elephants (*Loxondota africana, Loxondonto cyclotis*), chimpanzees (*Pan troglodytes*), and mountain gorillas (*Gorilla beringei ssp. beringei*)

1.6.1 Specific tasks:

i. Collate, review, and analyze publications and reports related to potential lion, elephant, chimpanzee, and mountain gorillas corridors in the GVL. The review will specifically:

   a. Identify and profile available species biodiversity data associated with each corridor link.

   b. Identify social and economic factors that affect the status of corridors for the named species.

   c. Identify governance types, including public, Indigenous Peoples and Local Communities (IP&LCs), and private or co-governed among others within the wildlife corridor being assessed.

ii. To identify the threats to existing known corridors for the named species (lions, elephants, chimpanzees and mountain gorillas) and recommend mitigation measures

iii. To identify the available suitable areas (core suitable areas) and those that require management interventions (reduce resistance to movement) to guarantee functionality for lions, elephants, chimpanzees and mountain gorillas through a land cover and land use analysis in the wildlife corridor areas.

iv. To identify the most feasible remaining wildlife corridors for management and conservation in GVL with specific reference to elephants, lions, chimpanzees and mountain gorillas through socioecological and habitat suitability modeling.

v. To enhance wildlife corridor management and conservation, the Conserved and Protected Areas, including OECMS, by recommending appropriate measures to managers and policymakers.

vi. Whenever called upon, during the consultancy, to present and discuss study findings to GVL technical working groups/ teams, including presentation of the final report. The meetings will be conducted virtually.

2. Methodology

2.1 Criteria to identify new corridors

We identified potential new corridors (i.e., *areas that maintain ecological connectivity between and within protected areas, often narrow (bottle necks) within a human dominated landscape)* using species occurrence and/ movement data, land cover and use mapping, and socio-ecological suitability modeling based on the following criteria:

1) Presence and habitat use of the target species within the protected areas
2) Habitat use of sites that link protected areas by the target species
3) Habitat use of sites that link habitats within protected areas (these sites are characterized by being narrow (bottle necks) compared to the surrounding areas

2.2 Literature review

We conducted a literature search using Google Scholar (September 2025) focusing on ecological, social, economic, governance and threat data for the target species (lion, chimpanzee, elephant, mountain gorilla) within the Greater Virunga Landscape. The following search terms (i.e., large mammal survey, aerial survey, ground survey, census, ranger monitoring data, corridor, movement, human-wildlife conflict, social and economic, governance framework, threats, illegal activities) were input into Google Scholar in combination with the names of the target species, and protected areas where the species is known to occur. We screened the Google Scholar page results by reading the titles and abstracts of the publications and reports. We stopped reviewing Google Scholar page results when no further relevant information related to our search terms were found.

This review enabled us to meet the requirements of the consultancy including;

a. Identify and profile available species biodiversity data associated with each corridor link.

b. Identify social and economic factors that affect the status of corridors for the named species.

c. Identify governance types, including public, Indigenous Peoples and Local Communities (IP&LCs), and private or co-governed among others within the wildlife corridor being assessed.

d. To identify the threats to existing known corridors for the named species (Lions, Elephants and Chimpanzees) and recommend mitigation measures.

2.3 Data collection

2.3.1 Ecological and Social-economic surveys

We conducted ecological and social-economic surveys to assess the status and functional connectivity of corridors within the Greater Virunga Landscape (Around Queen Elizabeth Conservation Area) between the 19th of September to the 4th of October 2025. Note: The ecological and social survey was only conducted for the seven previously identified corridors within the GVL. Additionally, a social survey was conducted to assess corridor functionality between the GVL and the Murchison – Semliki Landscape.

2.3.2 Ecological survey

We used Recces (Reconnaissance walks) to survey the presence and signs of target species, and to assess the structure of corridors in terms of habitat integrity. Reconnaissance walks are preferred to transect surveys when the goal is to obtain information on the presence or absence of a species. Recces were walked along a path of least resistance using predetermined Global Positioning coordinates (GPS) within the corridors. We recorded the location of all direct and indirect sightings (i.e., dung, pellets, scat) of all mammal species observed along the recce.

2.3.3 Social-economic survey

We administered a structured questionnaire using the KOBO Collect digital platform to gather information on species occurrence, human-wildlife conflict, effectiveness of interventions, income sources, and land tenure in relation to the status and functional connectivity of the Greater Virunga Landscape corridors. The respondents were purposefully sampled at household level based on their proximate (1 - 2 km buffer) to the target corridor. For each corridor, we aimed to interview between 30 – 40 respondents in line with previous studies in the landscape (e.g., Munanura, et al., 2021; Nampindo & Plumptre, 2005), and the statistical requirements suggested by the Central Limit Theorem. We gathered additional information on the habitat use of corridors by the target species through informal discussions with the Uganda Wildlife Rangers and National Forestry Authority staff.

We also assessed corridor use and threats between a potential corridor that links the Greater Virunga Landscape with a neighboring protected area (i.e., Toro – Semliki Wildlife Reserve).

2.3.4 Secondary data - Greater Virunga Landscape Partners

We obtained ecological, social, economic, and threat data from the Greater Virunga Partner Organizations (i.e., Uganda Wildlife Authority, Jane Goodall Institute, and the Wildlife Conservation Society) - to assess the status and functional connectivity of corridors within the Greater Virunga Landscape. The data from partner organizations consisted of species occurrence and abundance, human-wildlife conflict incidences, and illegal activities – for the period between 2003 – 20.

3. Data Analysis

3.1 Literature review and secondary data

We mapped the occurrence and distribution data of the target species (i.e., lion, elephant, chimpanzee, mountain gorilla) using Geographical Information Systems to visually assess spatial overlay within the seven corridors identified in 2008, and to identify potential new corridors. A spatial overlay involves mapping species occurrence records over the corridor area and analyzing whether any of the locations intersect the corridor. Additionally, we estimated ranging patterns for lions using telemetry data (14 individuals; 2018 - 2019) obtained from the Wildlife Conservation Society and analyzed using the AdehabitatHR package (R statistical software; Calenge, 2011). The AdehabitatHR package uses a Utilization Distribution (UD) model to estimate species' home ranges (Calenge, 2011). The UD model specifies the probability of space use by the animal and as such is preferred compared to Minimum Convex Polygon approaches in home range analysis studies (Calenge, 2011, Worton, 1989). We classified corridors into two categories: i) realized (currently functional), ii) non-realized (potentially functional). Corridors were classified as - realized when the target species was recorded in the recent past (ie.,2015 - 2022); non-realized when the target species was historically recorded to occur in the area but there are no recent records (2015 - 2022), and the habitat is highly modified.

3.2 Ecological and social-economic survey

Ecological: We mapped the presence of the target species using Geographical Information System to assess current corridor use. Furthermore, we assessed the status of the corridors by collecting data on the habitat integrity (i.e., describing whether the habitat is natural or modified).

Socioeconomic: We used descriptive statistics (percentages, bar charts, boxplots, heatmaps) to summarize and describe the responses, and parametric (Chi-square test, T - test) statistics to examine patterns and to assess relationships between responses.

3.3 Land Use Land Cover (LULC) Analysis

3.3.1 Data Acquisition and Preparation

Sentinel-2 Level-2A satellite images were acquired from the Copernicus Data Space Ecosystem *(https://dataspace.copernicus.eu/data-collections/copernicus-sentinel-data/sentinel-2)* covering the study area (all potential corridors in the GVL) for the period June to July 2025. This period corresponds to the dry season, selected to minimize cloud cover and ensure optimal visibility of surface features.

All selected scenes had less than 3% cloud cover, thereby reducing the need for extensive cloud or shadow masking. The Level-2A product provides bottom-of-atmosphere (BOA) reflectance, along with auxiliary layers such as the Scene Classification Layer (SCL), which is used to identify clouds, shadows, vegetation, and other surface features.

All image tiles covering the area of interest were preprocessed in ArcGIS Pro 3.2.1. First, the individual Sentinel-2 tiles, including the SCL band, were mosaicked to create a seamless image covering the entire study area. Bands with an original spatial resolution of 20 m were resampled to 10 m using the nearest neighbor resampling method to ensure consistency across all spectral layers. Subsequently, all 10 m and resampled 20 m bands were stacked into a single multiband composite raster. The composite was then clipped to the boundaries of the Area of Interest (AOI) to extract only the relevant portion of the imagery corresponding to the study site. The final output was a single multiband raster with a 10 m spatial resolution, providing a uniform and high-quality dataset for land cover classification and subsequent spatial analysis.

3.3.2 LULC Classification

A supervised classification approach using the support vector machine (SVM) was employed. SVM is well-suited for multispectral datasets and capable of handling non-linear relationships among spectral features (Moughal, 2013). Representative training samples were created using the image classification wizard of ArcGIS Pro to define the spectral characteristics of the major land cover types within the study area. Nine categories of land cover were identified for classification: Open Water, Forest, Agriculture, Urban Areas, Grassland, Bare Earth, Scrub, Tree Plantation, and Woodland. These categories were later consolidated into two broader classes: natural habitat and modified habitat.

Training sample collection was guided by the visual interpretation of high-resolution basemaps, existing land cover information, and ground truthing conducted during field visits in September 2025. This combination ensured accurate representation and differentiation of land cover classes, particularly in areas with similar spectral signatures.

3.3.3 Accuracy Assessment

Accuracy assessment was conducted to evaluate the reliability of the land cover classification results. A set of independent validation points was generated using the Create Accuracy Assessment Points tool in ArcGIS Pro. These points were stratified across all land cover classes to ensure adequate representation of each category. Reference data for validation were obtained through a combination of high-resolution imagery from Google Earth Pro and ground truth observations collected (Vijitharan et al., 2022). Accuracy assessment points were generated, and a confusion matrix was produced to compare the classified land cover values against the reference data.

From this matrix, key accuracy metrics were derived, including Overall Accuracy, Producer's Accuracy, User's Accuracy, and the Kappa Coefficient.

The Kappa coefficient is used to determine the agreement between classification accuracy and reference data (Pontius & Millones, 2011). This parameter reflects the difference between actual agreement and the agreement expected by chance. The overall accuracy represents the proportion of correctly classified samples relative to the total number of validation samples, while Producer's and User's accuracies measure the classification performance from the perspective of omission and commission errors, respectively.

3.4 Species distribution (habitat suitability) modeling

Species distribution models have been widely used to quantify how species use their environment (Elith & Leathwick., 2009; Pearson, 2008). Suitability analysis is often used to identify suitable habitat as a proxy for the potential presence and or occupancy of a species (Mbuh & Vruno, 2018). We estimated the realized and potential niche for lions, chimpanzees, elephants and mountain gorillas within the Greater Virunga Landscape using a species distribution model - a Maximum Entropy (MaxEnt) modeling algorithm (version 3.4.1). A realized niche describes the suitable habitat that is currently occupied by the species, while the potential niche describes the suitable habitat that is currently unoccupied by a species due to biotic interactions, anthropogenic threats, and/or dispersal constraints as characterized by maximum entropy probability distribution. We selected MaxEnt as our modeling approach because it has been shown to outperform other species distribution modeling algorithms (Elith et al., 2006). MaxEnt utilizes species presence only data and predictor variables to estimate the realized and potential niches of species from incomplete information by searching for a target probability distribution that has maximum entropy (Philips et al. 2004; Phillips et al., 2006). We utilized the default Maxent parameters (i.e., Auto features, a convergence threshold of 0.00001, a maximum of 10,000 background points, regularization multiplier of 1) to characterize the species occurrence – predictor variable relationships (Phillips & Dudík, 2008).

The maximum entropy probability distribution for each of the species was estimated through 10 bootstrap runs to ensure reliability of the results – with species occurrence data split into 70% training and 30% evaluation. We obtained a logistic output ranging from 0 to 1 from MaxEnt, representing the predicted realized and potential distribution of the target species within the Greater Virunga Landscape. Model performance was assessed using the receiver operating characteristic plots, and AUC values >= 0.8 were selected for our corridor analysis.

3.4.1 Species occurrence data

We obtained species occurrence data from the Wildlife Conservation Society (WCS), and Uganda Wildlife Authority (UWA) for the period between 2000 and 2022. The Wildlife Conservation Society has been conducting aerial and ground surveys and monitoring target species (i.e, lions, chimpanzee, elephants, within the Greater Virunga Landscape since the early 2000's. The Uganda Wildlife Authority collects species occurrence under the ranger monitoring program across all protected areas using the Spatial Monitoring and Reporting Tool (SMART) and/ or Earth Ranger.

3.4.2 Predictor variables

We used bioclimatic, topographic, and social-economic variables to estimate the realized and potential suitable habitat for the target species using MaxEnt. A total of 19 bioclimatic variables that are derived from monthly temperature and precipitation data were downloaded from the WorldClim website for global climate data (Fick & Hijmans, 2017). Topographic data was obtained from the USGS (*https://earthexplorer.usgs.gov*). The socio-economic variables used in the model include – distance to roads, distance from protected area boundary, and population density (number of people per kilometer; European Commission, GHSL Data Package 2023). We estimated the Pearson correlation coefficient among predictor variables to assess multicollinearity (Warren et al., 2010; *http://enmtools.blogspot.com/*). All predictor variables (12) with a correlation coefficient of less than +/- 0.75 were used in estimating the realized and potential suitable habitat for the target species in the Greater Virunga Landscape. The selected predictor variables represented the climate, topography, social, and economic factors that influence the distribution of the target species within the study area (Table 1).

Table 1: Predictor variables used in species distribution modeling

Predictor Variables	Variable Description	Variable type
Bio1	Annual Mean Temperature	Ecological
Bio3	Isothermality (BIO2/BIO7) (×100)	Ecological
Bio7	Temperature annual range	Ecological
Bio12	Annual precipitation	Ecological
Bio14	Precipitation of Driest Month	Ecological
Bio 19	Precipitation of Coldest Quarter	Ecological
gvl_dem	Elevation	Ecological
gvl_rivers	Distance to rivers	Ecological
gvl_roads	Distance to roads	Social
pop_dens_gvl	Human population density	Social
dist_pa_boundary	Distance to park boundary	Social

4. Results

4.1 Literature Review

4.1.1 Social economic context of the study area

4.1.1.1 Population Growth and Land Use Change

Almost all reviewed studies highlighted rapid population growth and expansion for agriculture and settlement as key social causes of habitat loss and corridor degradation in the Greater Virunga Landscape (Plumptre et al., 2021; Musavandalo et al., 2024). For example, the human population is projected to increase from 14.6 million in 2025 to at least 20 million by 2050 in Rwanda, from 50 million in 2025 to at least 80 million by 2050 in Uganda, and from 113 million in 2025 to atleast 200 million by 2050 in the DRC (World Health Organization, 2025). Infringement of buffer zones near protected areas has increased competition for land between people and wildlife, especially around QENP, Virunga, and Bwindi National Parks (Mapesa et al., 2013). Forest cover in the buffer zones near Virunga National Park and Queen Elizabeth National Park by 10% between 2000 and 2020 due to land conversion for smallholder farms, livestock grazing areas, and charcoal production (UNEP-WCMC., 2022; Plumptre et al., 2017). Such habitat fragmentation increases the isolation of wildlife, especially elephants and chimpanzees, which require large stretches of continuous natural cover to move and find food (Blake and Maisels., 2023; Frazier et al., 2021). Lions, although tolerant to semi-modified habitats, are affected by declines in wild prey and by humans encroaching into their space, restricting their home range (Packer et al., 2013). Infrastructure development, such as roads and human settlements, significantly impacts wildlife movement by creating barriers and increasing disturbance to diverse wildlife populations (Plumptre et al., 2016). Habitat fragmentation from these developments isolates wildlife populations and worsens existing issues like poaching (Nampindo et al., 2015). The growth of human settlements and infrastructure can result in savanna parks becoming more densely wooded, which poses a threat to ungulates (Plumptre et al., 2016). In the context of the Greater Virunga landscape, the trade-offs between economic development through infrastructure and the preservation of ecological corridors remain a critical challenge (Plumptre et al., 2016; Plumptre et al., 2017).

4.1.1.2 Human-wildlife conflict (HWC)

Human-wildlife conflict emerged as a recurrent social factor across species. Declines in elephant populations are rapidly occurring due to habitat loss and human-wildlife conflicts exacerbated by climate change (Nampindo & Randhir, 2024). Elephants and mountain gorillas are responsible for crop-raiding, lions for livestock depredation, and chimpanzees for crop and fruit-tree damage (Mugisha et al., 2022; Babaasa et al, 2013; Plumptre et al, 2007; Loveridge et al, 2017; Ndayishimiye et al, 2023). These conflicts often cause substantial economic losses (Nampindo & Randhir, 2024; Dickman et al, 2011).

This undermines local tolerance for wildlife, resulting in retaliatory killings, increased use of snares, and deliberate destruction of vegetated corridors. Areas experiencing frequent human-wildlife conflict tend to have reduced wildlife tolerance and higher rates of corridor encroachment (Treves & Karanth, 2003). Inadequate or delayed compensation mechanisms have been shown to exacerbate resentment and discourage community support for protected area protection (Musavandalo et al, 2024; Synman et al, 2023). Conversely, where conservation benefits are tangible, through tourism revenue sharing or employment, attitudes tend to be more positive (Synman et al, 2023).

4.1.1.3 Governance, Security, and Transboundary collaboration

Weak governance and insecurity, particularly in eastern DRC, have been identified as severe constraints to effective corridor management (Plumptre et al., 2021). Insecurity fosters illegal mining, poaching, and settlement in protected zones, while inconsistent law enforcement across borders undermines transboundary conservation initiatives (GVTC, 2021). Law enforcement is an important component of biodiversity conservation in protected areas, but it is often costly, and effectiveness is seldom monitored. Critchlow et al (2016) demonstrated in Uganda's Queen Elizabeth Protected Area that optimally allocating ranger patrols according to data collected during the patrols would substantially increase detections of illegal activities by more than 250% in extreme cases, without any additional resources being invested, thereby exemplifying a model for data-driven conservation intervention in settings with resource constraints. Plumptre et al. (2014) found that the success of law enforcement monitoring in the Albertine Rift region hinges on integrating social, ecological, and management considerations. They found that targeted ranger patrols, informed by spatial mapping of illegal activities, enhanced patrol efficiency, and reduced threats. The absence of harmonized management frameworks among Uganda, Rwanda, and the DRC further complicates coordinated conservation efforts (Refisch and Jenson, 2016; Trojisch, 2021). Effective conservation of elephants, for example, requires a transboundary management approach that includes climate change mitigation, cooperation among conservation agencies, and partnerships with all relevant stakeholders (Nampindo & Randhir, 2024).

4.1.1.4 Cultural Attitudes and Land Tenure

Traditional land tenure systems and cultural perceptions of wildlife also influence corridor outcomes. Land tenure systems arise from historical and cultural influences, reflecting the relationships between society, people, and land (Payne, 2002). Land and agriculture form a large share of rural livelihoods in Uganda: for example, about 80 % of rural households are classified as agricultural households (UBOS, 2019).

However, in many rural areas, unclear or contested land rights have contributed to uncontrolled agricultural expansion (Flintan et al., 2021). In the Greater Virunga Landscape, such tenure insecurity and conflicts over land use pose significant challenges to conservation efforts, particularly in areas bordering protected areas (Verweijen & Marijnen, 2018).

Regarding cultural attitudes, some traditions promote coexistence with wildlife, while others create negative perceptions, particularly when wildlife damages crops or threatens livestock (Ndayishimiye et al, 2023; Sabuhoro et al., 2023; Kolinski et al, 2021). These social dimensions often determine local willingness to support corridor conservation programs (Ochieng et al., 2021). Studies have shown that improving the quality of life for forest communities, for example, near mountain gorilla habitats, can increase perceptions of human-wildlife conflict, possibly due to increased funding for community development programs being associated with conflict (Sabuhoro et al., 2023).

4.1.1.5 Economic dependence on natural resources

High poverty levels and limited livelihood alternatives in many corridor-adjacent communities drive dependence on natural resources for survival (Ijang & Ndikumagenge, 2013; Baker et al, 2013). Households often rely on firewood, charcoal, and bushmeat to meet daily needs (Plumptre et al, 2021). In areas where conservation restrictions limit resource access, people may perceive protected areas and corridors as sources of lost opportunity. Empirical studies have shown that livelihood diversification programs and conservation-compatible enterprises (e.g., beekeeping, eco-tourism, and sustainable agriculture) can reduce illegal extraction and improve corridor stewardship (Nampindo et al., 2022; Plumptre et al., 2021). In the case of lions, livestock production emerged as a significant factor affecting their use of the corridors. Expansion of grazing areas into wildlife zones increases direct competition with wild prey species and heightens livestock depredation risks (Hickey et al., 2021; Treves & Karanth, 2003). These dynamics reduce prey availability and lead to retaliatory killings of lions, thereby weakening corridor viability. The reviewed studies consistently show that combined social and economic pressures result in habitat fragmentation, reduced connectivity, and altered animal movement patterns.

4.1.2 Threats to the corridors

This section summarizes the major threats affecting the status and functional connectivity of the corridors (20) in relation to the target species in the Greater Virunga Landscape. Globally, biodiversity is being threatened by five major stressors i) habitat loss and degradation (e.g., crop and livestock farming, settlements), ii) invasive species, iii) overexploitation (e.g., hunting, logging, fishing), iv) pollution, and v) climate change (Bellard et al., 2022; Hartfoot et al 2021; Maxwell et al., 2016). The conservation action plan for the Albertine Rift identified habitat loss and degradation, poaching, logging, oil and geothermal exploration, and invasive plant species as the primary threats to the conservation of biodiversity within the Greater Virunga Landscape (Plumptre et al., 2016).

The Queen Elizabeth Conservation Area action plan identified threats affecting the status and functional connectivity of corridors based on the target species - i) elephants (poaching, habitat loss, civil war, narrow corridors); ii) lions (poaching, poisoning, diseases); iii) chimpanzees (poaching, habitat loss; WCS, 2008). As such, habitat loss and poaching are the major threats affecting the conservation of biodiversity in the Greater Virunga Landscape.

The Queen Elizabeth Conservation Area corridor action plan highlighted seven corridors (i.e., Ishasha, Bwera, Muhokya, Dura, Kyambura - Kasyoha Kitomi; Kyambura gorge, Kasyoha Kitomi – Kalinzu) that provide ecological connectivity between and within protected areas for large mammals - especially lions, chimpanzees, and elephants in the Greater Virunga Landscape (WCS, 2008). The identified corridors were categorized based on the major habitat types – i) savanna (ie., Ishasha, Bwera, Muhokya, Dura), ii) forest (i.e., Kyambura – Kasyoha Kitomi, Kyambura gorge, Kasyoha Kitomi – Kalinzu). The savanna corridors are important for elephants and lions, while the forest corridors are important for elephants and chimpanzees.

Habitat loss and degradation – Landcover and land use maps (1995, 2001, 2005, 2010, 2015, 2017, 2019, 2021) for the Greater Virunga Landscape showed that most of vegetation within protected areas had remained natural (i.e., unmodified) while agriculture and settlements dominated the surrounding areas (Christensen, & Arsanjani, 2020; Musavandalo et al., 2024; Plumptre et al., 2017). However, within protected areas - Virunga National Park has experienced the most habitat loss and degradation mainly due to agricultural expansion– especially in north, central (bordering lake Edward), and southern sectors (Christensen, & Arsanjani, 2020; Plumptre et al., 2017). Furthermore, the Mwaro – Mikeno corridor (Virunga National Park) experienced rapid habitat loss and degradation in 2004 with an estimated 15km2 of tropical high forest cleared for agriculture, cattle grazing, settlements, firewood due to a civil war (Mubalama & Mbula, 2005). Another area in that has experienced rapid habitat loss and degradation due to agriculture expansion, timber harvesting, charcoal production, and increased poaching for bushmeat is the Sarambwa Wildlife Reserve (32km2, DRC) that's contiguous with Bwindi Impenetrable National Park (Uganda) in Uganda (Berggorilla & Regenwald Direkthilfe, 2020). Consequently, habitat loss and degradation leads to the decline in ecological connectivity between and within protected areas. Another form of habitat degradation is encroachment due to livestock grazing in the protected areas - which increases the probability of human-carnivore conflict resulting into retaliatory killings through poisoning (Schwartz,2024; Moreto, 2013).

Poaching for bushmeat and ivory - Poaching in the Greater Virunga Landscape increased drastically during the civil war in the 1970's and early 1980's in Uganda, and in the1990's for the Democratic Republic of Congo and Rwanda (Plumptre et al., 1997; Mubalama & Norbert Mushenzi, 2004; UWA, 2018). Although wildlife populations have largely increased or are stable within the Greater Virunga Landscape protected areas (UWA, 2018; Hickey et al., 2019a; Hickey et al., 2019b), except for some sectors in Virunga National

Park – poaching still remains a major concern. Using ranger-based monitoring data collected between 1999 - 2012, the spatial probability of occurrence of subsistence and commercial hunting was modeled and predicted across the Greater Virunga Landscape (Plumptre et al., 2017; Plumptre et al., 2014; Critchlow et al., 2015). The results showed that poaching was prevalent along the Ishasha corridor, Muhokya corridor; Kyambura – Kashyoha Kitoma corridor, Bwera corridor, Virunga north and south.

Aggregated threats - the spatial distribution and probability of occurrence for nine threats (i.e., snares, carcasses by poachers, poachers' camps, timber harvesting, charcoal making, harvesting of non-timber forest products; cultivation; livestock grazing, mining activities) were modeled and predicted across the Greater Virunga Landscape using Ranger based monitoring data collected over a 10 year period (2000 – 2012; Plumptre et al., 2017; Plumptre et al., 2014). The highest probability of occurrence for all the nine threats combined across the Greater Virunga Landscape was predicted to occur along the following areas – protected area boundaries, Virunga North (transition zone between forest and savanna habitats), Virunga South (area between Rutshuru and Katanda), Virunga Central (bordering lake Edward), Muhokya corridor, Bwera corridor, Kalinzu – Kashyoha Kitomi corridor, Kyambura – Kashyoha Kitomi corridor, Mwaro - Mikeno corridor, and the entire Kashyoha Kitomi Forest Reserve. Similarly, a study conducted in Queen Elizabeth National Park using Ranger-based monitoring data for the period between 1998 and 2013, mapped and predicted the occurrence of illegal activities (Critchlow et al., 2015). The results of the study showed that encroachment (i.e., cattle grazing withing the park) was mostly affecting Muhokya, Bwera and Dura corridors; while poaching was mostly prevalent within Bwera, Muhokya, Kyambura – Kasyohi Kitomi, and Dura corridors. The 2024/25 – 2033/2024 Queen Elizabeth Protected Area general management highlighted - expanding human settlements within the Muhokya corridor as a major threat to the movement of elephants (UWA, 2024).

4.1.3 Governance structures

The GVL encompasses an intricate mosaic of protected areas and wildlife corridors shared by Uganda, the Democratic Republic of Congo (DRC), and Rwanda. Governance of these areas integrates multiple institutions: the Uganda Wildlife Authority (UWA), Institute Congolais pour la Conservation de la Nature (ICCN; DRC), Rwanda Development Board (RDB; Rwanda), and the National Forestry Authority (NFA; Uganda), (Figures 2, 3). The Greater Virunga Transboundary Collaboration (GVTC) Treaty (GVTC, 2015) formalizes cross-border cooperation among these bodies.

The governance typology within the Greater Virunga Landscape (GVL) closely follows the framework developed by the International Union for Conservation of Nature (IUCN). This framework recognizes multiple forms of authority and responsibility in the management of protected and connected ecological areas, reflecting the diversity of institutions and communities involved across the transboundary landscape.

State or Public Governance

State or public governance refers to areas that fall directly under governmental authority. In the GVL, this includes national parks and wildlife reserves managed by statutory conservation agencies such as the UWA, the ICCN in the Democratic Republic of Congo, and the RDB. These agencies hold legal mandates to enforce conservation regulations, oversee resource use, and coordinate biodiversity protection within national boundaries.

Private Governance

Private governance encompasses conservation areas that are managed by private organizations or non-governmental entities. These may include private reserves, conservancies, or projects led by NGOs such as the Virunga Foundation, which operates under a management partnership with ICCN in Virunga National Park. Such arrangements often blend conservation objectives with investment in sustainable livelihoods, eco-tourism, and community-based initiatives.

Indigenous Peoples and Local Communities (IP&LCs)

Governance by Indigenous Peoples and Local Communities acknowledges the traditional and customary rights of local populations living adjacent to or within protected landscapes. In Uganda, this is often implemented through Collaborative Forest Management (CFM) agreements, where the NFA partners with local forest user groups to jointly manage Central Forest Reserves such as Kasyoha-Kitomi and Kalinzu. These arrangements provide communities with recognized access rights, responsibilities for resource stewardship, and opportunities for benefit sharing.

Co-governed or Shared Governance

Co-governed or shared governance involves formal partnerships that distribute authority and decision-making among multiple actors. In the GVL, such arrangements are exemplified by the GVTC, which coordinates joint conservation actions among UWA, ICCN, and RDB. Other forms include co-management agreements at site level, where communities, private operators, and state authorities work together through joint management committees or memoranda of understanding. These shared governance systems are essential for addressing ecological connectivity, law enforcement coordination, and human–wildlife coexistence across borders.

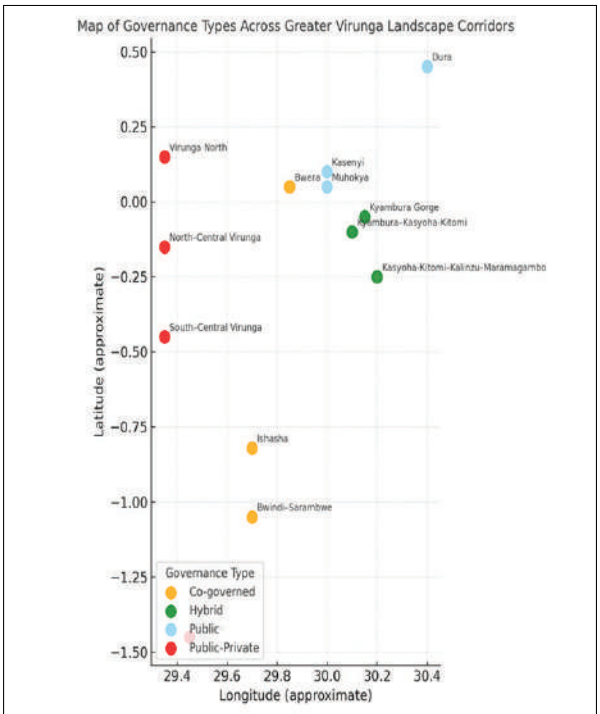


Figure 2: Schematic visualization of governance types across the main wildlife corridors of the Greater Virunga Landscape (GVL).

Each corridor is symbolized by its predominant governance arrangement. Blue = Public governance (e.g., UWA, ICCN, RDB), Orange = Co-governed/transboundary (e.g., ICCN & UWA), Green = Hybrid (e.g., NFA–UWA with CFM/IP&LC involvement), Red = Public–Private (e.g., ICCN–Virunga Foundation)

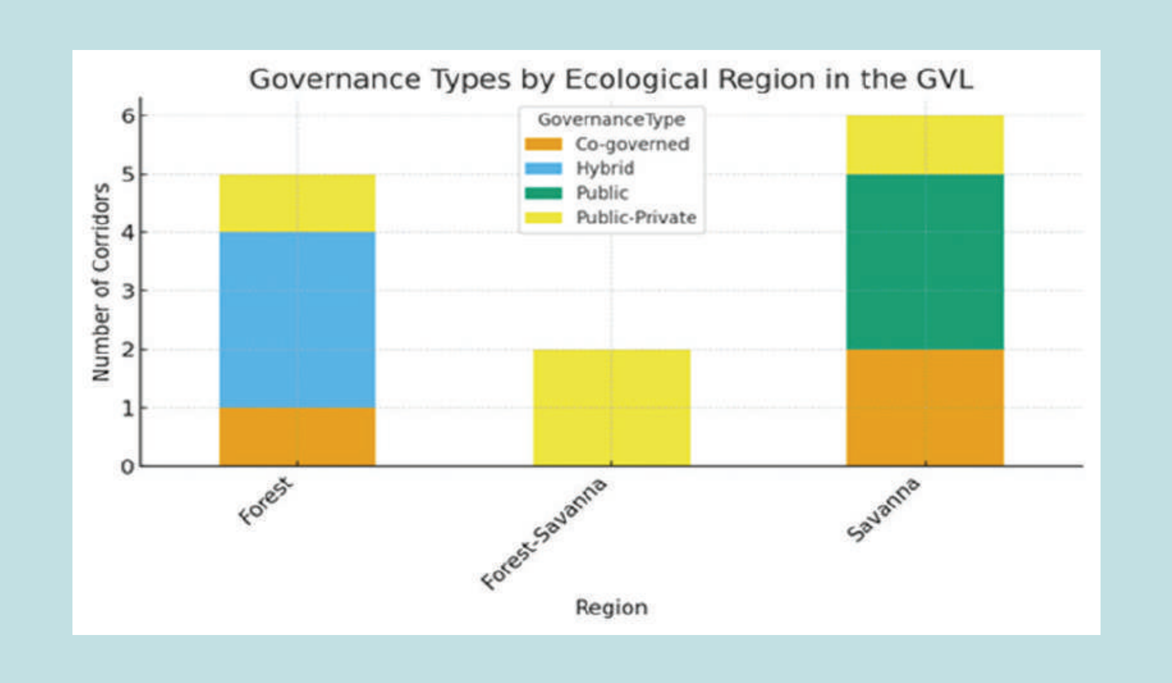


Figure 3: Governance types by ecological region.

Forest corridors show greater hybrid and co-governed structures due to overlapping mandates between NFA, UWA, and community-based CFM frameworks.

4.1.4 Vegetation of the Greater Virunga Landscape

Vegetation in the Greater Virunga Landscape is a function of the broad elevational gradient that ranges between 600 – 5100m a.s.l (Plumptre et al 2016). At the highest elevation there is alpine vegetation (approx. 3600 m and above), which gives way to sub-alpine vegetation that is dominated by giant Lobelia and giant heather (approx. 3000 – 3600m), followed by bamboo forest, and montane forest respectively (approx. 2000–3000 m; Owiunji et al., 2003). At medium to low elevations (2000 – 600m), the vegetation types are characterized by medium altitude rainforest, savannah habitat (i.e., grassland and woodland) and lowland rainforest (Figure 4). Outside protected areas, most of the natural vegetation has been converted to other forms land use mainly for agriculture and settlements (e.g., Christensen, & Arsanjani, 2020).

At low elevations, there has been an increase in woody vegetation, especially in Queen Elizabeth National Park that is attributed to the decline in the population of elephants in the 1970's and potential impacts of climate change (Ponce-Reyes et al 2017; Plumptre et al 2017; Lock, 1993). Climate in the Albertine Rift eco-region is predicted to be warmer and wetter towards the end of the 21st century and therefore likely to influence the spatial distribution of vegetation and the resident fauna (Ponce-Reyes et al 2017; Seimon & Picton Phillips, 2012).

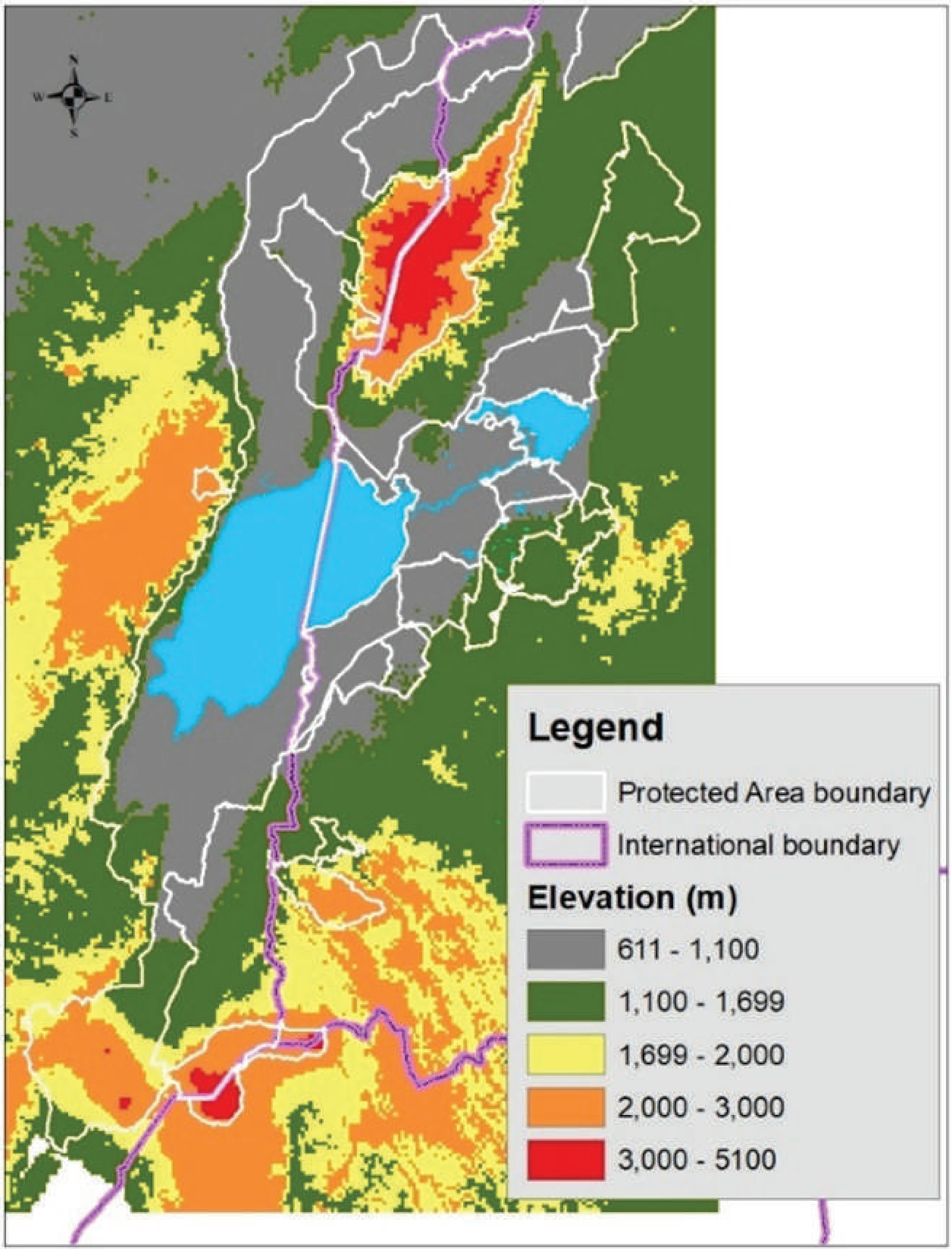


Figure 4: Elevation gradient across the Greater Virunga Landscape that is characteristic of specific vegetation types

4.1.5 Distribution, abundance and trends of key wildlife species

The primary species of focus for this study are - lion (*Panthera leo*), elephants (*Loxondota Africana & Loxondota cyclotis*), chimpanzees (*Pan troglodytes*), and mountain gorilla (*Gorilla beringei ssp. beringei*).

Lion (*Panthera leo*) - The conservation status of lions is listed as Vulnerable on the International Union for the Conservation of Nature Red List due to range contraction (more than 90% of its historical range), population declines, prey depletion, retaliatory killings, and poaching (Nicholson et al. 2023). The current ranging patterns of lions in the Greater Virunga Landscape includes Queen Elizabeth National Park, Kigezi Wildlife Reserve, Kyambura Wildlife Reserve, and Virunga National Park. The lion population in Queen Elizabeth National Park has experienced a steep decline from 200 individuals in 2004 to 39 individuals in 2022 (Figure 5; UWA, 2024). Given the current decline of lions in Queen Elizabeth Protected Area, it is plausible that lion populations in Virunga National Park have also declined due meta-population dynamics.

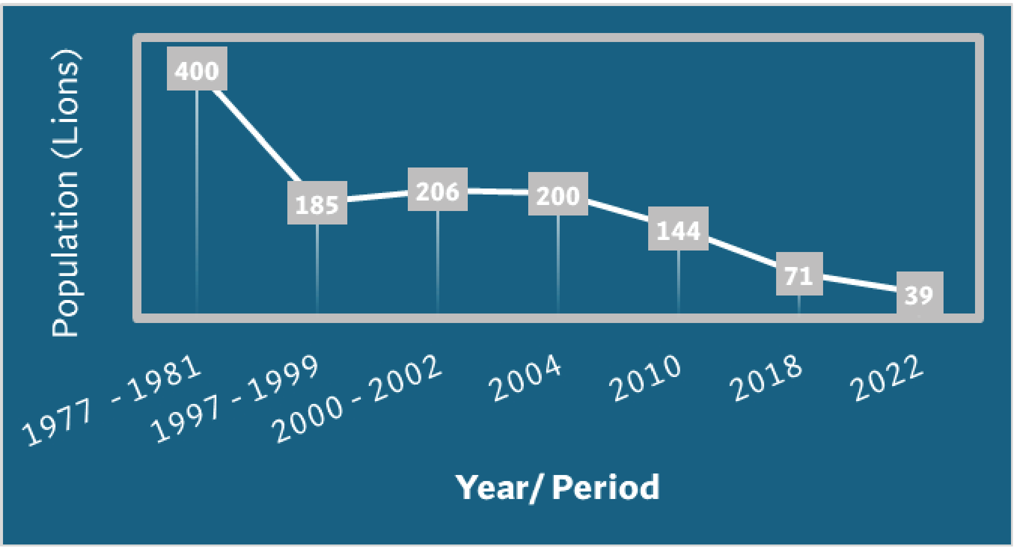


Figure 5: Population trend of lions in Queen Elizabeth Protected Area (i.e., Queen Elizabeth National Park, Kigezi Wildlife Reserve, Kyambura Wildlife Reserve). Source: UWA (2024)

African elephant – The Greater Virunga Landscape has two species of elephants: African savanna elephant (Loxondota Africana) that inhabits mainly savanna habitats, and the African Forest elephant (Loxondota cyclotis) that primarily inhabits forest habitats (Gobus et al., 2021a; 2021b). Although these species co-occur at savannah-forest ecotones, hybridization seems to be low (Gobus et al., 2021b; Kuhner et al., 2025). One of the sites where the two species and their hybrids were found to occur is Kibale National Park in western Uganda (Bonnald et al., 2022; Kuhner et al., 2025).

The two species of African elephants and/ their hybrids are widely distributed within the Greater Virunga Landscape having been recorded in almost all the protected areas. The African savanna elephant is classified as endangered, while African Forest elephant is classified as critically endangered on the International Union for the Conservation of Nature Red List due to habitat loss and degradation (range contraction) and poaching for ivory (Gobush et al., 2021a, Gobush et al., 2021b). Although elephants are declining throughout most of their range, their populations have been increasing in Queen Elizabeth National Park (Figure 6).

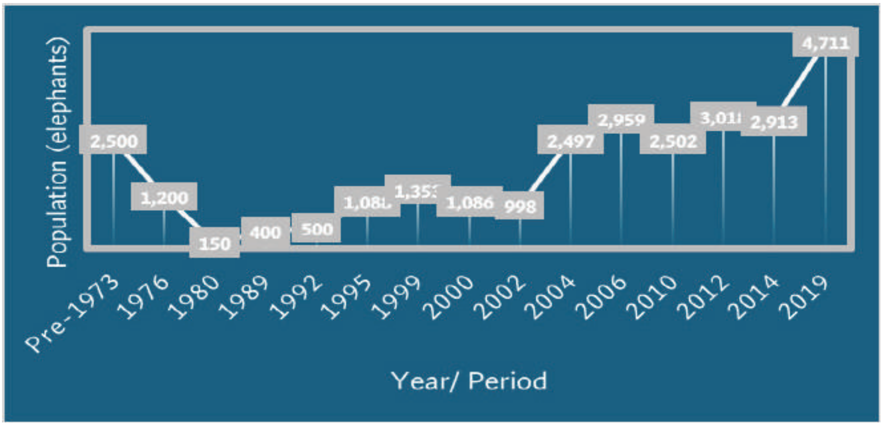


Figure 6: Population trend of elephants in Queen Elizabeth Protected Area (i.e., Queen Elizabeth National Park, Kigezi Wildlife Reserve, Kyambura Wildlife Reserve). Source: UWA (2024); Lamprey et al 2023

Chimpanzees (***Pan troglodytesi***) - The conservation status of chimpanzees is listed as endangered on the International Union for Conservation of Nature Red List due to poaching, habitat loss and degradation, and diseases (Humle et al 2016). Within the Greater Virunga Landscape, the chimpanzees occur in Kibale National Park, Bwindi Impenetrable National Park, Virunga National Park, Rwenzori National Park, Maramagambo and Kalinzu Forest Reserves, Kashyoha Kitomi Forest Reserve and Kyambura Wildlife Reserve. The population of chimpanzees are either stable or increasing in some of the key protected areas (Figure 7; Nangendo et al., 2022, Plumptre et al., 2003)

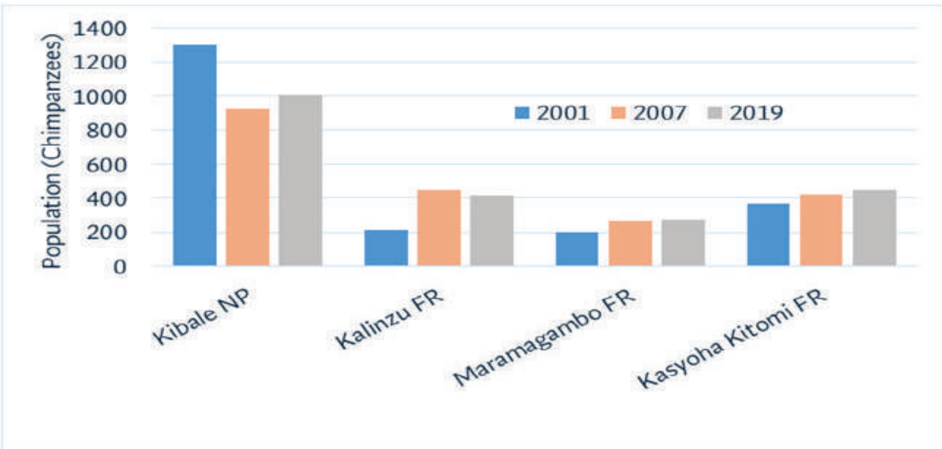


Figure 7: Population trend of chimpanzees in four protected areas in the Greater Virunga Landscape. (Source: Plumptre et al 2003, Wanyama et al, Nagendo et al., 2022)

Mountain gorilla (Gorilla beringei ssp. beringei) – Mountain gorillas are classified as endangered on the International Union for the Conservation of Nature Red List due to human Intrusions & disturbance, diseases, poaching, human-gorilla conflicts, habitat degradation and destruction, and the emerging impacts of climate change (Hickey et al., 2020). The distribution of mountain gorillas is restricted to two populations that inhabit transboundary protected areas within the Virunga Massif, and Bwindi – Sarambwe ecosystems. Virunga Massif encompasses Virunga National Park, Volcanoes National Park and Mgahinga Gorilla National Park and the Bwindi – Sarabwe ecosystem consists of Bwindi Impenetrable National Park and Sarambwe Nature Reserve. The population of mountain gorillas has been steadily increasing since the 1990s (Figures 8, 9; UWA (2018); Hickey et al 2019a; 2019b; Robbins et al., 2011)

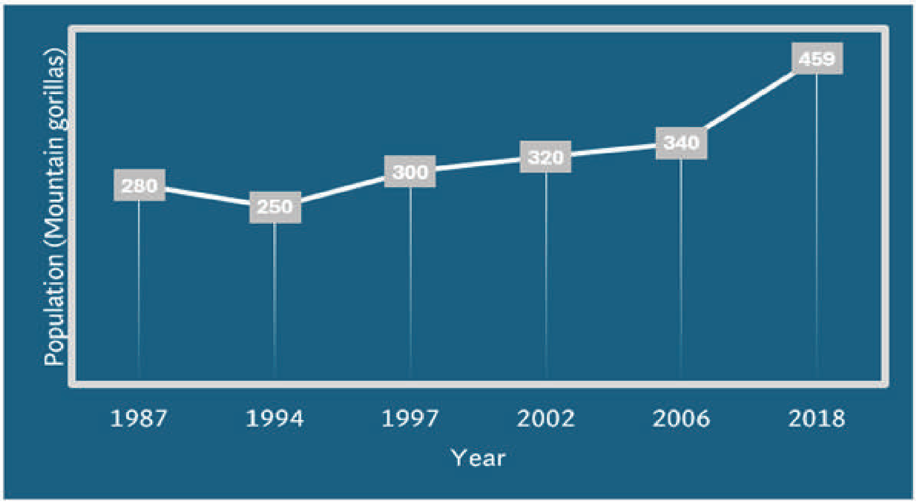


Figure 8: Population trend of Mountain gorillas in the Bwindi – Sarabwe ecosystem (Source: UWA (2018); Hickey et al 2019a)

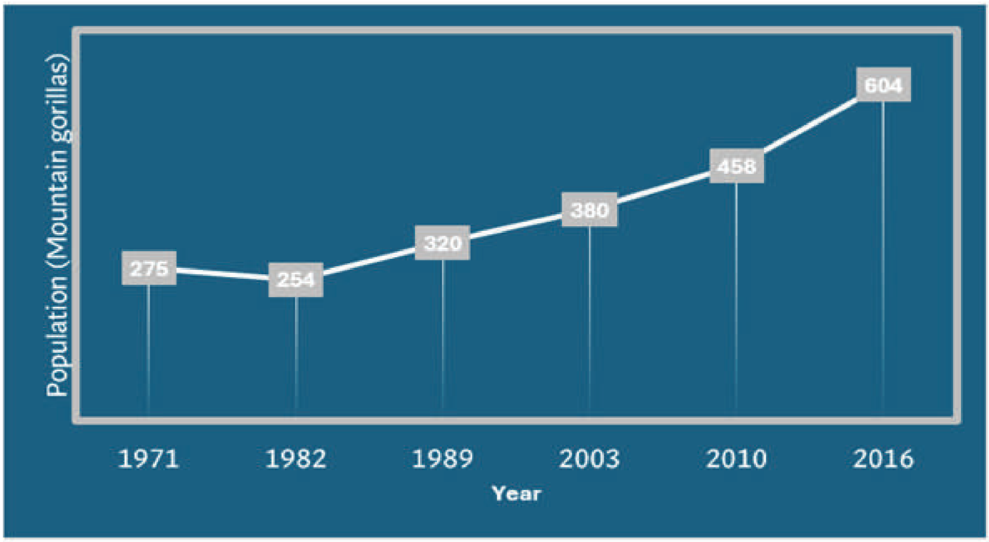


Figure 9: Population trend of Mountain gorillas in the Virunga Massifa (Hickey et al., 2019b; Robbins et al., 2011)

4.1.6 Ecological data associated with each corridor link.

Using Google scholar, we obtained a total of 33 reports and publications that contained ecological information describing the spatial distribution and abundance of lion, elephant, chimpanzee, and mountain gorilla populations within the Greater Virunga Landscape for the period between 1928 to 2023 (Table 2). Of the 33 reports and publications - 54% (18) contained biodiversity data on elephant populations, 27 % (9) on lion populations, 24-% (8) on chimpanzee populations, and 9% (3) on mountain gorilla populations.

The ecological data sourced from the Wildlife Conservation Society Uganda Program contained:- i) Lion telemetry data (14 individuals) – information on movement and distribution of lions in Queen Elizabeth and Virunga National Parks (2006 – 2011, 2018 – 2019); ii) Chimpanzee and elephants' data – information on occurrence, distribution, and abundance in Kalinzu, Maramagambo and Kasyoha Kitomi Forest reserves, Kibale National Park, Rwenzori National Park, and Kyambura Wildlife Reserve (1999, 2000, 2006, 2019, 2020). We obtained species occurrence data (2000 – 2022); on lions, elephants, chimpanzees and mountain gorillas from the Uganda Wildlife Authority collected under the Ranger monitoring program.

We used spatial overlay analysis (distribution map) to assess the current habitat use of the seven target corridors (Figure 1; Table 2), and to identify thirteen potential new corridors that are associated with the target species (lions, elephants, chimpanzees, mountain gorillas) within the Greater Virunga Landscape (Table 2; Figures 10, 11, 12, 13). The potential new corridors were identified based on whether: the species occurrence records intersected with site, the site was a narrow tract of land compared to the surrounding areas, and/ or the site was highly threatened by human activities (e.g, habitat degradation and poaching). We assessed the status and functional connectivity of 20 corridor sites, and categorized them as realized or potentially functional depending on whether recent (2015 -2025) species occurrence records intersected with the site. Thus, fifteen corridors were classified as realized, while five were classified as potentially functional. The twenty corridors are:

1. Ishasha corridor (savanna) – links southern QENP to VNP (Realized)
2. Bwera corridor (savanna) – links northern QENP to Virunga NP (Realized)
3. Muhokya corridor (savanna) - within northern QENP (Realized)
4. Dura corridor (savanna) - links northern QENP to Kibale NP (Realized)
5. The Kyambura - Kasyoha Kitomi corridor (forest; Realized)
6. Kyambura Gorge corridor - Kasyoha Kitomi (forest, Potentially functional)
7. Kasyoha-Kitomi - Kalinzu-Maramagambo corridor (forest) - (Potentially functional)
8. Bwindi – Sarambwe (Realized)

9. Mikeno corridor (forest) - within Southern Virunga NP (Realized)
10. Kisenyi corridor (forest) - within central QENP (Realized)
11. Virunga north (forest – savanna ecotone) - within Virunga NP (Potentially functional)
12. Virunga central (savanna) - within Virunga NP (Potentially functional)
13. Virunga south (forest – savanna ecotone) - within Virunga NP (Potentially functional)
14. Katwe corridor (savanna) – within QENP (Realized)
15. The neck (forest, Realized) – within Bwindi Impenetrable National Park
16. Virunga – Semliki (forest, Realized)
17. Rwenzori – Toro Semliki (savanna, Realized)
18. Volcanoes -Mgahinga (forest, Realized)
19. Virunga – Mgahinga (forest, Realized)
20. Volcanoes - Virunga (forest, Realized)

Table 2: Reports and peer reviewed publications on the occurrence, distribution and abundance of elephants, lions, chimpanzees, and mountain gorillas within the Greater Virunga Landscape.

The number in the target corridor column represents: 1 = Ishasha ; 2 = Bwera; 3 = Muhokya; 4 = Dura ; 5 = Kyambura - Kasyoha-Kitomi; 6 = Kyambura Gorge; 7= Kasyoha-Kitomi & Kalinzu-Maramagambo ; 8 = Bwindi – Sarambwe; 9 = Mikeno; 10 = Kisenyi; 11 = Virunga North; 12 = Virunga central, 13 = Virunga south, 14 = Katwe, 15 = The Neck, 16 = Virunga – Semliki, 17 = Rwenzori – Toro Semliki, 18 = Volcanoes – Mgahinga, 19 = Virunga – Mgahinga, 20 = Volcanoes - Virunga

Species	Target corridor	Year	Summary	Reference
Elephants & Chimpanzees	7	2007, 2021	Ground counts - abundance and distribution	Ayebare et al., 2025
Elephants	2, 3, 4, 7, 5	1929, 1959	Ranging patterns and movement of elephants	Brooks & Buss., 1962
Elephants	2	1968	Aerial surveys - abundance and distribution	Eltringham (1972)
Elephants	2, 1, 3	1970's	Aerial surveys - abundance and distribution	Eltringham & Malpas., 1980
Elephants	1	1998	Ground counts - abundance and distribution	Mubalama (2000).
Elephants & Chimpanzees	4	2005	Ground counts - abundance and distribution	Wanyama (2005)
Elephants	1	2006	Aerial surveys - abundance and distribution	Wanyama (2006)

Species	Target corridor	Year	Summary	Reference
Elephants	1, 2, 4	1960's, 1980's, 2000's	Population trend - Abundance and distribution	Plumpre et al., 2007
Elephants	1, 2	2010	Aerial surveys - abundance and distribution	Plumpre et al., 2010
Elephants	1	2014	Aerial surveys - abundance and distribution	Wanyama et al., 2014
Elephants	1, 2, 5	2018	Aerial surveys - abundance and distribution	Lamprey et al., 2023
Elephants	1, 2, 4, 5	2001 - 2014	action plan - abundance and distribution	UWA (2026)
Elephants	1	2001 - 2003	Migration routes	Keigwin et al., 2016
Elephants	9	2003 - 2004	Ground counts - abundance and distribution	Owiunji et al., 2005
Elephants	8	2020	Field notes	Berggorilla & Regenwald Direkthilfe (2020).
Lions	1, 2	2006 - 2011; 2018 - 2019	Home range analysis of lions	Ayebare et al., 2020
Lions	1, 2	1999 - 2006	Occurrence and abundance of lions	Treves et al., 2009
Lions	1	2009	Ground counts - abundance and distribution	Omoya et al., 2014
Lions	1	2005 - 2015	Home range analysis of Ishasha lions	Mudumba et al., 2015
Lions	1, 2	2018	Ground counts - abundance and distribution	Braczkowski et al., 2020
Lions	1	1998	Ground counts - abundance and distribution	Dricuru et al., 1999
Lions	1	2022	Ground counts - Carnivore action plan	UWA (2024)

Species	Target corridor	Year	Summary	Reference
Lions	1	1977, 1979	Distribution of lions - Mweya and Ishasha	Orsdol (1984)
Lions	1, 2, 3	2001 - 2009	Ground counts - Carnivore action plan	UWA (2010)
Chimpanzees	7, 5	2001 - 2002	Status of chimpanzees in Uganda - abundance and distribution	Plumptre et al., 2003
Chimpanzees	6; 7, 5; 8	2019 - 2020	Ground counts - abundance and distribution	Nagendo et al., 2022
Chimpanzees	7, 8	2001 - 2008	Chimpanzee action plan - abundance and distribution	Plumptre et al., 2010
Elephants & Chimpanzees	7	2008	Ground counts - abundance and distribution	Plumptre et al., 2008
Chimpanzees	6; 7; 5,8	1980 - 1990	Status of chimpanzees in Uganda - population viability	Edroma et al., 1997
Mountain Gorillas, Chimpanzees & Elephants	8,15	2018	Ground counts - abundance and distribution	Hickey et al., 2019a
Elephants	9, 18, 19, 20	2015-2016	Ground counts - abundance and distribution	Hickey et al., 2019b
Mountain Gorillas	8	1997, 2002	Ground counts - abundance and distribution	McNeilage et al., 2006
Mountain Gorillas	9	1959 - 1978	Population trend	Weber, A. W., & Vedder, 1983
Elephants, lions, chimpanzee	1,2,3,4,5,6,7, 8,9,10,14	1999 - 2020	Aerial and ground counts, telemetry data, camera trap data	Wildlife Conservation Society

Species	Target corridor	Year	Summary	Reference
Mountain Gorillas, Chimpanzees, Elephants & Lions	1,2,3,4,5,6,7, 8,9,10,11,12,13, 14,15,16,17,18,19,20	2000 - 2012	Ranger monitoring data	Uganda Wildlife Authority, Institut Congolais pour la Conservation de la Nature, Rwanda Development Board

Corridor – Summary

1. **Ishasha corridor (savanna):**– This is a transboundary corridor that connects southern QENP in Uganda to Virunga NP in the DRC. The target species using this corridor are elephants, lions, and occasionally chimpanzees (possibly dispersing from Maramagambo Forest Reserve) that reside along the riverine forest of the Ishasha river.

2. **Bwera corridor (savanna):**– This is a transboundary corridor that links northern QENP in Uganda to Virunga NP in the DRC. The target species using this corridor are elephants, and lions.

3. **Muhokya corridor (savanna, Uganda)** :– Measures approximately 500m at its narrowest point and is located west of lake George. It connects the Kasenyi and Dura sectors within QENP, enabling the movement of two target species (lions and elephants).

4. **Dura corridor (savanna, Uganda)** :- Located north of lake George and links QENP to Kibale National Park. We documented corridor habitat use by elephants and occasionally chimpanzees.

5. **The Kyambura - Kasyoha Kitomi corridor (forest, Uganda)** :– Links Kyambura Wildlife Reserve to Kashyoha Kitomi Forest Reserve through a narrow tract of land (forest habitat) that measures 350m at its narrowest point. The target species using this corridor are elephants and chimpanzees.

6. **Kyambura Gorge - Kasyoha Kitomi corridor (forest, Uganda)** :- Links Kyambura Wildlife Reserve to Kashyoha Kitomi Forest Reserve along Kyambura riverine forest. The target species potentially using this corridor are chimpanzees and elephants.

7. **Kasyoha-Kitomi - Kalinzu-Maramagambo corridor (forest, Uganda)** - Links Kashyoha Kitoma Forest Reserve to Kalinzu and Maramagambo Forest Reserves. The land use of three-kilometer corridor is currently plantation forestry (eucalyptus and pine) under the Collaborative Forest Management of the National Forestry Authority. The target species using this corridor are chimpanzees.

8. **Bwindi – Sarambwe (forest)** – This is transboundary corridor that Links Bwindi Impenetrable National Park in Uganda to Sarambwe Nature Reserve in the DRC. The target species using this corridor are mountain gorillas, chimpanzees and elephants.

9. **Mikeno corridor (forest, DRC)** – Measures approximately 1.6km at its narrowest point and is located in southern Virunga National Park. It connects the Mikeno and southern sectors within VNP, enabling the movement of elephants.

10. **Kisenyi corridor (forest, Uganda)** – Located within QENP and refers to the ishasha road section that is bordered by lake Edward in the west and Maramagabo Forest Reserve in the east. The Ishasha road is used by lions moving between the northern and southern sectors of QENP as they are avoiding forest habitat (Maramagambo Forest Reserve).

11. **Virunga north (forest – savanna ecotone, DRC)** :– Located north of Lake Edward and links the forest and savanna habitats of northern sector Virunga National Park. Virunga north corridor is highly impacted by habitat loss and degradation. The target species using this corridor are elephants.

12. **Virunga central (savanna, DRC)** :– Located on the western shores of Lake Edward and links the northern and southern sectors of Virunga National Park. Virunga central is highly degraded. The target species using this corridor are elephants.

13. **Virunga south (forest – savanna)** :- Located south of Lake Edward and links the forest and savanna habitats of southern Virunga National Park. Virunga south corridor is highly impacted by habitat loss and degradation. The target species using this corridor are elephants.

14. **Katwe corridor (Savanna, Uganda)** – Measures approximately 1.3km at its narrowest point and is located north of Katwe salt lake. It connects the crater and Bwera sectors within QENP, and enables the movement of two target species (lions and elephants).

15. **The neck (forest, Uganda)** – Located within Bwindi Impenetrable National Park and measures approximately 800m at its narrowest point. It connects the southern and northern sectors of Bwindi Impenetrable National Park.

16. **Virunga – Semliki (forest)** - This is a transboundary corridor that connects southern Semliki National Park in Uganda to Virunga NP in the DRC. The target species using this corridor are elephants and chimpanzees.

17. **Rwenzori – Toro Semliki (savanna, Uganda)** - The Greater Virunga Landscape (Rwenzori and Semliki National Parks) borders the Murchison Semliki Landscape (Toro-Semliki Wildlife Reserve) in the north separated by approximately 9km. Literature review and species distribution data showed that there were elephants in both Rwenzori National Park and Toro-Semliki Wildlife Reserves. The target species using this corridor is elephants. We further assessed the potential corridor connectivity during the social survey.

18. **Volcanoes – Mgahinga (Rwanda, Uganda)** – This is a forest corridor that links Volcanoes National Park in Rwanda to Mgahinga Gorilla National Park in Uganda. The target species are elephants and mountain gorillas.

19. **Volcanoes** – Virunga (Rwanda, DRC) - This is a forest corridor that links Volcanoes National Park in Rwanda to Virunga National Park in the DRC. The target species are elephants and mountain gorillas.

20. **Virunga – Mgahinga (DRC, Uganda)** - This is a forest corridor that links Virunga National Park in the DRC to Mgahinga Gorilla National Park in Uganda. The target species are elephants and mountain gorillas.

Elephant Distribution

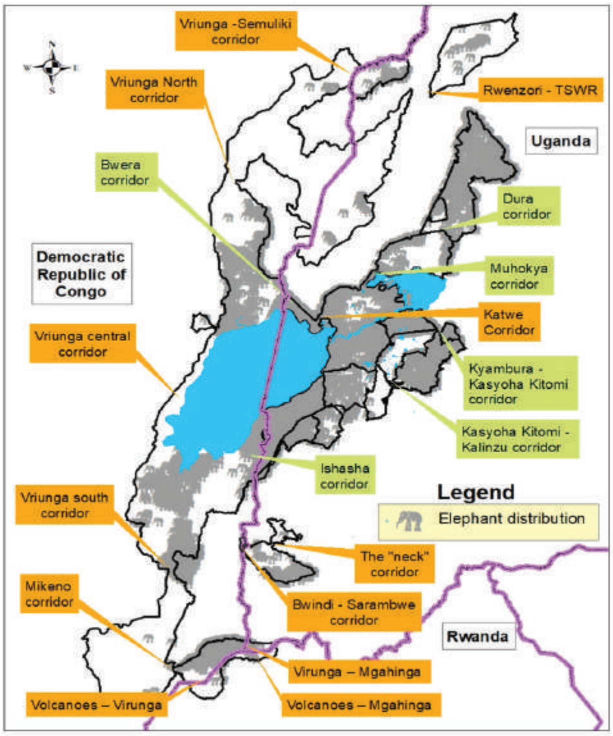


Figure 10: Distribution of elephants in the Greater Virunga Landscape and Toro-Semliki Wildlife Reserve

Corridors identified by WCS and partners in 2008 are shown in light green, while potential new corridors are shown in orange.

Lion Distribution

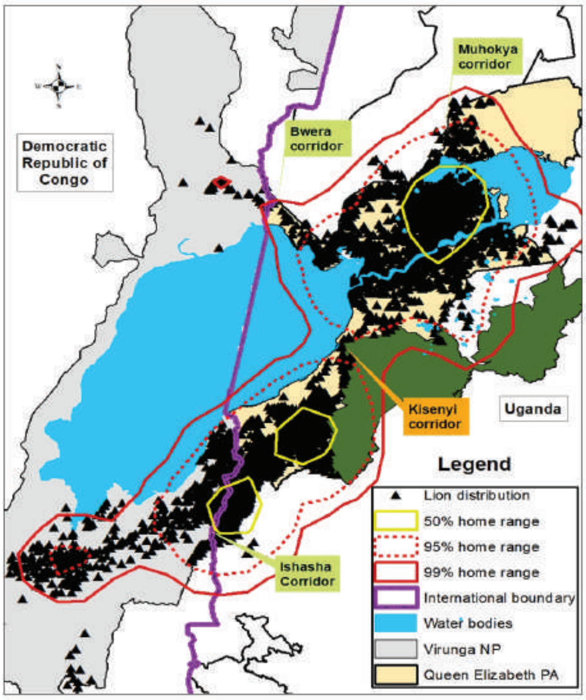


Figure 11: Ranging patterns of lions in the Greater Virunga Landscape

Chimpanzee Distribution

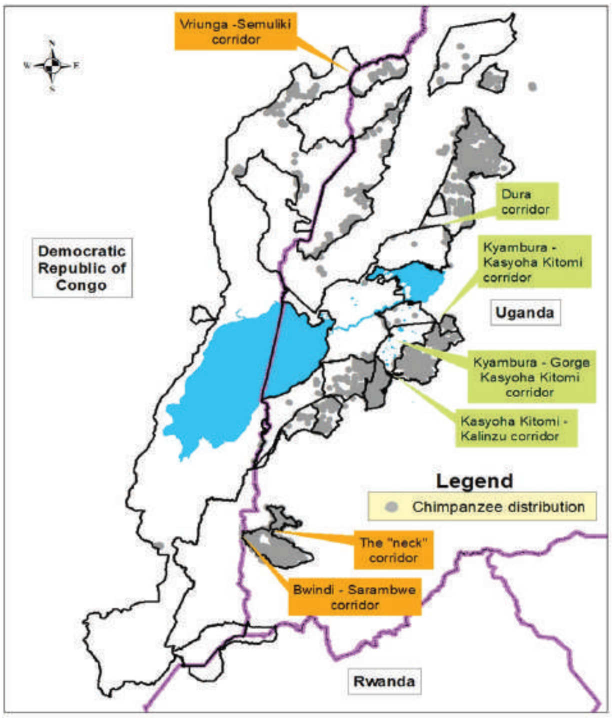


Figure 12: Distribution of chimpanzees in the Greater Virunga Landscape, and neighboring protected areas (Toro-Semliki Wildlife Reserve, and Itwara Forest Reserve)

Mountain Gorilla Distribution

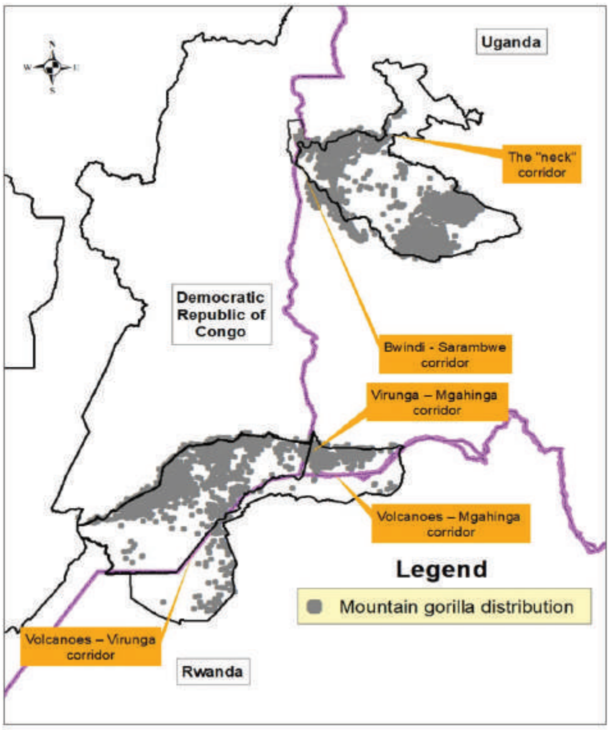


Figure 13: Distribution of mountain gorillas in the Greater Virunga Landscape

4.2 Field data Collection

4.2.1 Ecological survey results – species occurrence

A total of 18 kilometers were walked in seven target corridors (i.e,Bwera, Muhokya, Kyambura gorge - Kashyoha Kitomi, Kalinzu – Kashyoha Kitomi, Kyambura - Kashyoha Kitomi, Ishasha) to assess habitat use by the target species (lions, chimpanzees, elephants) and habitat integrity. The most frequently observed target species were elephants or their signs (dung), and they were recorded in five of the surveyed corridors, except for Kalinzu - Kashyoha Kitomi, and Kyambura - Kashyoha Kitomi (Figure 14). Corridor habitat use by chimpanzees (nest) was observed along the Kyambura river riverine forest (Kyambura gorge - Kashyoha Kitomi). There were no lion observations made during our survey, although the Uganda Wildlife Rangers confirmed their presence in Bwera, Muhokya and Ishasha corridors. Opportunistic observations about the presence of the target species were also made while driving within the corridor area.

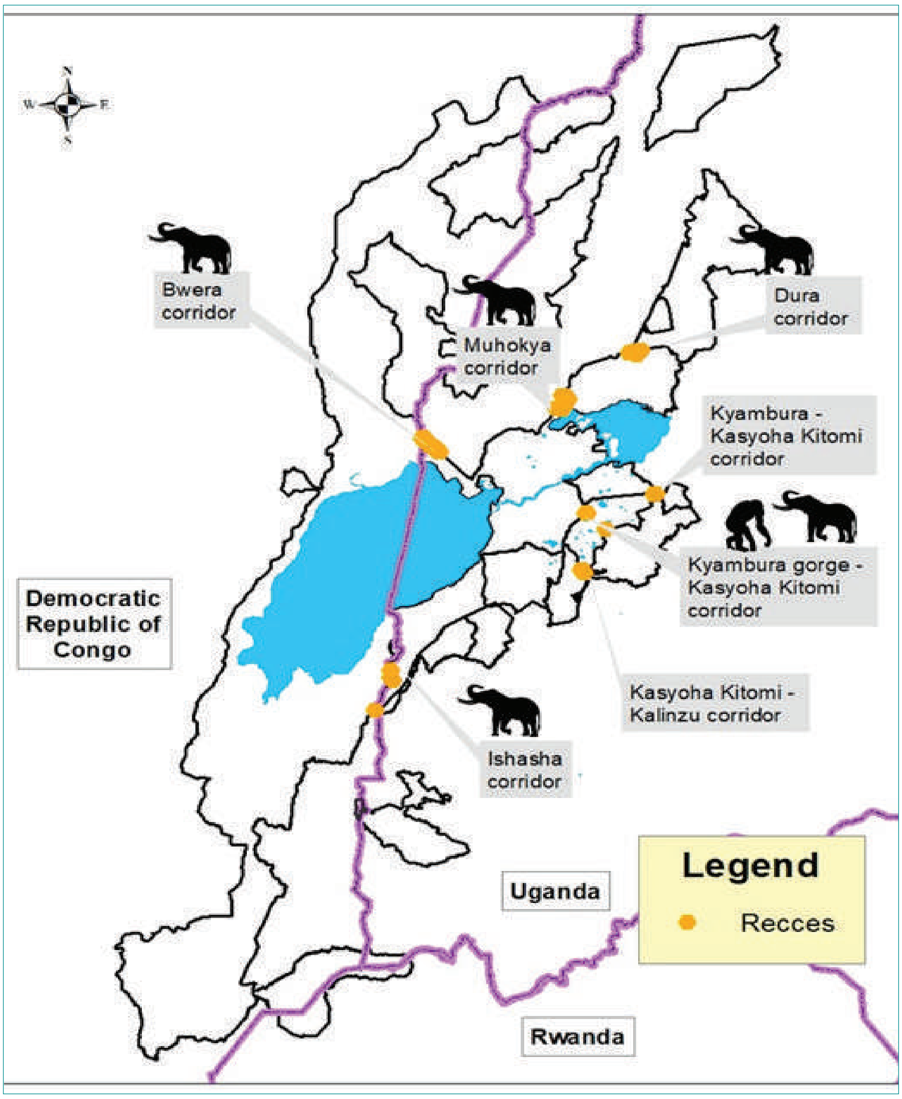


Figure 14: Locations of recces walked (orange points) during the ecological survey with silhouettes of species observed shown in black

4.2.2 Ecological survey results – habitat integrity

The Bwera corridor provides connectivity between the northern sectors of Queen Elizabeth National Park (Uganda) and Virunga National Park (DRC) across the Lhubiriha River that forms the boundary between Uganda and the Democratic Republic of Congo. The corridor habitat is unmodified, and is mainly dominated by grassland, wetland, and riverine forest habitats (Plate 1).

During the recce survey, we recorded corridor habitat use by the elephants, Uganda kob and buffalos. The Uganda Wildlife Authority constructed an electric fence along the northern boundary to mitigate human wildlife conflicts (Plate 1, bottom).

Plate 1: Major vegetation types within the Bwera corridor

Muhokya corridor is located west of Lake George and connects the Kasenyi and Dura sectors within Queen Elizabeth National Park. It measures approximately 500m at its narrowest point – wetland habitat (Plate 2, top). The corridors' vegetation is dominated by grassland, wooded grassland and wetland habitats.

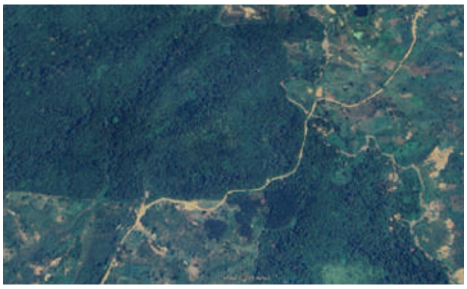
Uganda Wildlife Authority constructed an electric fence around the park boundary in the Muhokya corridor to mitigate human wildlife conflicts (Plate 2, bottom). We observed corridor habitat use in Muhokya by elephants, Uganda kob, bushbuck, waterbuck and buffalos.

Plate 2: Major vegetation types within the Muhokya corridor

Dura corridor is located north of Lake George and links Queen Elizabeth National Park to Kibale National Park. The major vegetation types include wetland, grassland, woodland, and forest habitats. We documented corridor habitat use by elephants and buffaloes.

Although, the vegetation is largely unmodified – future threats include the redevelopment of a railway line from Kampala to Kasese. There are remnant buildings of the former railway station that are currently being used as temporary housing for fishing.

Plate 3: Major vegetation types within the Dura corridor



Kyambura – Kashyoha Kitomi corridor links Kyambura Wildlife Reserve to Kashyoha Kitomi Forest Reserve through a narrow tract of land (forest habitat) that measures 350m at its narrowest point (Plate 4; top –from Google Earth). Buhindagi river and agriculture form the eastern border of the corridor, while the southwestern border in Kyambura Wildlife Reserve has been fenced with an electric fence to mitigate human wildlife conflict.

The major threat to the corridor is habitat conversion to agriculture and tree plantations (Plate 4, top). During the ecological recce survey, we recorded the presence of black & white colobus monkeys, and red tailed monkeys.

Plate 4: Landcover/use within the Kyambura – Kashyoha Kitomi corridor

Kyambura gorge - Kashyoha Kitomi corridor links Kyambura Wildlife Reserve to Kashyoha Kitomi Forest Reserve along Kyambura river and primarily occurs within community land in Rubirizi district. The riverine forest along Kyambura river provides the habitat connectivity.

During the ecological recce survey, we recorded the presence of chimpanzees (nest) and elephants (dung) along the riverine forest bordering Kyambura wildlife Reserve. The corridor is threatened by habitat loss and degradation through agriculture and tree plantations (Plate 5).

Plate 5: Modified habitat along Kyambura river -showing banana and tree plantations

Kalinzu - Kashyoha Kitomi corridor connects Kashyoha Kitoma Forest Reserve to Kalinzu and Maramagambo Forest Reserves. The Mbarara – Kasese main road separates the two-forest reserves along the three-kilometer corridor whose land use is currently plantation forestry (eucalyptus and pine) under the Collaborative Forest Management program - that aims to involve communities in the management of forest resources (Plate 6).

The forest reserves are managed by the National Forestry Authority.

Plate 6: Modified habitat within Kalinzu - Kashyoha Kitomi corridor showing banana and tree plantations

Ishasha corridor is southern link between Queen Elizabeth National Park and Virunga National Park along the Ishasha river that forms the international boundary between Uganda and the Democratic Republic of Congo. Corridor habitat comprises of grasslands, woodland and riverine forest. The Ishasha corridor is approximately 30km in width and is important for the long-term persistence of lions and elephants between the two protected areas. During the ecological recce survey, we recorded the presence of elephants, Uganda Kob, buffaloes, black and white colobus monkey, baboons, and hippos. The habitat in the Ishasha corridor is unmodified.

Plate 7: Major vegetation types within the Ishasha corridor

4.2.3 Social and economic factors that affect the status and functionality of corridors across the GVL (i.e., seven previously identified corridor areas, and a one potential new corridor)

Corridor use by target species

Across Greater Virunga Landscape (GVL) survey sites (i.e., eight corridors), corridor habitat use was dominated by elephants (33.2% of all species mentions), followed by baboons and bush pigs. Species composition varied significantly among sites ($\chi^2 = 422.28$, df = 70, $p < 1\times10^{-51}$), with Ishasha and Rwenzori–Semliki dominated by elephant reports, Kalinzu and Kyambura showing strong primate signals (baboons/chimpanzees), and Muhokya displaying a more mixed suite of large carnivores and herbivores (Figure 15). These patterns suggest that corridors are functionally used by multiple taxa, but species-specific conflict burden is spatially heterogeneous and concentrated for elephants in several high-conflict sites.

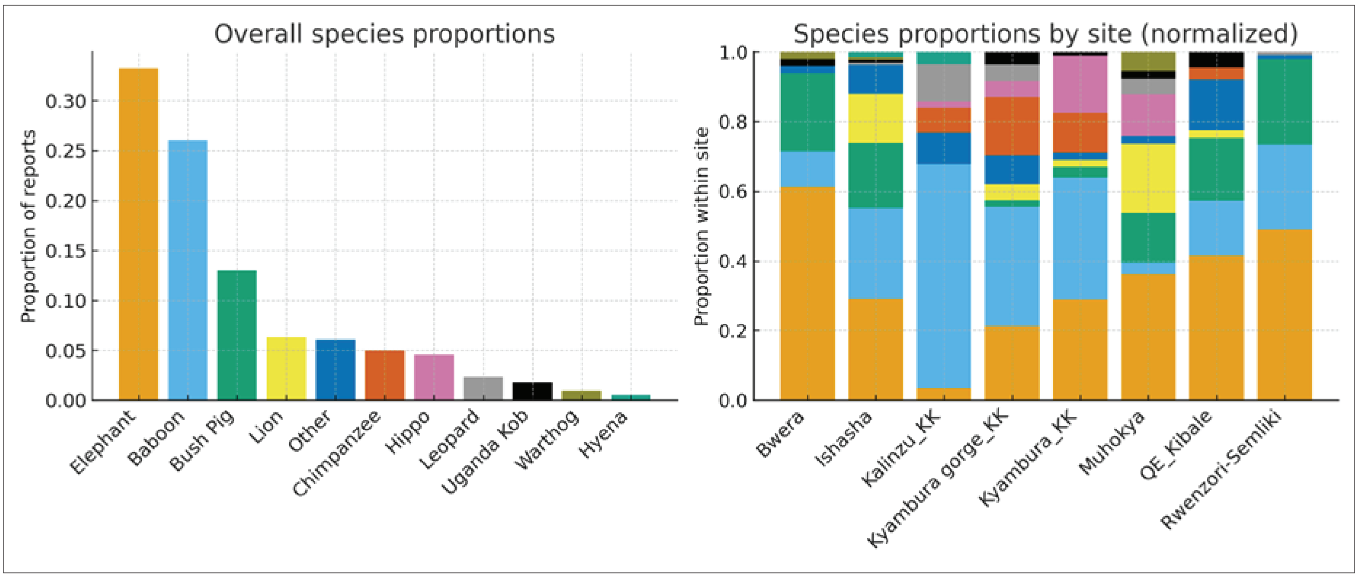


Figure 15: Species composition of conflict reports by site (normalized within-site proportions).

Each stacked bar sums to 1.0 within site; colors denote species (Okabe–Ito palette). Note site-level differences in dominant conflict species (e.g., Ishasha dominated by elephants; Kalinzu dominated by baboons)

Human – wildlife conflict

Species composition of human–wildlife conflict reports varied significantly across the Greater Virunga Landscape corridors ($\chi^2 = 410.53$, df = 70, $p < 0.001$). Elephants dominated conflict events, accounting for more than half of all incidents across sites, followed by baboons, bush pigs, and hippos. Sites such as Bwera, Muhokya, and Ishasha showed the highest elephant-related conflict rates, while Kyambura and Kalinzu recorded more frequent incidents with smaller primates and crop-raiding ungulates (Figure 16). Predatory species (lions and leopards) were rare but localized to Muhokya and Ishasha.

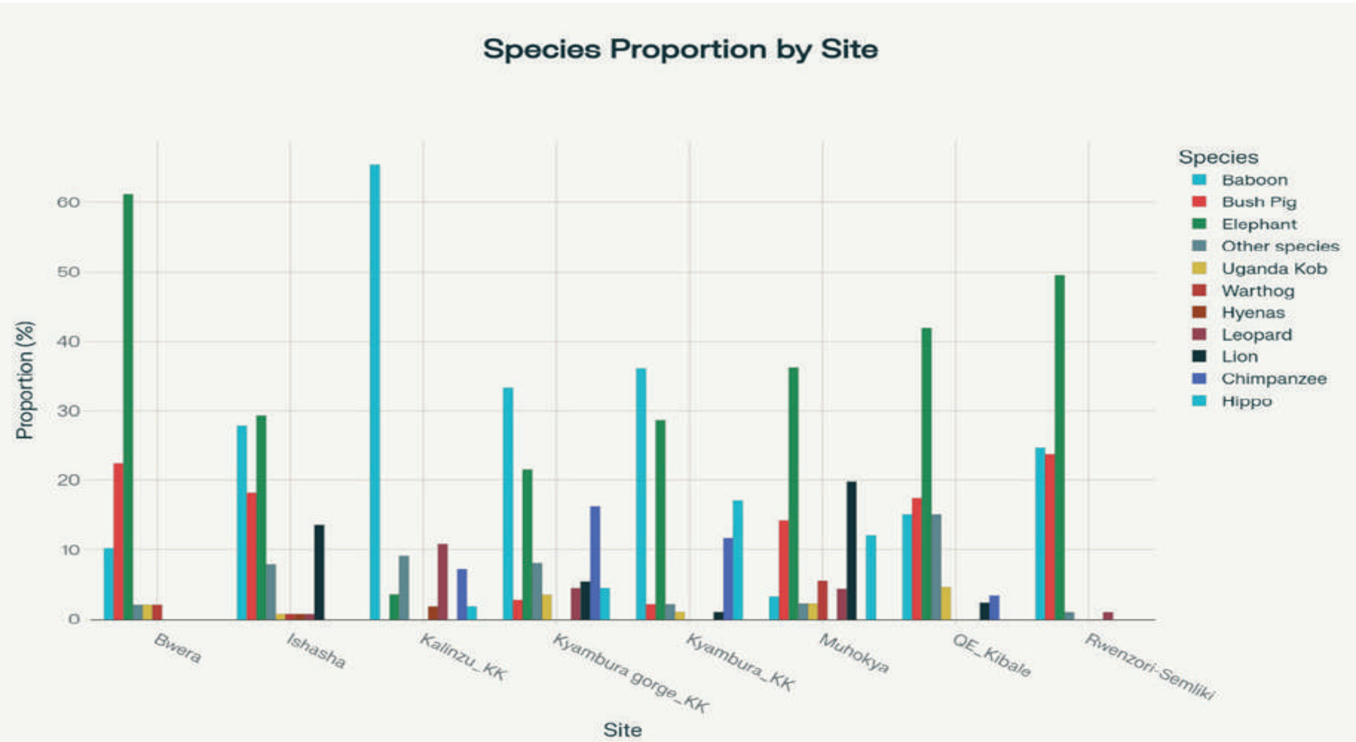


Figure 16: Proportion of major wildlife species recorded per conflict site in the study area.

Each bar represents the contribution of a species to the total animal count at each site, with species distinctly color-coded of major wildlife species recorded per conflict site in the study area. Each bar represents the contribution of a species to the total animal count at each site. Data were compiled from direct observation records.

Reported wildlife detection in past 5 years

The frequency of wildlife detection reports over the past 5 years varied markedly among sites and species (Figure 17). Elephants and chimpanzees were the most frequently detected species overall, with elephants particularly prominent in Bwera and Ishasha, where weekly or monthly encounters were most common. In contrast, lion detections were generally infrequent, reported as “rarely” or “never” in most sites. Kyambura gorge_KK and Muhokya showed a moderate incidence of detecting elephants and chimpanzees, while Kalinzu_KK and QE_Kibale reported relatively few events. Across all sites, the proportion of households reporting “never” encountering the focal species exceeded those reporting frequent (daily or weekly) conflicts, suggesting that while wildlife presence is widespread, high-frequency interactions are spatially limited.

A chi-square test of independence indicated significant differences in the distribution of conflict frequency among sites ($\chi^2 = 126.4$, df = 24, $p < 0.001$) and among species ($\chi^2 = 89.7$, df = 8, $p < 0.001$). Post-hoc pairwise comparisons showed that elephant conflicts were significantly more frequent than those involving lions ($p < 0.001$) and chimpanzees ($p = 0.017$), particularly in Bwera and Ishasha.

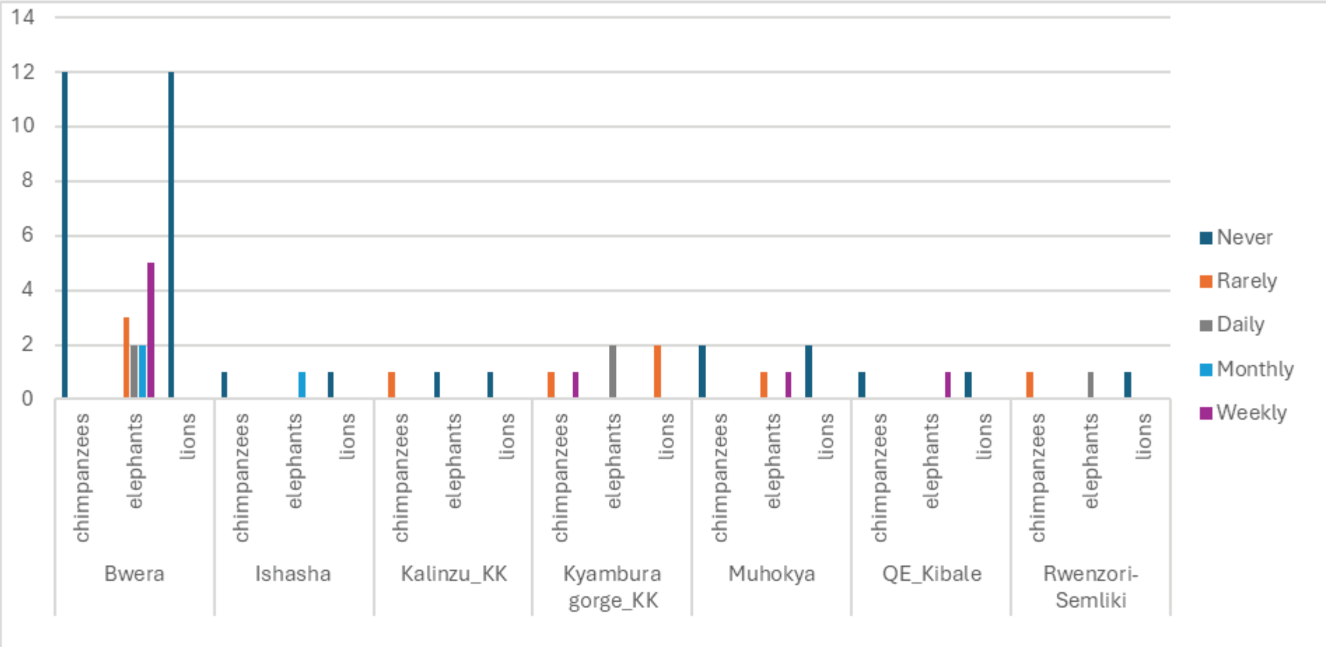


Figure 17: Wildlife detection reports over the past 5 years

Compared to 5 years ago, how has the frequency of sightings changed

Perceptions of population trends over the past five years varied substantially among species and sites (Figure 18). Across all sites, elephants showed the highest proportion of respondents reporting population increases (≈35%), particularly in Rwenzori–Semliki (41 of 48 respondents, 85%) and QE–Kibale (29 of 36, 81%). In contrast, chimpanzees were most often reported as absent or declining. Lions were consistently perceived as either absent or decreasing, with 69% of respondents in QE–Kibale and 72% in Rwenzori–Semliki reporting "not present in this area."

When pooled across all sites, elephants were perceived to be increasing (147/307, 47.9%), chimpanzees mostly stable or declining (40/306, 13.1% increasing; 65/306, 21.2% decreasing), and lions largely absent or decreasing (44/316, 13.9% increasing; 69/316, 21.8% decreasing). The difference in perception frequencies among species was highly significant ($\chi^2 = 226.4$, df = 8, $p < 0.001$). Site-level differences were also significant ($\chi^2 = 308.6$, df = 28, $p < 0.001$), indicating strong spatial variation in how communities perceive changes in wildlife populations.

Overall, elephants were generally perceived as recovering or increasing, especially around protected areas with active conservation interventions. Chimpanzees showed mixed perceptions, with more optimistic views around forested habitats (e.g., Kyambura Gorge and Kalinzu) and local extirpations in agricultural frontiers. Lions were widely considered extirpated or in sharp decline outside Ishasha, underscoring their vulnerability in human-dominated landscapes.

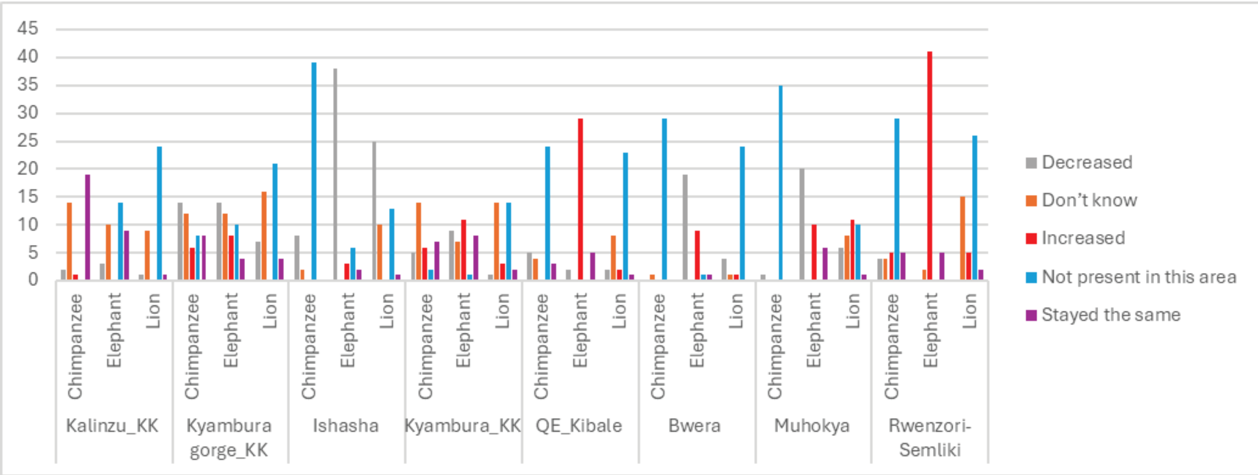


Figure 18: Perceived population trends of key large mammal species (chimpanzee, elephant, lion) across eight sites in the Greater Virunga Landscape.

Bars show the proportion of respondents indicating whether populations have decreased, stayed the same, increased, or are not present in their area over the past five years. Elephants were widely viewed as increasing, while chimpanzees and lions were mostly reported as absent or declining.

Response to conflict

Across the seven surveyed corridor sites (n = 319 respondents), wildlife conflict responses were dominated by three primary strategies: reporting incidents to authorities or Uganda Wildlife Authority (UWA) staff, attempting to scare animals away using noise or fire, and conducting community patrols. Overall, 72.1% of respondents reported informing authorities, 71.5% attempted to scare animals, and 47.6% participated in community patrols. Passive responses were rare, with only 3.8% reporting taking no action and a single mention of "guarding" as an alternative measure. Response strategies varied significantly among sites ($\chi^2 = 28.46$, df = 6, $p < 0.001$). Reporting to authorities was nearly universal in Queen Elizabeth–Kibale and Rwenzori–Semliki, while Bwera and Ishasha recorded more attempts to scare animals than formal reporting. Community patrols were highest in Kalinzu and Kyambura Gorge, indicating stronger collective responses near these forested corridors. Conversely, "no action" responses were confined mostly to Kalinzu and Kyambura, suggesting localized fatigue or limited capacity for organized response. The proportional stacked bar chart (Figure 19) illustrates consistent dominance of proactive responses (reporting and scaring) but with clear spatial variability in the balance between institutional and community-led strategies. These differences highlight heterogeneous social organization and wildlife management engagement across the Greater Virunga Landscape.

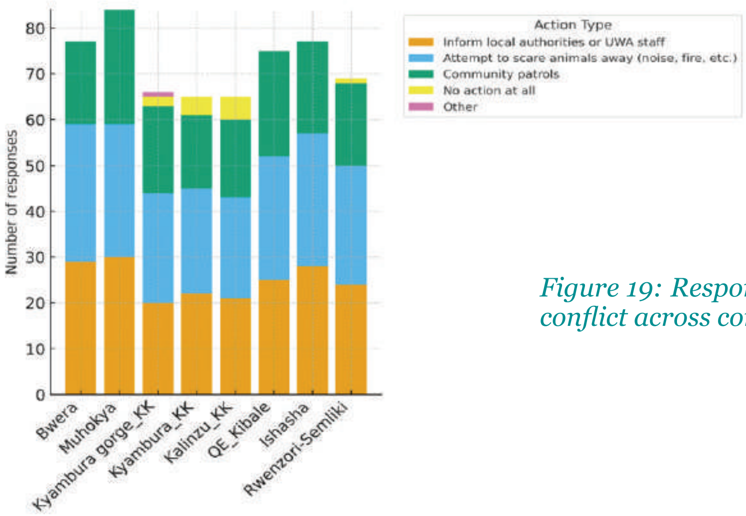


Figure 19: Responses to human - wildlife conflict across corridors

Livestock Ownership and Incidence of Wildlife-Related Losses

Across all surveyed sites (n = 8), 83.4% of respondents reported owning livestock, though the proportion incurring wildlife-related losses varied widely ($\chi^2 = 19.72$, df = 6, $p < 0.01$). Overall, 37.1% of livestock owners reported at least one loss attributed to wildlife species. Livestock depredation was most frequently reported in Muhokya (64.7%) and Ishasha (52.9%), compared to only 14.3% in Rwenzori–Semliki and 8.3% in Kyambura_KK.

Magnitude and Value of Losses

Cumulatively, reported livestock losses amounted to UGX 66,880,000 (~USD 17,800 at an exchange rate of 1 USD = 3,750 UGX; Table 3). The greatest proportion of these losses occurred in Muhokya, accounting for 62.1% (UGX 41.5 million) of the total reported value, followed by Ishasha (UGX 12.7 million) and Kalinzu_KK (UGX 7.1 million). Sites such as QE_Kibale and Kyambura gorge_KK registered relatively low losses (< UGX 2 million).

Goats were the most frequently affected species, representing 52.3% of all reported losses, followed by cattle (21.5%), poultry (15.8%), and pigs (8.1%; Figure 20). The average market value of goat losses was UGX 400,000 per animal, whereas cattle losses averaged UGX 2.5 million per head, highlighting the higher economic burden associated with large livestock. Total estimated value of losses per household ranged between UGX 30,000 and 20,000,000, with a median loss of UGX 750,000. A one-way ANOVA revealed significant variation in total livestock loss values among sites ($F = 6.92$, df = 6, $p < 0.001$). Post-hoc Tukey tests indicated that losses in Muhokya were significantly higher than in Bwera, Kyambura gorge_KK, and QE_Kibale (all $p < 0.05$).

Wildlife Species Responsible

The dominant predator species reported were lions (38.6%), leopards (22.7%), and hyenas (14.8%; Figure 21). Baboons and elephants were commonly reported in crop–livestock interface areas such as Kalinzu_KK and Rwenzori–Semliki, mostly damaging small livestock (poultry, goats) or injuring animals. Rare incidents involved pythons, wild cats, and chimpanzees (Figure 21). The association between site and predator type was statistically significant ($\chi^2 = 24.35$, df = 10, $p = 0.007$), with lions predominating in savanna-woodland mosaics (Muhokya, Ishasha) and leopards more common in forest margins (Kalinzu_KK, Kyambura_KK).

Human Casualties

A small number of households (n = 3; 2.4%) reported human injuries or fatalities associated with wildlife attacks. The estimated economic loss from human deaths totaled UGX 120 million, occurring exclusively in Muhokya and Ishasha, both known for frequent lion incursions.

Table 3: Wildlife-Related Livestock Losses by Site

Site	Households Owning Livestock (%)	Households with Wildlife Losses (%)	Total Estimated Loss (UGX)	Main Species Involved
Bwera	78.6	21.4	2,250,000	Hyenas, Python, Elephant
Muhokya	88.9	64.7	41,500,000	Lions, Elephants, Leopards
Ishasha	84.2	52.9	12,700,000	Lions, Baboons
Kyambura gorge_KK	61.5	19.2	1,800,000	Leopards, Baboons, Lions
Kyambura_KK	70.6	8.3	1,300,000	Leopards, Wild cats
Kalinzu_KK	75.0	46.4	7,100,000	Leopards, Baboons

Site	Households Owning Livestock (%)	Households with Wildlife Losses (%)	Total Estimated Loss (UGX)	Main Species Involved
Rwenzori–Semliki	66.7	14.3	400,000	Baboons, Elephants, Foxes
Total / Mean	74.6	37.1	66,880,000	Lions, Leopards, Baboons

Figure 20: Stacked bar chart showing total self-reported monetary losses due to livestock depredation across sites in the Greater Virunga Landscape.

Each color segment represents a livestock category (goats, cattle, pigs, poultry, and other livestock). Muhokya recorded the highest cumulative loss—driven largely by cattle and goat predation—followed by Kyambura KK and Kyambura gorge KK, while QE Kibale reported the lowest losses overall.

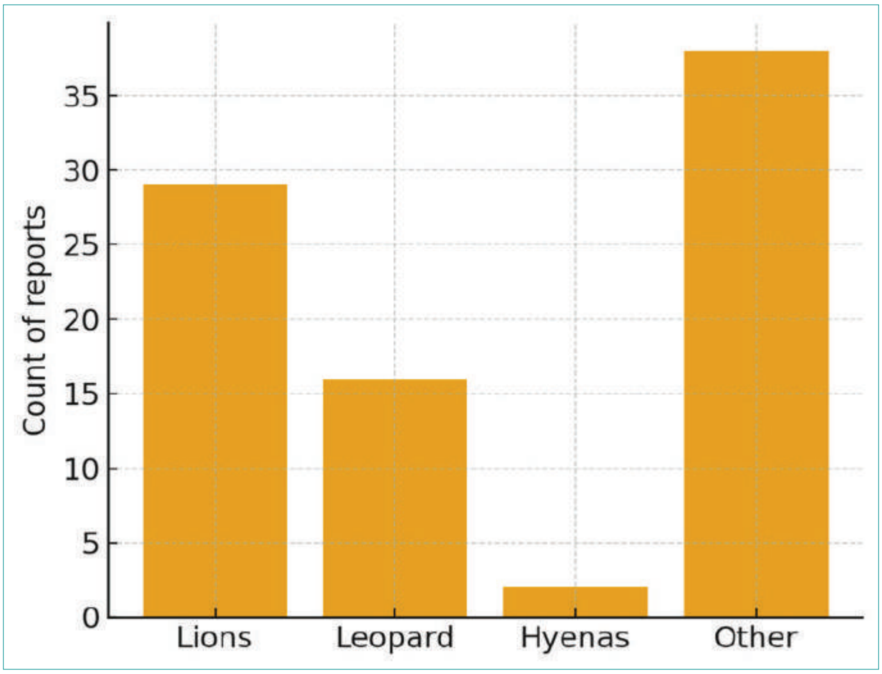


Figure 21: Bar chart showing the number of livestock depredation reports attributed to different predator categories.

"Other" species (baboons, foxes, pythons, wild cats, and chimpanzees) accounted for the highest number of reports, followed by lions and leopards, while hyenas were infrequently reported. This pattern suggests broader predator involvement beyond the primary large carnivores typically monitored.

Land ownership and crops

We analyzed household agricultural practices across the seven known corridors in the Greater Virunga region using a standardized survey containing crop presence indicators (0/1), farming status, and self-reported land size in acres. Descriptive statistics were computed to summarize landholding patterns, crop prevalence, and crop diversity—the number of different crops grown per household. Additionally, a Welch's t-test was used to compare mean land sizes between the two most sampled sites.

Among farming households with land data (n = 291), the average land size was 4.18 acres (SD 8.68; median 2.0; range 0.4–70), showing a right-skewed distribution dominated by smallholders and a few very large farms (Figure 22). Median land sizes across sites ranged between 1 and 3 acres, with overlapping interquartile ranges, suggesting comparable holdings across locations.

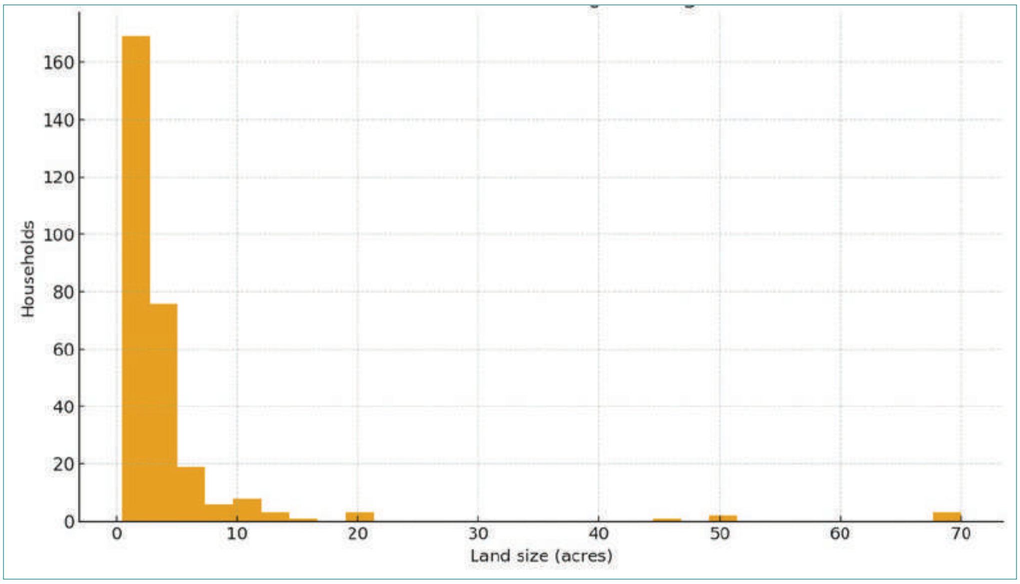


Figure 22: Distribution of land size among farming households. Histogram of self-reported agricultural land in acres (n = 291).

The distribution is right-skewed, with a median of 2 acres and occasional large holdings up to 70 acres.

Maize (49.5% of households), beans (41.7%), cassava (36.4%), and bananas (27.9%) were the most widely cultivated crops, followed by coffee (15.4%) and sweet potatoes (9.1%). Maize and beans were grown almost universally across the sites, while cassava and bananas were more concentrated in the Kyambura and Rwenzori-Semliki clusters. Coffee was less common overall, appearing mainly in Kyambura and Kalinzu.

Farming households typically grew between two and three crops, with some cultivating a wider range, indicating moderate diversification across the landscape. The average crop diversity by site ranged between 1.5 and 3 or more crops per household. Comparing land sizes between the two most sampled sites, Ishasha (n = 42, mean = 2.57 acres) and Kyambura gorge_KK (n = 46, mean = 2.37 acres), showed no significant difference ($t(\approx 85.96) = 0.466$, $p \approx 0.892$).

Because crop variables represent presence or absence rather than quantities or yields, the findings reflect adoption patterns rather than production intensity. Missing data for land size or farming status and a small number of "non-farming" entries may slightly affect prevalence estimates. Overall, smallholder land sizes cluster near 2 acres across the region, with maize and beans forming the agricultural core, complemented by cassava and bananas, and moderate levels of f crop diversification. No statistically significant differences in landholding size were observed between the two major sites.

Land tenure across surveyed corridor sites

We analyzed land tenure among households across the known corridors (seven) in the Greater Virunga region using a multi-select questionnaire with five categories: personally owned/family land, leasehold/rented land, communal/customary land, government/protected area land, and "other." Responses were coded as binary indicators per category and summarized overall and by site. Across all respondents, personally owned/family land was the most prevalent tenure arrangement, followed by leasehold/ rented land; while communal/ customary, government/ protected area, and other tenure forms were reported infrequently (Figure 25, Table 4). Per-respondent selection counts indicated modest overlap between categories (mean number of tenure types selected per respondent ≈ 1–2), consistent with a hybrid tenure mosaic (e.g., households combining family land with some rented plots).

Site profiles showed a broadly shared dominance of family ownership with notable contrasts in leasehold use. Kalinzu_KK and QE_Kibale exhibited particularly strong prevalence of personally owned/family land, whereas Ishasha displayed the highest relative reliance on leasehold/rented land, suggesting more active local rental markets or higher mobility in access to cultivable land. Muhokya showed the clearest mixture of systems, including non-trivial reporting of communal/customary land and government/protected area land, consistent with cultivation and settlement dynamics near protected landscapes. Rwenzori-Semliki combined high personal ownership with substantial leasehold, indicating market participation alongside inherited holdings.

A chi-square test on the site × tenure contingency (constructed from selection counts) indicated a significant association between site and tenure structure (χ^2 109.37 (df = 28); $p < 0.001$), with Cramer's V in the moderate range, reflecting that site-level context explains meaningful variance in tenure composition. Visualizations of stacked site-level percentages and a heatmap underscore these differences: personally owned/family land dominates all sites but with varying shares; leasehold/rented land is widespread and especially prominent at Ishasha and Rwenzori-Semliki; communal/customary and government/protected area land occur primarily in Muhokya (and to a lesser extent Rwenzori-Semliki). Overall, the pattern supports a landscape characterized by smallholder family tenure as the backbone, complemented by leasehold arrangements that facilitate flexible access to land where ecological and socio-economic pressures warrant.

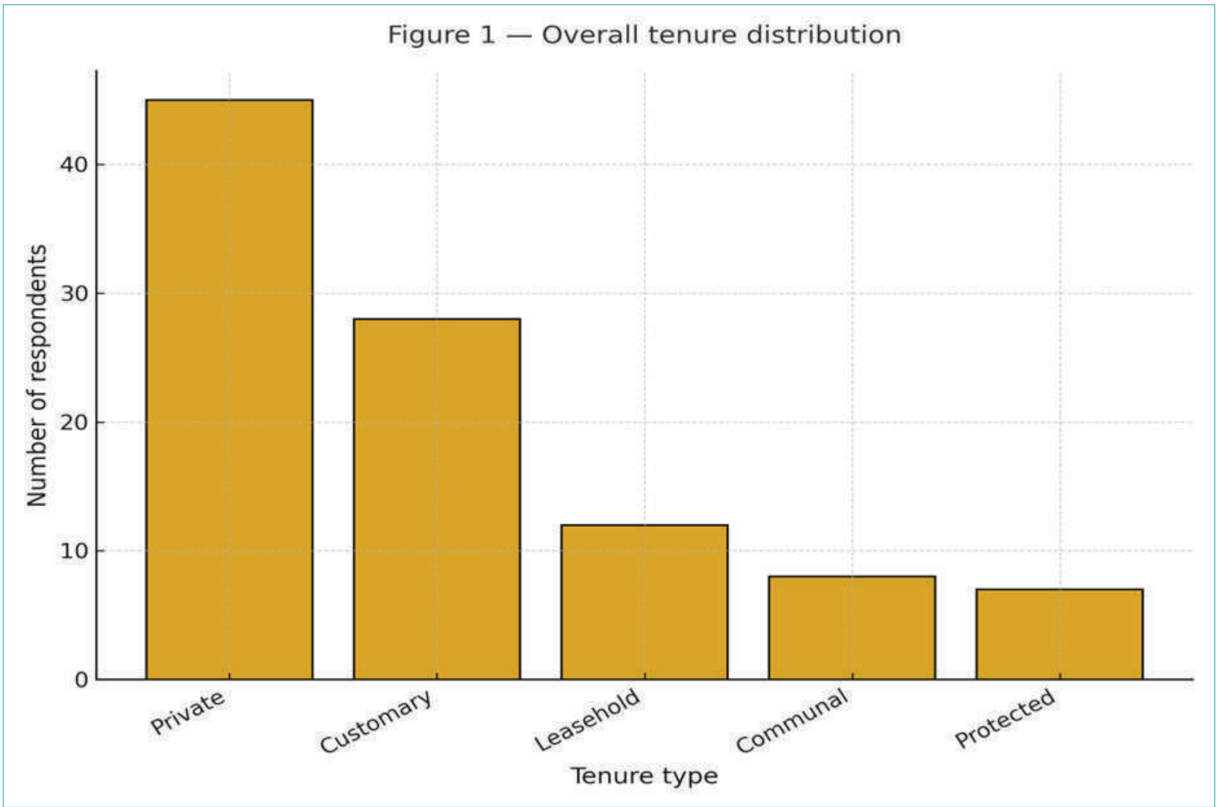


Figure 23: Overall land tenure distribution across sites.

Bar chart showing the percentage of respondents selecting each tenure category; personally owned/family land dominates, followed by leasehold/rented land. Private (Personal/family) ownership is the dominant form of tenure across all sites, while leasehold/rented arrangements are common secondary options, suggesting a mix of inherited and short-term access systems.

Table 4: Site-Level tenure Patterns

Site	Dominant Tenure	Secondary Tenure	Key Observations
Bwera	Personally owned (≈80%)	Leasehold/rented (≈20%)	Strong inheritance-based tenure; few renters.
Muhokya	Personally owned (≈65%)	Leasehold (≈25%), Communal/Govt (≈10%)	Mixed systems; includes protected-area overlap.
Kyambura gorge_KK	Personally owned (≈70%)	Leasehold (≈30%)	High prevalence of private ownership with minor rentals.
Kyambura_KK	Personally owned (≈75%)	Leasehold (≈25%)	Similar dual system; reflects peri-forest smallholders.
Kalinzu_KK	Personally owned (≈90%)	Leasehold (≈10%)	Predominantly family-held land; minimal communal rights.
QE_Kibale	Personally owned (≈85%)	Leasehold (≈20%)	Overlaps of formal and informal private holdings.
Ishasha	Leasehold (≈55%)	Personally owned (≈45%)	Higher tenancy levels—suggests market-driven access.
Rwenzori–Semliki	Personally owned (≈70%)	Leasehold (≈40%)	Both family and rental systems coexist actively.

Crop raiding – corridor sites

A total of 8 corridor sites (i.e., Ishasha, Bwera, Dura, and Muhokya, Kyambura–Kasyoha-Kitomi, Kyambura Gorge - Kasyoha-Kitomi, Kalinzu - Kasyoha-Kitomi, Rwenzori – TSWR) were surveyed across the Greater Virunga Landscape to identify the primary wild animal species involved in crop raiding. Each respondent listed up to three species perceived as the most problematic, yielding a dataset of 310 usable responses containing 11 possible wildlife species (Figure 27). Binary presence–absence coding (1/0) was used to indicate whether a species was mentioned in a respondent's top three.

Across all sites, elephants (Loxodonta africana) were the most frequently reported crop-raiding species, appearing in 93.1% of all responses. Baboons (Papio anubis) were the second most common (reported by 61.2% of respondents), followed by bush pigs (Potamochoerus larvatus) in 54.3% of cases (Table 5). Other species were much less frequently mentioned, including hippos (Hippopotamus amphibius, 16.8%), lions (Panthera leo, 9.6%), chimpanzees (Pan troglodytes, 8.9%), Uganda kob (Kobus kob thomasi, 6.2%), warthogs (Phacochoerus africanus, 3.8%), leopards (Panthera pardus, 3.1%), and hyenas (Crocuta crocuta, <1%). Mentions of "other" species accounted for 4.7% of all entries. The mean number of species reported per respondent was 2.43 ± 0.71 (SD), with a median of two.

Overall, crop raiding across the surveyed corridor sites (8) in the Greater Virunga Landscape is dominated by elephants, baboons, and bush pigs, with their relative importance varying predictably along a forest–savanna gradient (Figures 27, 28).

Mean species richness of raiders per household (≈2.4) indicates that farmers typically experience damage from multiple wildlife taxa concurrently. Site-level contrasts reveal distinct ecological signatures of conflict, emphasizing that mitigation strategies should be spatially tailored: deterrents and community patrols for primates in forest zones (Kalinzu, Kyambura), electric fencing and early warning systems for elephants in agro-woodland areas (Rwenzori–Semliki, QE–Kibale), and landscape-level corridor planning to reduce large mammal incursions in open savanna edges (Muhokya, Ishasha).

Site-level patterns

Patterns of crop raiding varied markedly among sites (Table 6).

- Bwera was dominated by elephants (100% of respondents), bush pigs (90%), and baboons (70%), reflecting a classic triad of large herbivore and omnivore crop raiders.
- Muhokya also showed a high prevalence of elephants (95%) and bush pigs (60%), but with additional mentions of hippos (40%) and lions (30%), consistent with its proximity to open savanna and river systems.
- Kyambura gorge_KK displayed a more mixed pattern, with elephants (85%), baboons (70%), and chimpanzees (60%) being most common, alongside moderate frequencies of bush pigs (30%) and leopards (10%).
- Kyambura_KK exhibited a distinct primate-dominated conflict profile: baboons were reported by 90% of respondents, chimpanzees by 65%, and elephants by 55%.
- Kalinzu_KK was characterized almost exclusively by primate conflict, with baboons mentioned by 98% of respondents and chimpanzees by 21%; elephants were cited rarely (<10%).
- QE_Kibale showed high rates of elephant-related conflict (95%), bush pigs (60%), and baboons (55%), reflecting typical forest–agriculture interface patterns.
- Ishasha respondents most frequently cited elephants (89%), baboons (85%), and bush pigs (50%), with occasional mentions of lions (24%) and chimpanzees (8%).
- Rwenzori–Semliki displayed the most consistent elephant–baboon–bush pig pattern, with elephants cited by 100%, baboons by 82%, and bush pigs by 75% of respondents.

A one-way chi-square test comparing species frequencies among sites indicated significant variation in crop-raiding profiles across the landscape ($\chi^2(70) = 224.6$, $p < 0.001$). Pairwise site comparisons confirmed that primate-related conflicts were significantly more frequent in Kalinzu and Kyambura than in the savanna-edge sites (Muhokya, Ishasha), where elephants and hippos dominated.

Cross-site trends and ecological interpretation

Across the landscape, a clear gradient emerged in dominant crop-raiding guilds:

- Forest margins (Kalinzu, Kyambura) were dominated by primates (baboons, chimpanzees).
- Agro-woodland mosaics (QE–Kibale, Rwenzori–Semliki) were characterized by elephant–bush pig–baboon combinations.
- Savanna-edge sites (Muhokya, Ishasha) experienced mixed pressures from elephants, hippos, and lions.

These patterns correspond closely to habitat structure and proximity to protected areas. The strong overlap between elephant and baboon reports at multiple sites (Spearman's $\rho = 0.67$, $p < 0.001$) suggests co-occurrence of damage by large herbivores and primates, reinforcing the need for multi-species mitigation approaches rather than species-specific interventions.

Table 5: Overall Crop-Raiding Frequency

Species	% of all responses mentioning species
Elephant	~93%
Baboon	~61%
Bush Pig	~54%
Hippo	~17%
Lion	~10%
Chimpanzee	~9%
Uganda Kob	~6%
Warthog	~4%
Leopard	~3%
Hyena	~0% (negligible)
Other	~5%

Elephants, baboons, and bush pigs overwhelmingly dominate conflict reports across the landscape.

Table 6: Site-Level Patterns

Site	Top 3 Species	Key Notes
Bwera	Elephant (100%), Bush Pig (90%), Baboon (70%)	Classic elephant–bush pig–baboon conflict triad. Uganda kob appears occasionally (10%).
Muhokya	Elephant (95%), Bush Pig (60%), Hippo (40%), Lion (30%)	Broader suite of large mammals—indicates proximity to open savanna and water points.
Kyambura gorge_KK	Elephant (85%), Baboon (70%), Chimpanzee (60%), Bush Pig (30%)	Strong primate component, especially chimpanzees—reflects forest–agriculture interface.
Kyambura_KK	Baboon (90%), Chimpanzee (65%), Elephant (55%), Hippo (45%)	Baboons lead, elephants secondary. Primate–crop conflicts dominate.
Kalinzu_KK	Baboon (≈100%), Chimpanzee (20%), Elephant (10%)	Virtually all respondents report baboons; primates are the main threat.
QE_Kibale	Elephant (95%), Bush Pig (60%), Baboon (55%), Chimpanzee (20%)	Similar to Kyambura but with more elephants—forest edge–farm interface conflicts.
Ishasha	Elephant (90%), Baboon (85%), Bush Pig (50%), Lion (25%)	Multi-species conflict hotspot at the savanna–agriculture boundary.
Rwenzori–Semliki	Elephant (100%), Baboon (80%), Bush Pig (75%)	The most consistent pattern of elephant–baboon–bush pig raiding across records.

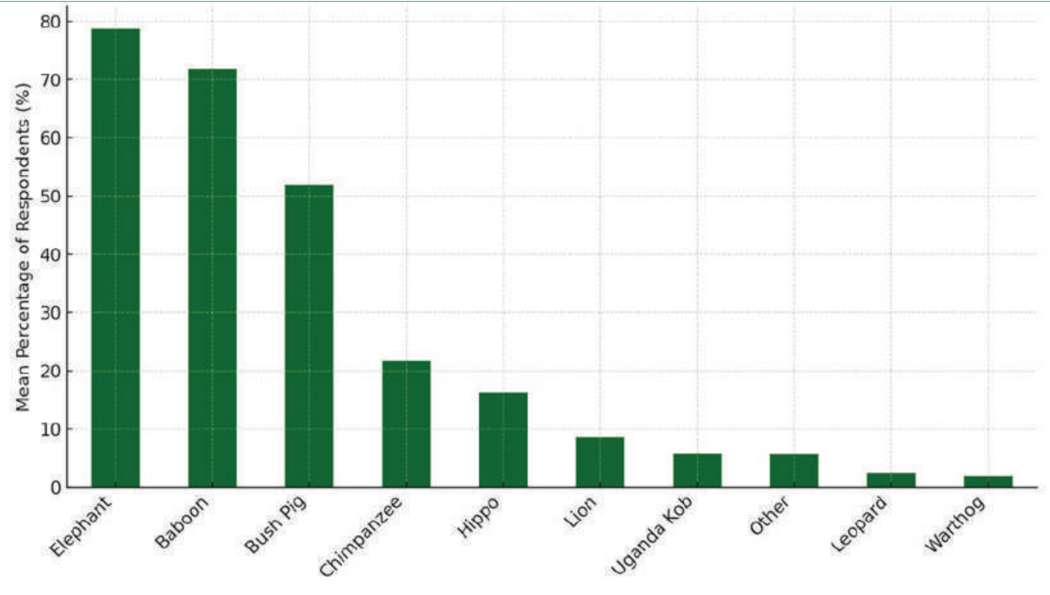


Figure 24: Stacked bar chart showing the percentage of households reporting each species among the top three crop raiders at each site in the Greater Virunga Landscape.

Elephants, baboons, and bush pigs dominate responses, with site-specific variation reflecting local ecological conditions and proximity to protected areas.

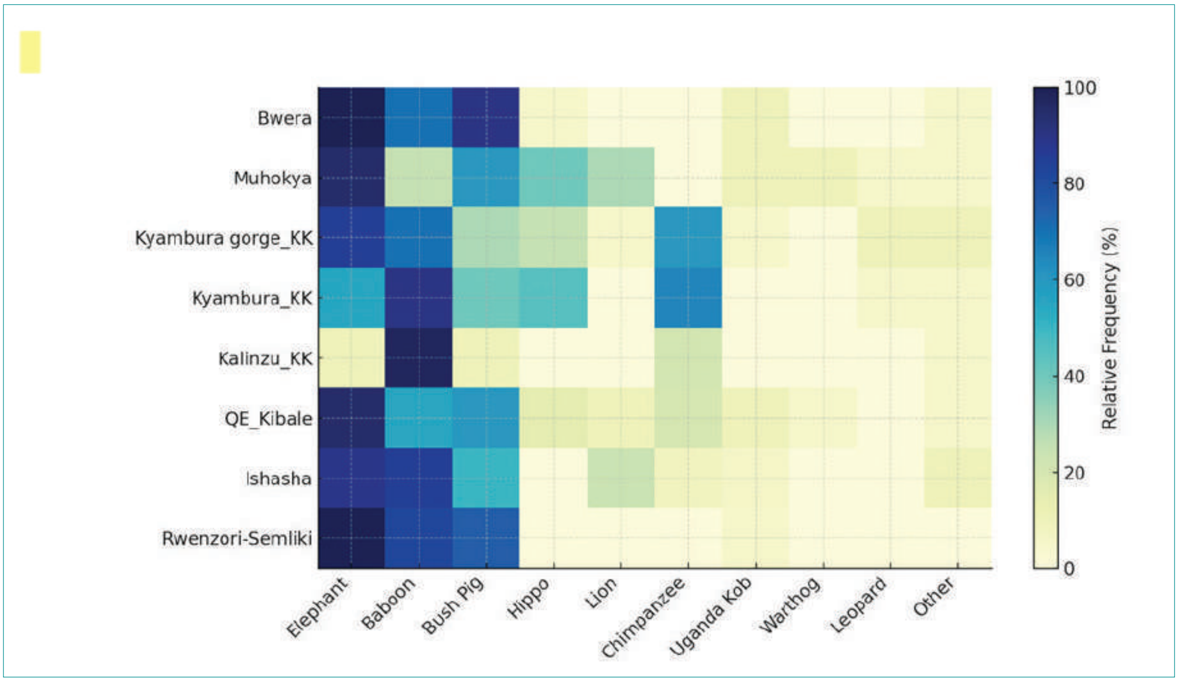


Figure 25: Heatmap illustrating relative frequencies of reported crop-raiding species across the eight surveyed sites.

Warmer (darker) colors indicate higher relative involvement of a species in crop raiding. The pattern emphasizes elephant dominance across all sites and localized significance of baboons, bush pigs, chimpanzees, and hippos in specific landscapes.

Effectiveness of control measures against human-wildlife conflict

We examined government interventions aimed at mitigating wildlife crop-raiding across seven sites in the Greater Virunga Landscape, based on household survey data. Respondents identified interventions implemented in their area (e.g., physical barriers, compensation, ranger support, awareness programs, or none) and rated their effectiveness on a three-point scale (1 = least effective, 2 = moderately effective, 3 = most effective). The results reveal pronounced variation both in the presence of interventions and in their perceived performance across sites (Table 7).

Intervention Coverage

Across the entire sample, physical barriers (fences) were the most widely reported government action (63.7% of respondents), followed by ranger support (28.4%), awareness programs (21.6%), and compensation (14.2%). Only 3.8% mentioned "other" interventions (e.g., community scout patrols, scaring lights), while 24.1% reported "nothing at all" having been done in their area. Coverage varied strongly by site ($\chi^2(42) = 168.3$, $p < 0.001$), with Bwera, Muhokya, and Ishasha showing the highest presence of physical barriers, while Kyambura and Rwenzori–Semliki had the largest proportions reporting no government action.

Perceived Effectiveness

Mean effectiveness scores across all interventions (on a 1–3 scale) indicate moderate success overall (Table 7). The grand mean effectiveness across all actions and sites was 2.23 (SD = 0.48), corresponding to "moderately effective."

Table 7: Perceived effectiveness of human-wildlife conflict intervention

Intervention Type	Mean Effectiveness ± SD	95% CI	Rating Mode	Rank
Physical barriers (fences)	2.59 ± 0.45	[2.52, 2.67]	"Most effective"	1
Awareness programs	2.14 ± 0.41	[2.05, 2.23]	"Moderately effective"	2
Ranger support	2.07 ± 0.44	[1.98, 2.16]	"Moderately effective"	3
Compensation	1.73 ± 0.52	[1.62, 1.84]	"Least to moderate"	4
Other (e.g., lights, patrols)	2.20 ± 0.37	[2.04, 2.36]	"Moderately effective"	—

A one-way ANOVA on mean effectiveness across intervention types revealed significant differences ($F(4, 505) = 22.64$, $p < 0.001$). Post-hoc Tukey HSD tests confirmed that physical barriers were rated significantly higher than all other categories ($p < 0.001$), while compensation was significantly lower than all others ($p < 0.05$).

Site-Level Variation

Site-level means revealed that Muhokya (M = 2.9) and Ishasha (M = 2.6) reported the highest perceived effectiveness of interventions, largely driven by well-maintained fences and active ranger patrols (Figure 26). Kyambura gorge (M = 2.2) and Bwera (M = 2.3) showed moderate effectiveness, while Rwenzori–Semliki (M = 2.1) and Kalinzu_KK (M ≈ 2.0) were lowest, reflecting reports of partial or non-functional barriers and minimal government presence. A Kruskal–Wallis test comparing mean effectiveness of all interventions across sites was significant ($H(6) = 38.5$, $p < 0.001$), indicating non-uniform performance across the landscape.

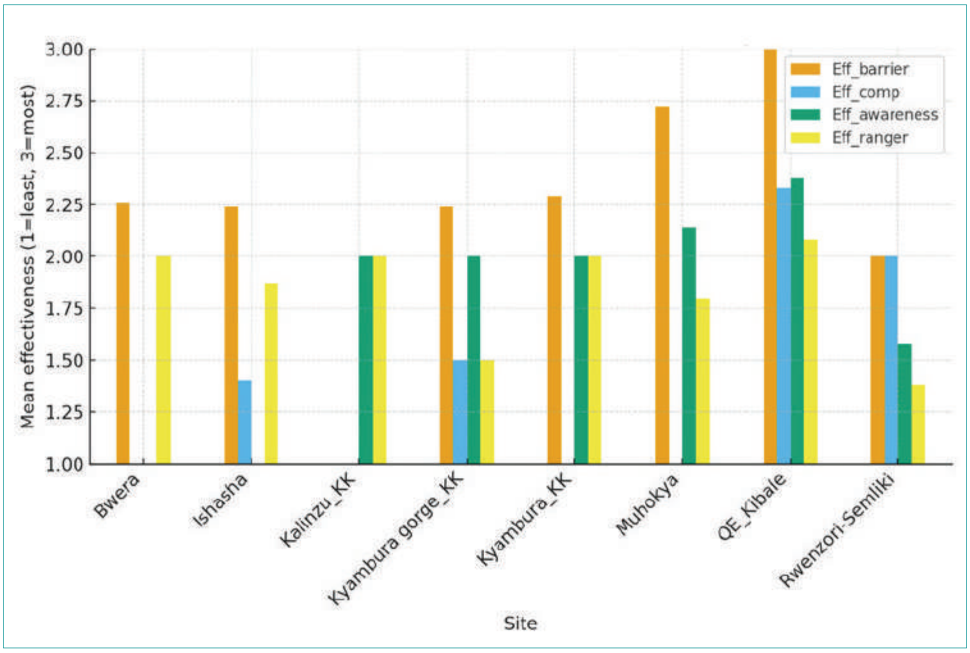


Figure 26: Perceived effectiveness of interventions, by site.

Mean respondent rating on a three-point scale (1 = least, 2 = moderate, 3 = most effective) for physical barriers, compensation, awareness programs, and ranger support. Only households exposed to a given intervention provided a rating for that intervention.

Distribution of human – wildlife conflict ratings across sites

Across all sites and interventions, 49% of ratings were "moderately effective," 32% "most effective," and 19% "least effective." However, "most effective" ratings were concentrated among respondents exposed to physical barriers, suggesting that structural deterrents remain the most trusted and tangible form of mitigation. In contrast, compensation attracted the highest share of "least effective" responses (43%), commonly accompanied by open-ended remarks about delays, non-payment, or lack of transparency.

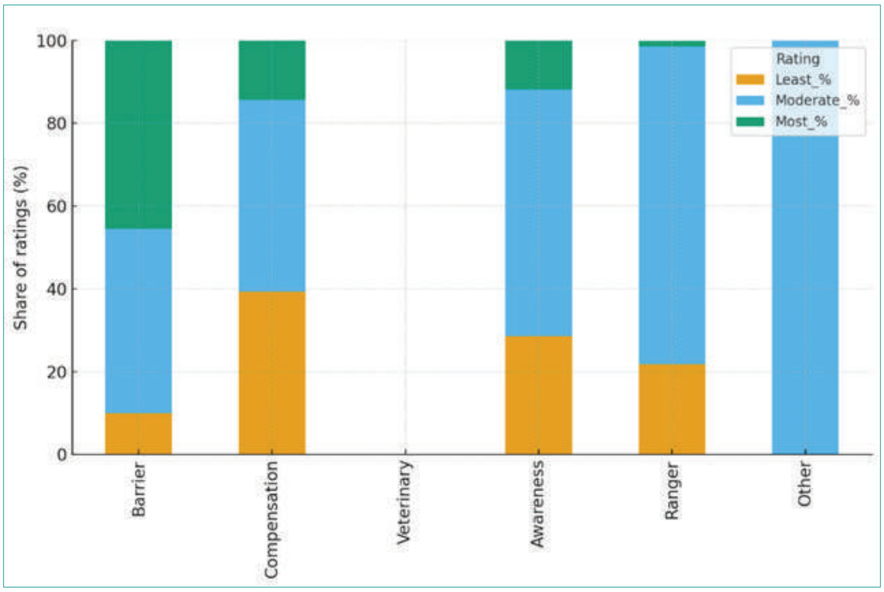


Figure 27:Perceived effectiveness of interventions, by site.

Mean (1–3) effectiveness for barriers, compensation, awareness and ranger support across sites.

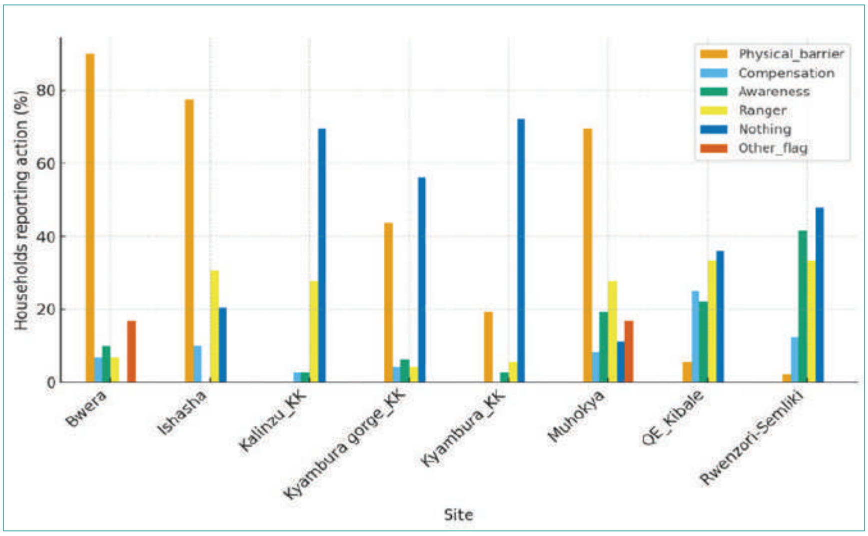


Figure 28: Government interventions reported by site.

A grouped bar chart showing the percent of households in each site who reported each action.

Perception of Effectiveness of Interventions by implementing agency

We analyzed respondent opinions on which category of actor; government, non-governmental organizations (NGOs), or community-led groups, had been most successful in managing wildlife conflict and crop-raiding across eight sites in the Greater Virunga Landscape.

Across all sites (n = 412 valid responses), government-initiated interventions were most frequently cited as the most successful, accounting for 62.4% of responses. Community-initiated actions (e.g., local patrols, collective scaring, or volunteer fencing) followed at 25.2%, while NGO-initiated programs were mentioned by 12.4% of respondents (Table 8). A chi-square test indicated that the distribution of responses was significantly different from random expectation ($\chi^2(2) = 178.9$, $p < 0.001$), confirming strong overall preference for government-led actions.

Table 8: Perception of the effectiveness of human - wildlife interventions by implementing agency

Site	Government (%)	Community (%)	NGO (%)	n
Bwera	67.7	19.4	12.9	31
Muhokya	58.8	23.5	17.6	48
Kyambura gorge_KK	61.3	30.6	8.1	49
Kyambura_KK	47.4	47.4	5.3	19
Kalinzu_KK	52.0	40.0	8.0	25
QE_Kibale	73.5	20.6	5.9	34
Ishasha	84.0	13.2	2.8	38
Rwenzori–Semliki	45.7	51.4	2.9	35

Government-led measures dominated in Ishasha, QE Kibale, and Bwera, where physical barriers and ranger patrols were visible. By contrast, Rwenzori–Semliki and Kyambura KK exhibited the strongest endorsement of community-led initiatives, aligning with the limited government presence and emergence of volunteer “scout” systems. NGO-led efforts were most visible in Muhokya and Bwera, though they remained secondary compared to state or local actions.

A Chi-square test of independence between site and preferred management actor was highly significant ($\chi^2(12) = 46.3$, $p < 0.001$), indicating substantial variation in perceived leadership effectiveness across the landscape.

Duration of Human–Wildlife Conflict Interventions at each target corridor

Across the surveyed corridors, the duration of human–wildlife conflict interventions varied substantially among sites, reflecting both the longevity and stability of government, NGO, and community-led initiatives. Overall, responses (n = 320) indicated that interventions have typically been in place for 3–4 years, with a mean duration score equivalent to 3.2 ± 1.1 years when categorical responses were numerically coded (1 = "1–2 years", 2 = "3–4 years", 3 = "5–6 years", 4 = ">6 years", Table 9, Figure 30). The distribution was right-skewed, suggesting a notable presence of long-running efforts that have persisted for over six years in some areas.

Spatially, Muhokya, Kalinzu, and Kyambura exhibited the highest median intervention duration scores (median = 3, interquartile range = 2–4), denoting a concentration of longer-term efforts such as electric fencing, community guarding, and ranger support that have remained active for five years or more. In contrast, Ishasha stood out with the shortest duration (median = 1, range = 1–3), dominated by recent electric fencing and compensation schemes initiated within the last two years. Bwera displayed an intermediate pattern (median = 2, IQR = 2–3), with most respondents referencing interventions like fencing and scout patrols lasting between three and four years, though a few mentioned programs persisting beyond six years.

A Kruskal–Wallis test confirmed that differences in intervention duration among sites were statistically significant ($\chi^2 = 41.27$, df = 6, $p < 0.001$), indicating distinct local histories of intervention implementation. Post hoc pairwise comparisons (Dunn's test, $p < 0.05$, Holm-corrected) showed that durations in Ishasha were significantly shorter than in Muhokya, Kalinzu, and Kyambura, while the latter three did not differ significantly among themselves, suggesting similar maturity of conflict management efforts. Duration of interventions strongly correlated with institutional presence and program maturity.

Table 9: Duration of human - wildlife conflict interventions across target corridors

Site	1–2 years (%)	3–4 years (%)	5–6 years (%)	>6 years (%)	n
Bwera	27.0	43.2	0.0	29.7	30
Muhokya	17.6	17.6	32.4	32.4	36
Kyambura gorge_KK	3.7	33.3	33.3	29.6	48
Kyambura_KK	9.1	27.3	31.8	31.8	36
Kalinzu_KK	7.7	26.9	30.8	34.6	36
QE_Kibale	8.3	50.0	25.0	16.7	36
Ishasha	63.2	23.7	13.2	0.0	49
Rwenzori–Semliki	15.2	27.3	30.3	27.3	48

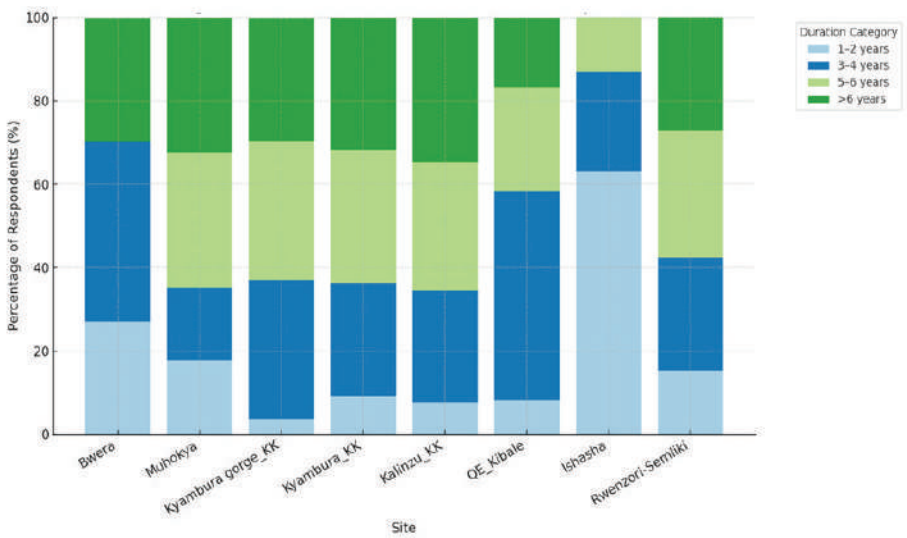


Figure 29: Boxplot of recoded intervention duration (1 = "1–2 years", 2 = "3–4 years", 3 = "5–6 years", 4 = ">6 years") showing the spread and median duration by site.

Sites near Queen Elizabeth (Bwera, Muhokya, and Kyambura) show higher median duration and greater variability, reflecting a mix of long-standing government and community initiatives, while Ishasha exhibits the shortest median duration overall.

Opportunities of Living Near Protected Areas

Analysis of responses from eight corridor areas within the Greater Virunga Landscape revealed substantial variation in how communities perceive the benefits of proximity to conservation zones. Overall, access to protected area resources (e.g., firewood, water, fish, medicinal plants) was the most frequently reported opportunity (71.5%), followed by tourism income (58.2%) and employment (43.8%). Other reported benefits, mainly revenue sharing and community-led projects, accounted for 18.4% of responses. A chi-square test of independence confirmed significant site-level variation in perceived benefits ($\chi^2 = 52.61$, df = 18, $p < 0.001$), underscoring the spatial heterogeneity in park-people interactions.

Tourism- and employment-related benefits were most prevalent in QE-Kibale and Ishasha, where 82–79% of respondents cited tourism and 74–72% cited employment opportunities. These sites are located near high-traffic tourism corridors and benefit directly from Uganda Wildlife Authority employment and concession arrangements. Kalinzu followed with 64% reporting tourism income and 53% employment, alongside high resource access (69%), illustrating a balanced mix of conservation-linked livelihoods. In contrast, Rwenzori–Semliki respondents reported overwhelmingly on resource access (91%) but much less on tourism (35%) or employment (30%), suggesting reliance on subsistence and traditional resource use rather than formal conservation employment. Bwera and Muhokya presented intermediate profiles, with mixed mentions of tourism, employment, and resource-based benefits—often tied to revenue sharing and environmental education programs. Kyambura respondents emphasized access to natural resources (83%) and community projects from revenue-sharing funds, but less tourism participation.

The mean number of distinct benefits reported per respondent differed significantly across sites ($F(6, 343) = 7.42$, $p < 0.001$; Figure 31). Communities near Kalinzu ($M = 2.4 \pm 0.9$) and QE-Kibale ($M = 2.3 \pm 1.0$) experienced the highest benefit diversity, while Rwenzori–Semliki recorded the fewest ($M = 1.3 \pm 0.7$). Post-hoc Tukey tests showed that Kalinzu and QE-Kibale significantly differed from Rwenzori–Semliki and Kyambura (all $p < 0.05$). Correlation analysis (Cramér's V) revealed a strong positive association between tourism income and employment ($V = 0.67$, $p < 0.001$), indicating these benefits often co-occur in tourism-active zones, while resource access correlated moderately with "other" benefits ($V = 0.31$, $p < 0.05$; Figure 32).

These results suggest that the nature and diversity of benefits from protected areas are context-dependent, shaped by local tourism infrastructure, conservation governance, and community participation schemes (Figure 33). Tourism-rich sites derive direct financial and employment gains, while remote or less-visited landscapes rely on ecosystem service access and collective livelihood initiatives. Collectively, the findings underscore that well-structured benefit-sharing mechanisms and community inclusion in conservation management enhance both local welfare and support for biodiversity protection.

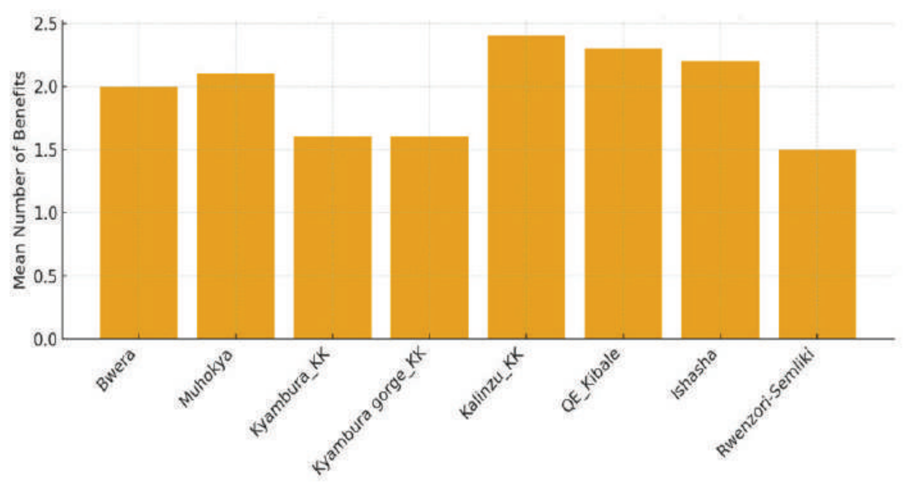


Figure 30: Bar chart showing variation in the average number of benefits mentioned per respondent.

Kalinzu (M = 2.4) and QE-Kibale (M = 2.3) exhibit the greatest diversity of perceived benefits, while Rwenzori–Semliki and Kyambura show the fewest (M ≤ 1.5), indicating spatial disparities in the breadth of opportunities derived from proximity to protected areas.

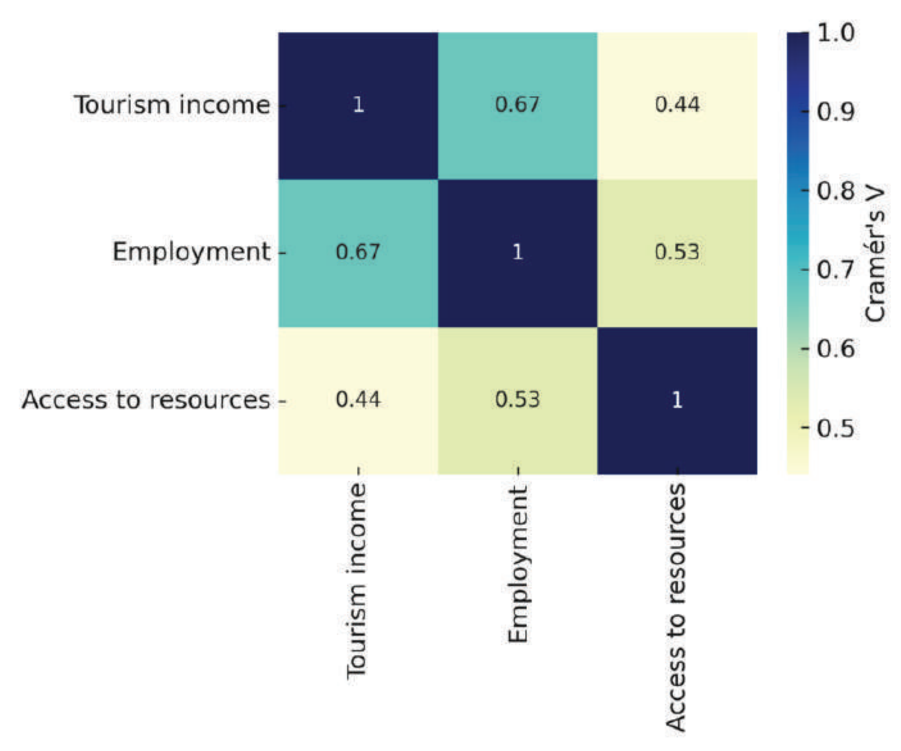


Figure 31: Heatmap illustrating the strength of association between benefit categories.

Tourism income and employment are strongly correlated (V = 0.67), suggesting that tourism development drives local job creation. Access to resources shows moderate overlap with both tourism (V = 0.44) and employment (V = 0.53), indicating partial interdependence between ecological access and economic opportunities near protected areas.

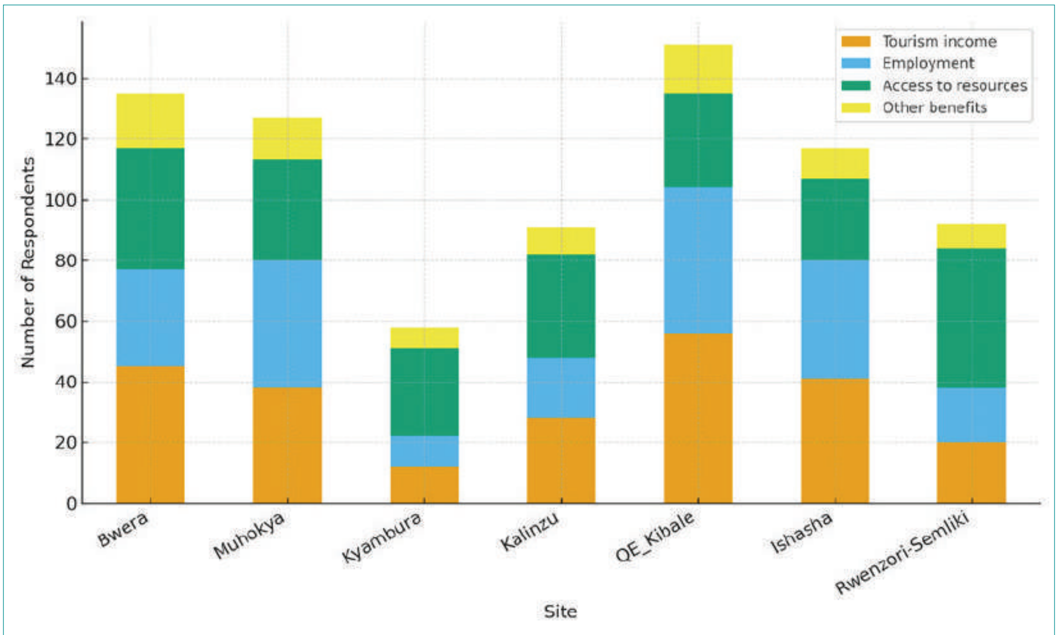


Figure 32: Stacked bar chart showing the proportion of respondents citing each benefit type—tourism income, employment, access to protected area resources (e.g., firewood, water, fish, medicinal plants), and other benefits such as revenue sharing—by site.

Tourism and employment benefits dominate in QE-Kibale, Ishasha, and Muhokya, whereas access to natural resources is the most prevalent benefit in Rwenzori–Semliki and Kyambura clusters.

Challenges of living near protected areas

Across all sites (N=263 responses), the most commonly reported difficulty was crop/livestock damage (reported in 231/263 = 87.8% of responses), followed by safety risks (128/263 = 48.7%), and restricted land use (113/263 = 43.0%). "Other" challenges were rarely marked in this dataset (0%). The distribution of challenge types differed sharply by site. Aggregating binary selections into a site × challenge contingency table and testing independence yields a highly significant association (χ^2 test on 6 sites × 3 core challenge types; $p < 0.001$), indicating that sites vary meaningfully in which problems dominate.

Site-level counts show that QE_Kibale and Ishasha report the heaviest burden of multi-dimensional conflict (many records include all three: damage, safety, and land-use limits), whereas Kyambura_KK and Kyambura gorge_KK include a higher share of single-issue reports (typically crop/livestock damage alone). The mean number of challenges per respondent also varied by site (from ~1.0–1.1 at Kyambura_KK/Kyambura gorge_KK to ~2.3–2.7 at QE_Kibale/Ishasha), reflecting greater co-occurrence of threats around Queen Elizabeth and Ishasha sectors (Figure 34).

Correlations among the three core challenge types (binary co-reporting) were positive overall; notably, safety risks tended to co-occur with crop/livestock damage and restricted land use, consistent with sites experiencing more frequent incursions also facing personal risk and use restrictions (Figure 35). Practically, these patterns argue for site-tailored strategies: crop damage mitigation is universal, but high-burden sites require simultaneous investment in safety measures (rapid response/ranger presence) and land-use conflict resolution, while lower-burden Kyambura sites can prioritize crop protection first (Figure 36).

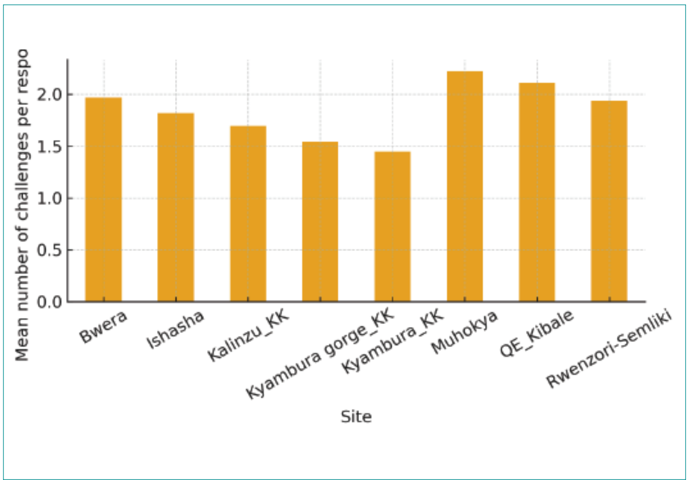


Figure 33: Bar chart of the mean number of challenge types reported per respondent by site (row-wise sum of binary selections divided by respondents).

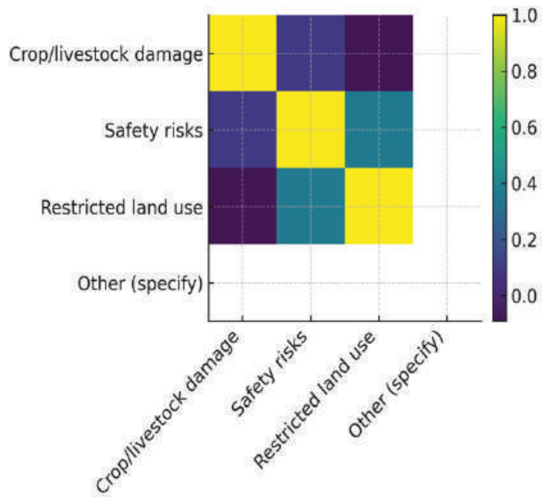


Figure 34: Correlation analysis among core challenges of living near a protected area.

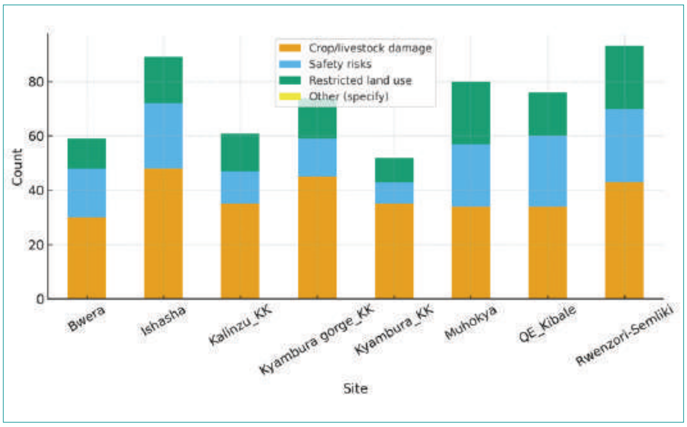


Figure 35: Stacked bar chart of reported challenge types (crop/livestock damage, safety risks, restricted land use) by site; counts per site are stacked by type.

Proposed solutions to minimize the cost of living near corridors (protected areas)

Respondents most frequently requested compensation schemes (254 selections; 79.6% of respondents), followed by community-based conservation projects (172; 53.9%), alternative livelihoods (131; 41.1%), and other measures (29; 9.1%). A site × option chi-square on the counts matrix indicated no strong evidence of heterogeneity in the overall mix of options across sites ($\chi^2(21)=27.13$, $p=0.167$). However, the number of options endorsed per respondent varied by site (one-way ANOVA on 0–4 selections: $F=11.46$, $p<0.001$), with higher endorsement intensity in several sites. The option indicators showed positive co-selection patterns (pairwise correlations among the four binary indicators ranged from small to moderate), consistent with respondents often favoring multiple, complementary measures rather than single silver bullets (Figure 36).

Aggregated selection counts (stacked bars) show compensation as the lead preference in every site, with community projects a strong second in QE_Kibale, Muhokya, and Rwenzori-Semliki; alternative livelihoods are especially visible in Ishasha and Rwenzori-Semliki (Figure 37). The mean number of measures per respondent (0–4 scale) was highest in QE_Kibale and Muhokya, intermediate in Ishasha and Rwenzori-Semliki, and lower but still substantial in Bwera, Kyambura (gorge/KK), and Kalinzu_KK, aligning with the ANOVA result (Figure 38)

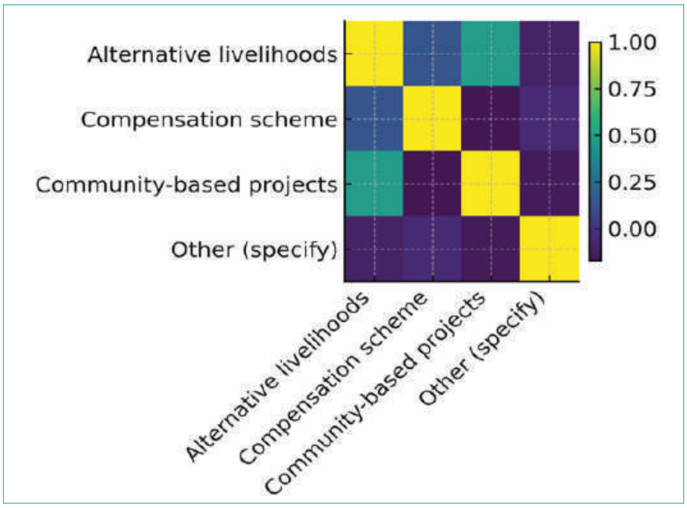


Figure 36: Heatmap of correlations among requested measure types. Cell intensity represents the Pearson correlation between binary indicators for selecting each option; darker cells indicate stronger co-selection.

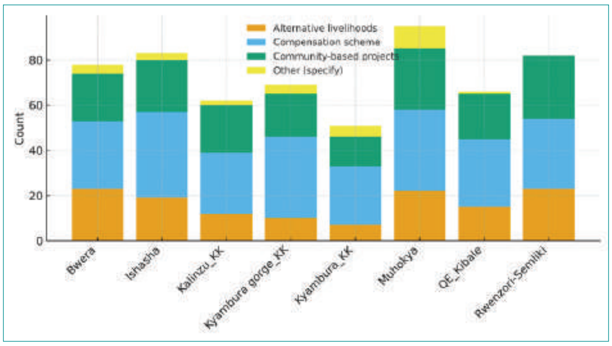


Figure 37: Stacked bar chart of coexistence measures requested by site.

Bars show the count of selections per option within each site; x-axis labels are angled to prevent overlap; legend identifies options.

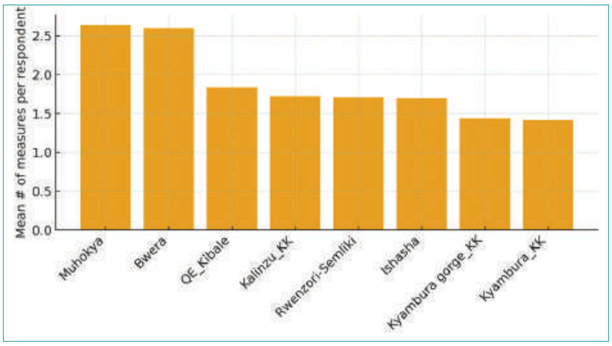


Figure 38: Mean number of measures requested per respondent, by site.

Bars show the average count of selected options (0–4) in each site; x-axis labels are angled to prevent overlap

Demographic Characteristics of Respondents

A total of 319 respondents were surveyed across eight sites bordering protected areas within the Greater Virunga Landscape. Sample sizes per site ranged from 30 in Bwera in Kyambura_KK to 49 in Ishasha (Table 10). The majority of respondents were aged 36–50 years, and the overall gender distribution was male-biased, with the proportion of males ranging from 48% in Kalinzu_KK to 68% in Kyambura_KK (Figure 39). Most respondents had attained primary-level education, a reflection of the generally low formal education levels typical of rural households near protected areas.

The mean family size ranged from 7.4 to 10.2 individuals, with the largest households observed in Muhokya and Rwenzori–Semliki, suggesting relatively high dependency ratios in these areas (Figure 40). Across all sites, over 75% of respondents were household heads, indicating that responses likely reflect decision-makers and land managers. The average duration of residence ranged from 22.4 years in Bwera to 31.2 years in Muhokya, showing a predominance of long-term residents with considerable place-based knowledge and experience with wildlife–human interactions (Figure 41).

These demographic patterns suggest that the sample captures a relatively stable and mature population segment, primarily male household heads with modest educational attainment and strong ties to their landscapes. This demographic profile is typical of agricultural and pastoral communities living adjacent to protected areas and provides context for interpreting their experiences with wildlife conflict, land use, and coexistence interventions.

Table 10: Summary of demographic characteristics by site

Site	Sample Size	Mean Family Size	Proportion Male (%)	Median Education Level	Proportion HH Heads (%)	Mean Residence (yrs)
Bwera	30	8.5	63.3	Primary	80.0	22.4
Muhokya	36	10.2	57.1	Primary	75.0	31.2
Kyambura gorge_KK	48	8.7	64.3	Primary	85.7	25.3
Kyambura_KK	36	9.1	68.2	Primary	81.8	23.6
Kalinzu_KK	36	7.4	48.0	Primary	72.0	28.7
QE_Kibale	36	8.9	53.1	Primary	78.1	30.5
Ishasha	49	7.8	60.0	Primary	83.3	28.4
Rwenzori-Semliki	48	9.3	55.0	Primary	76.0	26.9

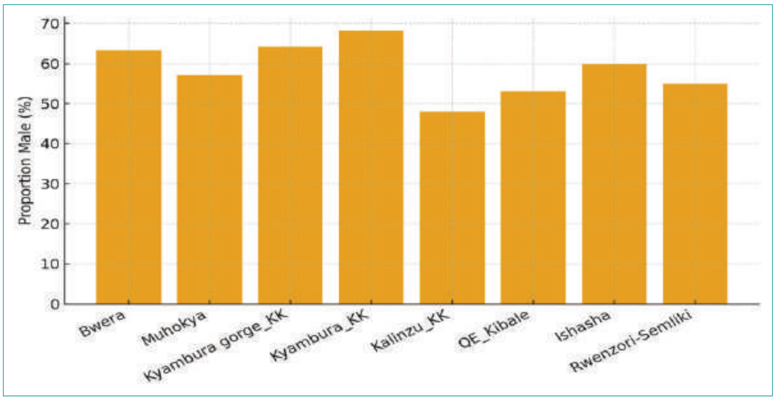


Figure 39: Proportion of male respondents by site.

This figure shows the percentage of male respondents at each study site, indicating a generally male-dominated respondent pool across the landscape.

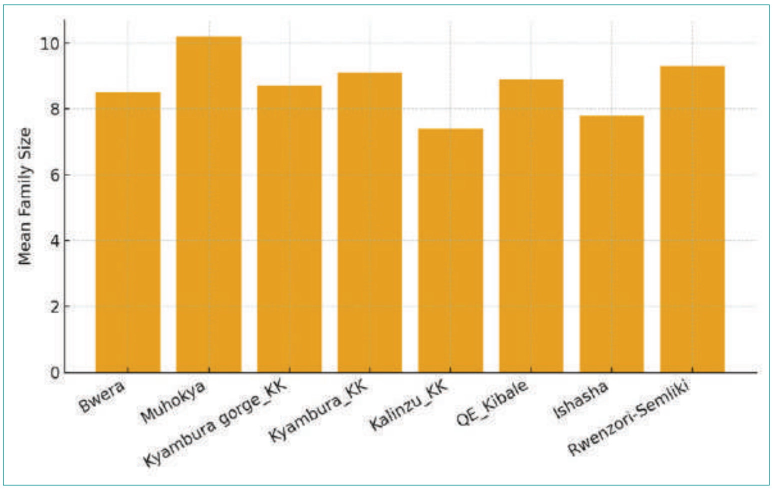


Figure 40: Mean family size by site.

Average household size (including dependents) across sites, showing relatively large family structures, particularly in Muhokya and Rwenzori–Semliki.

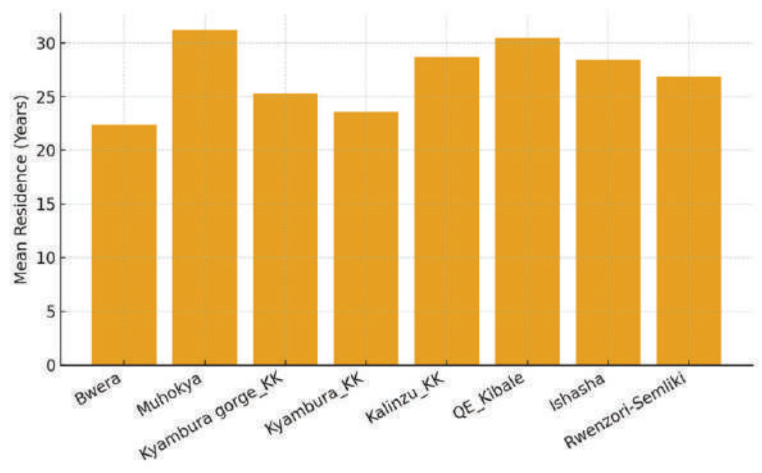


Figure 41: Mean years of residence by site.

Average duration of residence in each village, reflecting long-term settlement and potential for deep local ecological knowledge.

Sources of Livelihood across corridor sites

Across all sites, livelihoods are dominated by subsistence farming, frequently combined with livestock keeping and, to a lesser extent, business/trading and casual labor (Figure 42). Fishing is concentrated in Muhokya (often paired with livestock), while professional employment, remittances, tourism-related activities, and NGO/project support are rare across the sample. Site profiles show similar reliance on smallholder production systems, with modest diversification into petty trade and day labor; Kyambura (both sites) and Kalinzu show especially high stacking of subsistence farming with livestock keeping, while Ishasha and QE_Kibale display more frequent add-ons of casual labor and business/trading alongside farming (Figures 42, 43)

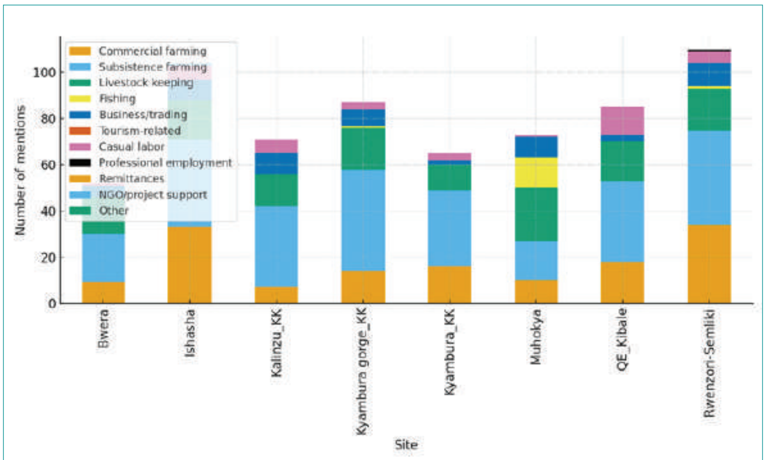


Figure 42: Counts of respondents selecting each livelihood option across all sites (multi-response question; totals exceed 100%).

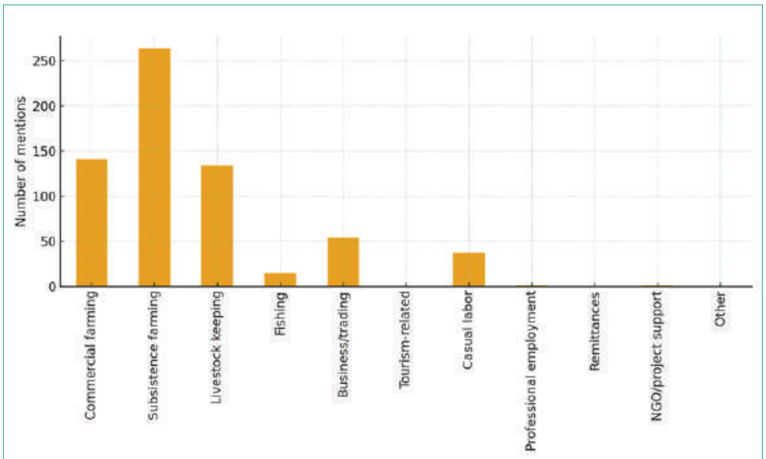


Figure 43: Counts of respondents selecting each livelihood option across all sites (multi-response question; totals exceed 100%). Bars are ordered by frequency to highlight the dominance of subsistence farming, followed by livestock keeping and business/trading.

4.3 Land cover and land use analysis

The land cover classification yielded an Overall Accuracy of 72.5% and a Kappa Coefficient of 0.67, indicating a substantial agreement between the classified map and the reference data. The maximum Kappa value of 0.67 is considered a good assessment of accuracy (Alam et al., 2021; Aneesha Satya et al., 2020; Perović et al., 2018; Rahman et al., 2017). These results demonstrate that the classification effectively captured the spatial distribution and heterogeneity of land cover types within the study area (Figure 44).

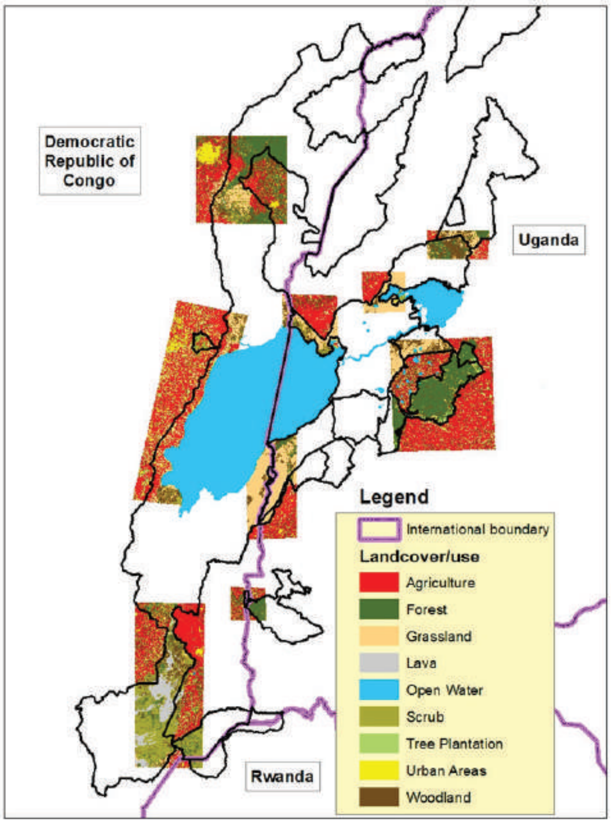


Figure 44: The 2025 landcover and landcover use map for the target corridors within the Greater Virunga Landscape.

4.3.1 Land cover and land use analysis – core and modified habitats

We estimated the core suitable and modified habitats within the corridors by reclassifying the landcover/ use classes into two categories: i) Natural habitat - representing core suitability that facilitates movement of target species, ii) Modified habitat representing increased resistance to the movement of the target species. The natural habitat category was derived by combining forest, grassland, scrub, and woodland classes, while the modified habitat category was derived by combining agriculture, tree plantation, and urban areas classes (Figure 45).

A total of eight corridors were mapped containing modified habitats (i.e., agriculture, tree plantation, settlements) which increases resistance to the movement of the target species - they are highlighted in orange (Figure 45, left).

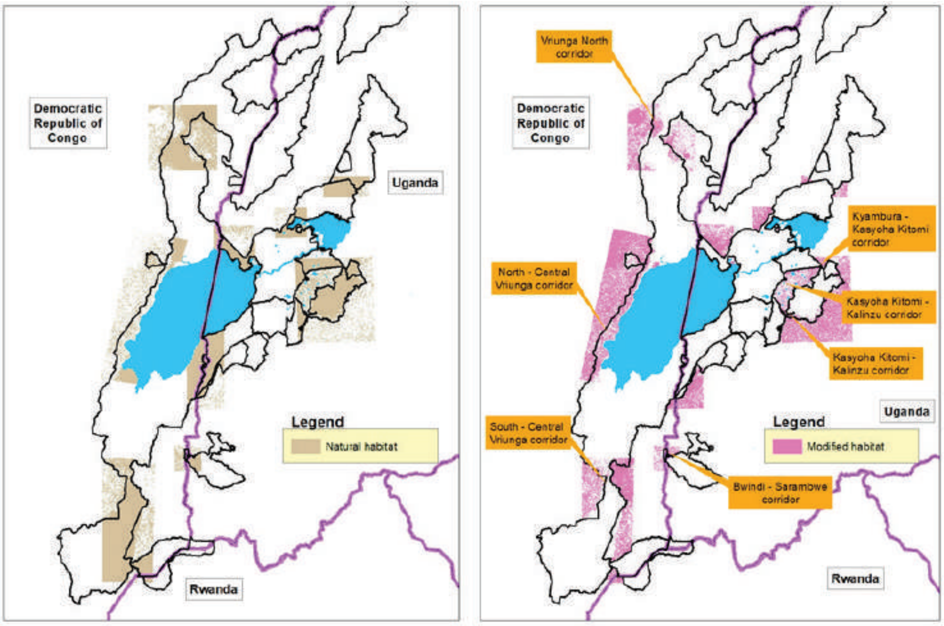
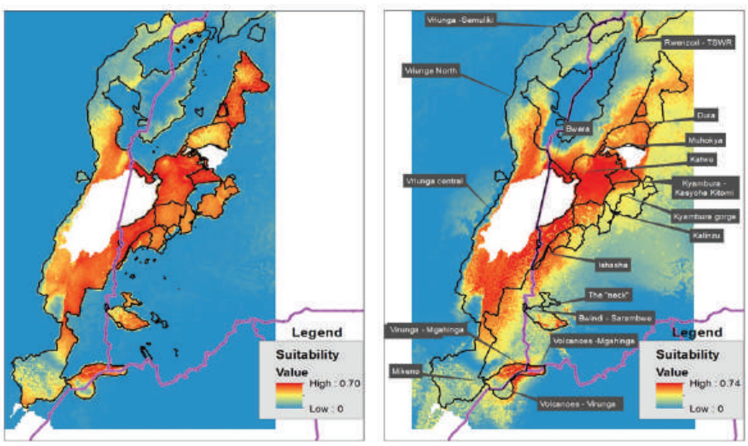


Figure 45: Distributoin of natural (right) and modified (left) habitats within the target corridors.

4.4 Socio-economic and habitat suitability modeling

We used Maximum Entropy modeling approach to predict the realized and potential suitable habitats for elephants, lions, chimpanzees, and mountain gorillas within the Greater Virunga Landscape using a combination of socio-economic and ecological variables, and ecological variables separately – to identify the most feasible remaining wildlife corridors for management and conservation in the Greater Virunga Landscape.

The socio - ecological suitability model estimated the realized and potential distribution accounting for climatic variability and being constrained by anthropogenic threats (e.g., population density, distance to park boundary), while the ecological model estimates the realized and potential distribution under the equilibrium assumption (i.e., species occupies all the available suitable habitat; Figures 46, 47, 48, 49). Thus, we identified the most feasible corridors for all the four target species based on their predicted realized and potential distributions, and potential threats as accounted for by the socio-economic model.



Elephant – suitability modeling

The suitability models show that elephants are widely distributed within the Greater Virunga Landscape (Figure 46). Of the 20 corridors identified, elephants were predicted to use 18 (Figure 46).

Figure 46: Elephants - probability of suitability under the socio-ecological model (left) and ecological model (right).

African lion – suitability modeling

Of the 20 corridors identified, lions were predicted to use five (Figure 47).

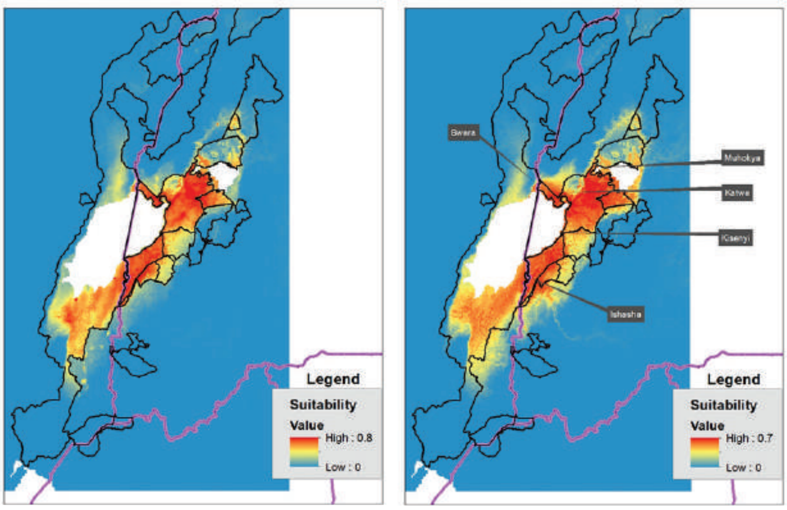


Figure 47: African lions - probability of suitability under the socio-ecological model (left) and ecological model (right).

Chimpanzee – suitability modeling

Of the 20 corridors identified, chimpanzees were predicted to use six (Figure 48)

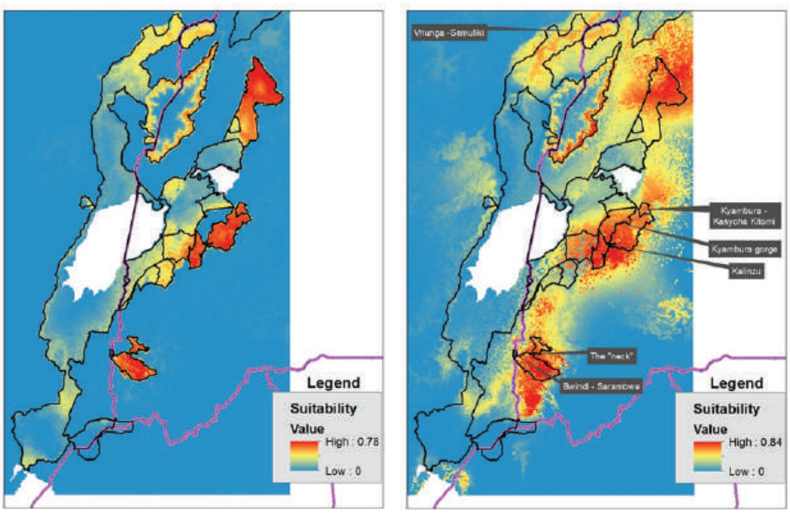


Figure 48: Chimpanzees - probability of suitability under the socio-ecological model (left) and ecological model (right).

Mountain gorilla – suitability modeling

Of the 20 corridors identified, mountain gorillas were predicted to use five (Figure 48)

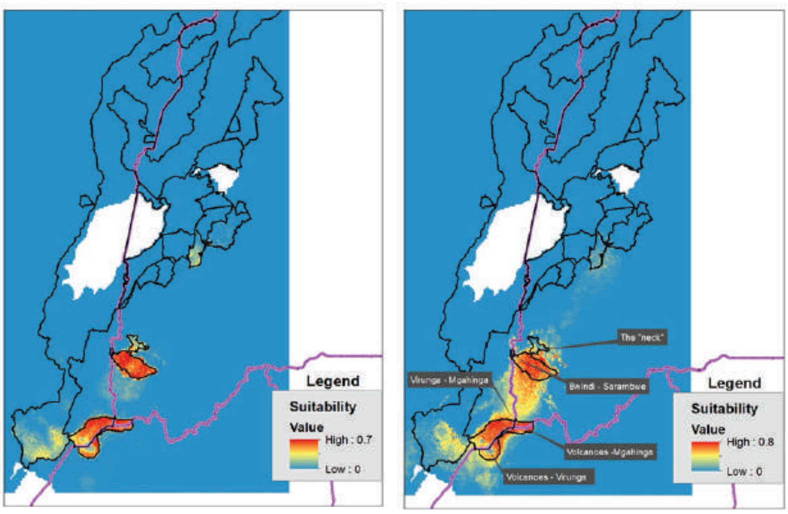


Figure 49: Mountain gorillas probability of suitability under the socio-ecological model (left) and ecological model (right).

Table 11: A summary of characteristics of each corridor (i.e., target species, protected area, country, governance, habitat integreity, functionality, habitat type, threats)

ID	Corridor	Target species	Protected Area	Country	Governance	Status	Functionality	Habitat	Threats
1	**Ishasha**	Lions, Elephant	QEPA, VNP	Uganda & DRC	ICCN, UWA	Natural	Realized	Savanna	Poaching
2	**Bwera**	Lions, Elephant	QEPA, VNP	Uganda & DRC	ICCN, UWA	Natural	Realized	Savanna	Poaching,
3	**Muhokya**	Lions, Elephant	QEPA	Uganda	UWA	Natural	Realized	Savanna	Poaching, narrow corridor width (~600m), human - wildlife conflict
4	**Dura**	Elephant	QEPA, Kibale NP	Uganda	UWA	Natural	Realized	Forest	Poaching
5	**Kyambura - Kasyoha Kitomi**	Chimpanzee, Elephant	Kyambura WR, Kasyoha Kitomi FR	Uganda	UWA, NFA	Natural	Realized	Forest	Corridor width is narrow (~350m)
6	**Kyambura WR (Gorge) - Kasyoha Kitomi FR**	Chimpanzee, Elephant	Kyambura WR, Kasyoha Kitomi FR	Uganda	UWA, NFA, Community	Modified	Potentially	Forest	Habitat degradation, Corridor width narrow (riverine forest)
7	**Kalinzu - Kasyoha Kitomi**	Chimpanzee, Elephant	Kalinzu FR, Kasyoha Kitomi FR	Uganda	UWA, NFA	Modified	Potentially	Forest	Habitat degradation
8	**Bwindi – Sarambwe**	Mountain gorilla, Chimpanzee, Elephant	Bwindi INP, Sarambwe NR	Uganda	ICCN, UWA	Natural	Realized	Forest	Poaching, habitat degradation
9	**Mikeno**	Elephant	VNP	DRC	ICCN	Natural	Realized	Forest	Poaching, habitat degradation, civil armed conflict

ID	Corridor	Target species	Protected Area	Country	Governance	Status	Functionality	Habitat	Threats
10	Kisenyi	Lions	QEPA	Uganda	UWA	Natural	Realized	Forest	Poaching
11	Virunga North	Elephant	VNP	DRC	ICCN	Modified	Potentially	Savanna - forest ecotone	Poaching, habitat loss & degradation, civil armed conflict
12	Virunga Central	Elephant	VNP	DRC	ICCN	Modified	Potentially	Savanna	Poaching, habitat loss & degradation, civil armed conflict
13	Virunga South	Elephant	VNP	DRC	ICCN	Modified	Potentially	Savanna - forest ecotone	Poaching, habitat loss & degradation,civil armed conflict
14	Katwe	Lions, Elephant	QEPA	Uganda	UWA	Natural	Realized	Forest	Poaching
15	The neck	Mountain gorilla, Chimpanzee, Elephant	Bwindi INP	Uganda	UWA	Natural	Realized	Forest	Poaching, corridor is narrow
16	Virunga – Semliki	Chimpanzee, Elephant	VNP, Semliki NP	DRC & Uganda	ICCN, UWA	Natural	Realized	Forest	Poaching, habitat loss & degradation, armed conflict
17	Rwenzori - Semliki	Elephant	Rwenzori NP, Semliki WR	Uganda	UWA, Community	Modified	Realized	Savanna	Habitat loss and degradation
18	Volcanoes -Mgahinga	Mountain gorilla, Chimpanzee, Elephant	Volcanoes NP, VNP	DRC & Uganda	RDB, UWA	Natural	Realized	Forest	Poaching, climate change
19	Virunga - Mgahinga	Mountain gorilla, Elephant	Mgahinga GNP, VNP	Rwanda & DRC	RDB, UWA	Natural	Realized	Forest	Poaching, climate change
20	Volcanoes - Virunga	Mountain gorilla, Elephant	VNP, Volcanoes NP	Rwanda & Uganda	ICCN, RDB	Natural	Realized	Forest	Poaching, climate change

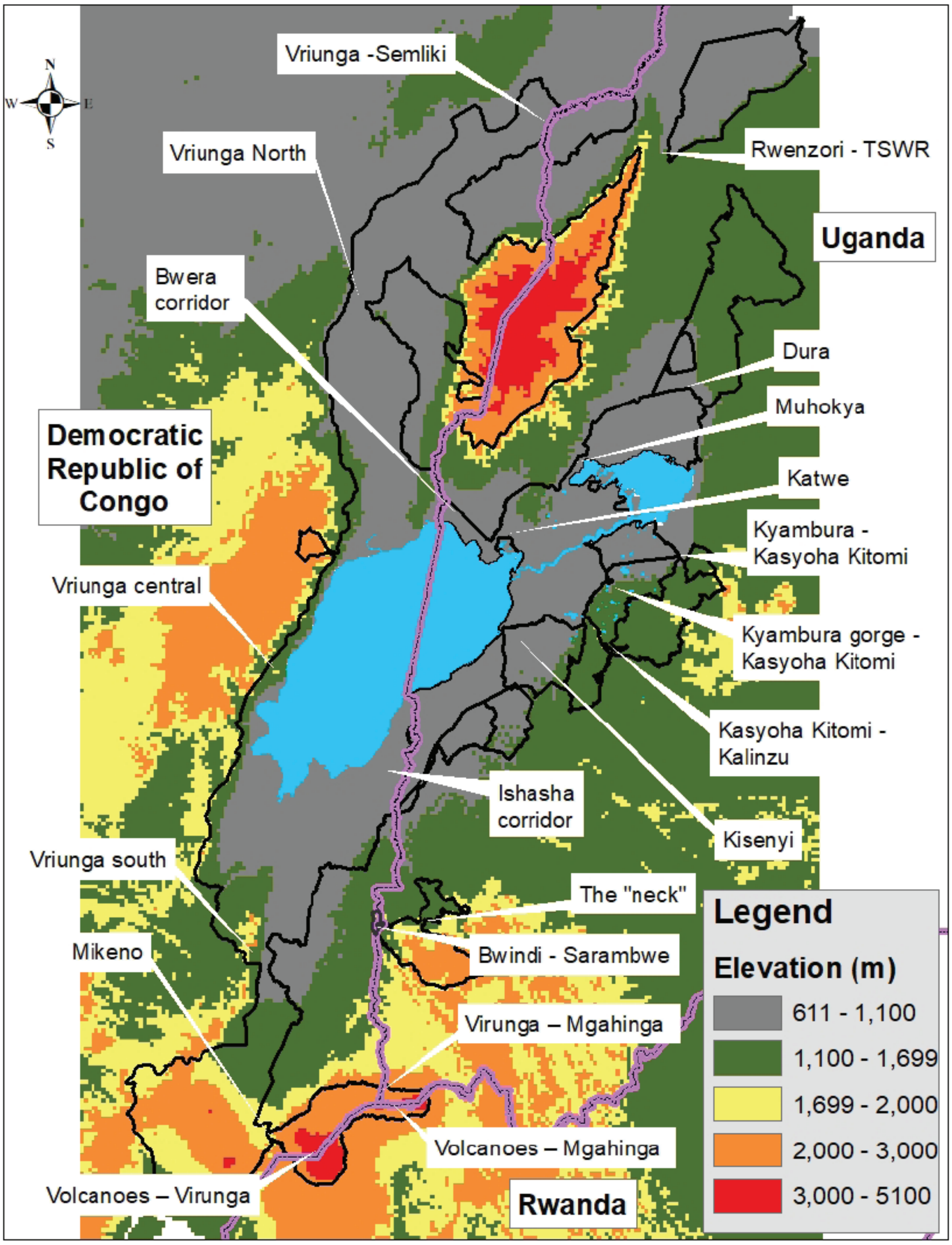


Figure 50: Map of the Greater Virunga Landscape showing all the 20 assessed corridors and the elevation gradient

5. Discussion

We assessed the status and functional connectivity of the seven existing corridors and identified 13 new corridors focusing on four target species (elephants, lions, chimpanzees, mountain gorillas) within and around the Greater Virunga Landscape (Table1, Figures 2, 3, 4, 5). Of the 20 corridors assessed, 75% (15) were categorized as currently functional, while the remaining corridors were classified as potentially functional based on the presence or absence of recent species' occurrence records (2010 – 2025), and the reported species habitat use during the ecological and social surveys (Figures 2, 3,4, 5, 46, 47, 48, 49, 50).

The results of a literature review, suitability modeling, landcover and land use mapping, ecological and social surveys were used to identify potential corridors for the four target species. Elephants were the most widely distributed species in the Greater Virunga Landscape inhabiting both savanna and forest habitats, and potentially utilizing all the corridors identified (Figures 2, 46). Furthermore, we documented corridor use by elephants between the Greater Virunga Landscape (specifically Rwenzori National Park) and Toro-Semlki National Park.

Lions were majorly ranging in the northern, and Ishasha sectors of Queen Elizabeth National Park (QENP), and the southern sector of Virunga National Park (VNP) – suggesting that the savanna habitats in both Queen Elizabeth and Virunga National Parks are important for the long-term survival of lions in the landscape (Figure 3, 47). Corridor habitat use by lions was documented and predicted for the Ishasha corridor (connecting southern QENP and VNP), Kisenyi corridor (connecting southern and northern sectors of QENP), Bwera corridor (connecting northern QENP and VNP) and the Muhokya corridor (connecting Kasenyi to Dura sectors within QENP).

Chimpanzee corridor habitat use (six) was documented and predicted for the Virunga – Semliki corridor (linking northern VNP and Semliki NP), Kyambura Wildlife Reserve and Kashyoha Kitomi Forest Reserve, Kyambura gorge and Kashoyha Kitomi Forest Reserve, Kalinzu and kasyoha kitomi Forest Reserves, and within the Bwindi – Sarambwe ecosystem (Figures 4, 48). The chimpanzee habitat suitability models indicate that most of their historical niche that's no longer available due land use change stretched from Kisoro district to the north of Kibale National Park through Maramagabo-Kalinzu and kasyoha kitomi Forest Reserves, east of lake Gergo and through Mpanga (Figure 48).

Mountain gorillas inhabit the Bwindi – Sarambwe ecosystem and the Virunga massif (Figure 5). We documented and predicted mountain gorilla corridor use linking Bwindi Impenetratable National Park and Sarambwe Nature Reserve, and the northern and southern sectors of Bwindi Impenetrable National Park, and within the Virunga massif among the three protected areas (Volcanoes - Mgahinga, Virunga - Mgahinga, Volcanoes – Virunga, Figures 5, 49). The ecological habitat suitability model for the mountain predicted the availability of a potential niche between Bwindi – Sarambwe ecosystem and Virunga massif, while socio-ecological suitability predicted the realized and potential niche to be limited by protected area boundaries (Figure 49). These results suggest that the current distribution of mountain gorillas is limited by anthropogenic activities, and the area between Bwindi -Sarambwe ecosystem and Virunga massif could be part of its historical range (McGahey et al. 2013).

Status of key species (populations and trends)

Despite populations decline of the African elephants throughout most of their range, there has been a steady increase of their populations in the Greater Virunga Landscape. Across the surveyed corridors, elephants were generally perceived as increasing (Figures 15, 16, 17, 18). These findings are consistent with aerial survey results that show a population increase of elephants in Queen Elizabeth Protected Area (Lampret et al., 2020). The elephant population in Queen Elizabeth National Park has steadily increased from 400 individuals in the 1980's to 4711 individuals in 2018 (Figure 6). Similarly, the elephant population is showing an increasing trend in the Virunga Massif, Kibale National Park, and Bwindi Impenetrable National Park – Uganda (Twahirwa et al., 2025; UWA, 2018; Hickey et al., 2019a, 2019b). The increase of elephants in Queen Elizabeth National Park is also attributed to immigration across the Ishasha corridor from Virunga National Park (Plumptre et al., 2007).

Lion sightings were mostly reported to occur in the savannah corridors of Muhokya and Ishasha (Figure 16). The population trend of lions was perceived to be decreasing in the Ishasha corridor, while it was stable in the Muhokya corridor (Figure 18). Generally, the lion population in Queen Elizabeth Protected Area has experienced a steep decline of more than 70% from 144 individuals in 2010 to 39 individuals in 2022 (Figure 5; UWA, 2024). Although, the prey population is increasing in both Queen Elizabeth and Virunga National Parks (Lamprey et al., 2020), the lion population in the landscape continues to decline due to poaching as a by catch, human-wildlife conflict, habitat loss and degradation, lack of awareness about the importance of carnivores in general, and the lack of coordinated research on lions to inform conservation actions (UWA, 2024).Treves et al. (2009) predicted a maximum of 132 and 82 lions to inhabit Queen Elizabeth National Park and Virunga National Park, respectively, during the period 2003 -2006 based on prey biomass. The study concluded that the two protected areas have a potential abundance of lions of 905 individuals – given that the threats were mitigated (i.e., prey depletion due to poaching, retaliatory killings).

Habitat use by chimpanzees was documented in the forest corridors of Kyambura gorge_KK and Kyambura_KK (Figures 15, 16, 17). The population trend of chimpanzees around these corridors was perceived to be generally stable (decreasing in some areas and increasing in others). A recent census of chimpanzees in Uganda showed that their populations are either stable or increasing in most protected areas within the Greater Virunga Landscape (Figure 7; Nangendo et al., 2022, Plumptre et al., 2003). For example, the population of chimpanzees in Kibale National Park was 921 individuals in 2007 and 1,001 in 2019, while their population in Kalinzu and Marmagambo forests was 715 in 2007 and 695 individuals in 2019 (Figure 7). The population estimate for chimpanzees in Virunga National Park (ie., Semuliki forests) was estimated at 1327 individuals in 2008 (Plumptre, 2008a). During the same field excursion, chimpanzee nests were recorded along the Ishasha river, in addition to the observing 10 chimpanzees. The observation of chimpanzees along the Ishasha river suggested potential dispersal from Maramagambo and Kalinzu forest Reserves.

The population of mountain gorillas increased from 340 individuals in 2006 to 470 individuals in 2018 in Bwindi – Sarambwe ecosystems, and from 458 individuals in 2010 to 604 individuals in 2016 in the Virunga massif (Hickey et al., 2019a, Hickey et al., 2019b; UWA, 2018; Robbins et al., 2011; Figures 8 & 9). The increase of mountain gorilla populations in Bwindi – Sarambwe ecosystem, and Virunga Massif is attributed to the reduction of direct threats (poaching, and diseases). A study on the population trends of mountain gorillas in the Virunga Massif showed that habituated mountain gorilla groups had a higher population growth rate compared to unhabituated gorillas due to the additional care received by the habituated groups (Robbins et al., 2011)

Threats to corridors

Habitat loss and degradation, and poaching are the two major threats affecting status and functionality of corridors in the Greater Virunga Landscape (Christensen, & Arsanjani, 2020; Musavandalo et al., 2024; Plumptre et al., 2017; Plumptre et al., 2014). The 2025 landcover and use map for the Greater Virunga Landscape showed that 43% (7) of the identified corridors were impacted by habitat loss and degradation (Figures 44 & 45). Habitat loss and degradation within corridors was primarily documented in Virunga National Park (i.e., Virunga north corridor, Virunga central corridor, Virunga South corridor), Sarabwe Nature Reserve (i.e, Bwindi – Sarabwe corridor) in the Democratic Republic of Congo (DRC), and the Kyambura gorge_KK, and Kalinzu_KK corridors in Uganda (Figure 44). The high rate of habitat loss and degradation in Virunga National Park is attributed to civil wars in Eastern DRC that have compromised the administration of protected areas in the region. Habitat loss and degradation has been mostly documented for the northern, western (bordering lake Edward), and southern sectors of Virunga National Park (Musavandalo et al., 2024; Christensen, & Arsanjani, 2020; Plumptre et al.,2017). The Kyambura gorge_KK corridor which links Kyambura Wildlife Reserve (gorge) to Kashyoha Kitoma Forest Reserve, has a highly degraded riverine forest (Kyambura river). The 100m riverbank protected zone for Kyambura river has been degraded by subsistence farmland and tree plantations, and thus requires restoration along with buffer crops to reduce human–wildlife conflicts. The Kalinzu_KK corridor land use is under plantation forestry. Under the National Forestry Authority Collaborative Forest Management (CFM) program, local communities planted eucalyptus, and pine plantations within the three km wide corridor – which negatively affected the corridor functionality by increasing resistance to the movement of the target species (Liu et al 2018; Elisa et al., 2024). Collaborative Forest Management program was designed with the aim of delivering a net positive impact on both conservation and livelihoods (Mawa et al 2022, Mawa et al., 2020). As such, there is need to balance conservation and livelihood goals under Collaborative Forest Management to enhance corridor functionality.

An analysis of the Greater Virunga Landscape ranger-based monitoring data (2000 – 2012), found that poaching was prevalent along the Ishasha, Muhokya, Dura, Kyambura_KK, Bwera, Virunga north and south corridors (Plumptre et al., 2017; Critchlow et al., 2015; Plumptre et al., 2014). Additionally, recent illegal activity data for the Queen Elizabeth Protected Area (2014 – 2022), identified Muhokya, Dura, and Bwera corridors as hotspots. However, poaching showed a decreasing trend from 600 incidences in 2019 to 178 incidences in 2022 across the Queen Elizabeth Protected Area. The declines in poaching incidences could be attributed to increased law enforcement and/or the ongoing program of fencing the park using an electric fence to mitigate human – wildlife conflicts.

Human – wildlife interactions and interventions along corridor sites

Across the Greater Virunga Landscape elephants accounted for more than half of the all the human wildlife conflict incidences (crop raiding) – especially in Bwera, Muhokya and Ishasha (Figures 16, 24, 25, Tables 5, 6). The results from the social- economic survey are consistent with spatial overlay analysis and suitability modeling which showed that elephants are the most widely distributed target species in the Greater Virunga Landscape (Figure 10). Human wildlife conflict incidences by lions were localized to Muhokya and Ishasha corridors – indicating persistent carnivore presence along key savanna corridors. While chimpanzee human – wildlife conflict incidences were localized along the forest corridors of Kalinzu_KK, Kyambura gorge_KK, and Kyambura_KK. Overall, conflict profiles reflected distinct ecological gradients across the landscape from forest - agriculture mosaics to open savanna systems - emphasizing the need for corridor-specific mitigation approaches).

Previous studies on human wildlife conflict in the GVL, identified elephants, chimpanzees, habituated mountain gorillas and lions being among the some of the major (e.g., Seiler & Robbins, 2016; Babaasa et al., 2013; Chiyo & Cochrane, 2005). As such, results from previous studies are consistent with the socio-economic survey results from this survey.

There was a strong spatial gradient in wildlife–livestock conflict across the surveyed corridor sites. Losses were disproportionately concentrated in Muhokya and Ishasha, reflecting both high predator density and extensive livestock ownership. Livestock losses in the Muhokya corridor accounted for 62.1% (UGX 41.5) of the total reported value – highlighting the opportunity cost of living near protected areas. Carnivore predation, primarily by lions and leopards, accounted for the bulk of reported losses, while omnivorous species such as baboons and elephants contributed to smaller but more widespread damages. Despite the low frequency of human casualties, the associated economic and psychological burden remains considerable, particularly for subsistence livestock keepers.

The most impactful and positively perceived intervention in relation to mitigating human-wildlife conflicts around the corridor sites were physical barriers (Table 7; Figures 26, 27, 28) Physical barriers (e.g., trenches, electric fence) significantly outperformed non-structural measures (Figures 27, 28). Awareness programs and ranger support contributed moderately, particularly when implemented alongside barriers, while compensation mechanisms remain ineffective in practice due to poor delivery or coverage. The spatial inequality in intervention presence, with some sites reporting no action at all, emerges as a major limitation to equitable conflict management across the Greater Virunga Landscape.

Respondents showed a consistent belief that government institutions remained the principal and most trusted agents in mitigating human - wildlife conflict, particularly in areas where infrastructure (fences) or ranger deployment were evident. However, community-based approaches showed prominence where formal enforcement is weak, emphasizing the adaptive, locally owned mechanisms emerging in lower-capacity zones such as Rwenzori–Semliki and Kyambura. The comparatively limited preference of NGO-led efforts may reflect shorter project cycles or less visibility at household level. Overall, these results indicated a dual governance model, where government infrastructure and ranger support provide the backbone of formal mitigation, complemented by grassroots vigilance networks that fill operational gaps.

Governance structure and effectiveness

Governance across the GVL demonstrates a layered and institutionally diverse structure that reflects the transboundary nature of the ecosystem. The landscape is primarily administered through a network of state and intergovernmental frameworks, with additional influence from private partnerships and community-based management arrangements. The combined effect of these governance types underpins the landscape's resilience but also highlights the need for coherence across jurisdictions and institutional mandates.

The predominance of state and transboundary governance, anchored in the mandates of the UWA, the ICCN, the RDB, and coordinated under the GVTC forms the legal and operational backbone of conservation management in the region. These agencies collectively ensure that the GVL's protected areas are managed under statutory frameworks, providing consistency in enforcement, monitoring, and ecological planning. Complementing this, the CFM initiatives led by the NFA formalize the participation of Indigenous Peoples and Local Communities in the stewardship of Central Forest Reserves such as Kasyoha-Kitomi and Kalinzu (NFA, 2019).

This integration of statutory oversight with local participation embodies a practical approach to decentralizing conservation responsibilities while enhancing local legitimacy.

The GVTC Treaty represents one of the most advanced examples of transboundary conservation governance in sub-Saharan Africa. It establishes a legal foundation for shared management of wildlife corridors and protected areas that straddle national boundaries, notably in the Ishasha and Bwindi–Sarambwe corridors (GVTC, 2015). Through joint operational committees and harmonized management plans, the treaty provides the enabling environment for data sharing, coordinated law enforcement, and synchronized ecological monitoring. This institutionalized collaboration seeks to mitigate the risks associated with fragmented national policies and enhances the continuity of conservation actions across borders.

In the Democratic Republic of Congo, the ICCN–Virunga Foundation partnership stands as a model for state–private co-management. The partnership delegates operational responsibilities for Virunga National Park to the Virunga Foundation while maintaining ICCN's statutory authority (Virunga Foundation, 2014). This arrangement has improved funding stability, bolstered enforcement capacity, and fostered community engagement programs that align conservation objectives with local socio-economic development. It reflects the potential of hybrid governance structures to address persistent challenges of capacity and resource scarcity in state-managed systems.

Equally significant is the contribution of community-led governance mechanisms, particularly those facilitated through CFM and other participatory frameworks. These initiatives have strengthened local stewardship by embedding communities in the decision-making process, granting resource access rights, and formalizing benefit-sharing agreements. Evidence from forest corridors such as Kasyoha-Kitomi and Kalinzu demonstrates that these arrangements improve conflict mitigation, reduce illegal resource extraction, and increase household incentives for sustainable resource use (WWF, 2018). The participatory nature of such governance approaches reinforces social cohesion and aligns conservation outcomes with community welfare.

The effectiveness of corridor governance in the GVL ultimately hinges on policy harmonization between wildlife and forestry institutions, institutional strengthening of community-based frameworks, and the sustainability of transboundary collaboration under the GVTC mechanism. Harmonizing management standards and information-sharing protocols among UWA, NFA, ICCN, and RDB will be critical to avoiding jurisdictional overlaps and ensuring coherent ecological outcomes. At the same time, reinforcing CFM structures can amplify the role of IP&LCs as custodians of landscape connectivity, ensuring that conservation benefits are equitably distributed.

Sustained investment in transboundary collaboration, backed by formal treaties and community-level participation, offers resilient governance architecture capable of withstanding political shifts and institutional fragmentation. The GVL thus serves as a living lab for testing integrative governance models that combine state authority, local empowerment, and cross-border cooperation to achieve long-term ecological and social resilience.

Conclusion – corridor Status and functionality

We established the status and functional connectivity of 20 corridor sites within the GVL targeting four umbrella species (i.e., lions, elephants, chimpanzees, mountain gorillas, Table 11). The status of the corridors was assessed in relation to the habitat condition and quality at the site, while the functional connectivity was assessed based on the whether species occurrence records of the target species intersected with the site and/ the site was predicted to be suitable. We found that 75% (15) of the corridors had unmodified habitat (natural), and were providing ecological connectivity to the target species. The remaining corridors (5) that are potentially nonfunctional were primarily affected by habitat loss and degradation specifically in Virunga National Park (i.e., Virunga north, Virunga central, Virunga south), the Kasyoha-Kitomi Forest Reserve, and in the community area along Kyambura river. Elephants were the most widely distributed species in the GVL, potentially using all the assessed corridors in the GVL, except one (Kalinzu_KK). Lions and chimpanzees were identified to be using five corridors, while mountain gorillas were using two corridors.

Our study highlights the importance of corridors within the GVL in relation to facilitating ecological connectivity between and within protected areas, and the need to develop corridor specific mitigation measures to improve their management and conservation.

Study limitations

During the execution of this study, we faced some limitations that should be considered while interpretating the results.

i. Data access and availability: We encountered challenges in accessing recent species and threat data (2014 – 2024) from the GVL partners. Most of the data gaps are in relation to Virunga National Park, Bwindi Impenetrable National Park, Rwenzori National Park, Volcanoes National Park, and Kibale National Park.

ii. Time constraints: This study was scheduled to be completed within a period of three months (90 days). However, due to delays in accessing the data from partners – we were unable to complete the study within the scheduled timeframe.

5.1 Recommendations - General

To enhance wildlife corridor management and conservation, the Conserved and Protected Areas, including OECMS, we recommend the following measures to managers and policymakers.

i. Strengthening law enforcement to prevent encroachment (habitat loss and degradation) and poaching. Generally, managers can enhance the effectiveness of law enforcement to deter encroachment and poaching by increasing patrol coverage at corridor sites that have been identified as hotspots using ranger-based monitoring data on illegal activities. In situations, where habitat loss and degradation has already occurred or is ongoing – protected area mangers can carry out community engagements to determine, demarcate the boundary, and evict the encroaches in combination with developing long-term law enforcement, and habitat restoration plans. This recommendation assumes that the corridor sites are under the management of park authorities, which is not the case for some of the corridor sites in Virunga National Park where there is insecurity. In situations where there is insecurity, protected area authorities have to wait for peace to prevail.

ii. Mitigating human wildlife conflict at corridor sites by promoting physical barriers (e.g., electric fencing, trenching), compensation schemes, and community-initiated projects. Communities living near the corridor sites in the GVL identified physical barriers, compensation schemes and community-initiated projects as their preferred mechanism of mitigating human wildlife conflicts. As such we recommend that protected area managers and policy makers should implement and operationalize the application of physical barriers (especially electric fencing), in combination with a community governed compensation schemed to mitigate human wildlife conflict at corridor sites.

iii. Enhancing corridor functionality in community areas. The opportunity cost of living near protected areas is generally considered high due to crop raiding and/ depredation. Thus, reviving the functionality of corridors that occur in community areas (e.g., Kyambura gorge - Kasyoha-Kitomi Forest Reserve) requires buy-in from community members. Together with developing a habitat restoration plan, managers and policy makers should develop a community engagement plan. Consequently, major goals of the community engagement plan should include developing comprehensive measures to mitigate potential human wildlife conflicts, and to assess potential incentives (e.g., access to markets for the buffer crops) to community members living near the corridor sites.

iv. Assessing effects of Collaborative Forest Management (CFM) on corridor sites. Collaborative Forest Management was developed by the National Forestry Authority with the goal of promoting conservation and improving the livelihoods of communities living near Forest Reserves in Uganda. Some of the allowed activities under CFM include - collecting non-timber forest products (e.g., firewood), and developing tree plantations. Thus, some of the corridor sites under the National Forestry Authority management (e.g., Kasyoha-Kitomi Forest Reserve) have pine and eucalyptus plantations - which increase resistance to movement of the target species.

We recommend that in identified corridor sites - community members should be encouraged to plant native trees in combination with additional incentives (e.g., access to premium carbon markets) – given that native trees take a longer period to mature.

v. Identifying potential land for expanding the size of the narrow corridor sites (e.g., land purchase or leasing). Some of the corridors in the GVL are very narrow (e.g; Muhokya corridor ~600m, Kyambura_KK ~300m). The land-tenure system around the corridor sites in the GVL was dominated by personally/family-owned land, followed by leasehold/rented land - suggesting that land decisions are primarily made at the household level rather than at community level. A study to purchase 66ha of land under cultivation between Kyambura and KKFR corridor was estimated at US$ 142,805 in 2006 (Nampindo et al., 2006). Using an inflation rate of 5% inflation per year since 2006 (19 years), would bring the current potential price to US$ 360,676, approximately $5,465 per ha. Although the present price of land around the narrow corridors might higher compared to our estimates, this example shows that the price of land will continue to increase in the future. Land leasing together with planting buffer crops has been proposed as an option to land purchasing (Nampindo et al., 2006)

vi. Carry out research based on the identified data gaps. We recommend - conducting an ecological and social economic survey for all the new corridors, assessing the effects of Collaborative Forest Management on corridor use by the target species, assessing the effect of the electric fence on corridor use by the target species, assessing wildlife use of corridors across seasons, assessing how governance affects decision making across corridors among stakeholders, assessing the sustainability of compensation schemes as a mechanism to mitigate human wildlife conflicts, assessing the benefits of community initiated projects vs other approaches of delivering assistance to communities living near protected areas, and the dissemination of these research findings back to the community.

5.2 Corridor specific recommendations

1. Ishasha (Uganda and DRC) – This is transboundary savanna corridor that links southern Queen Elizabeth National Park (Uganda) to Virunga National (DRC) along the Ishasha River. The habitat is natural (i.e., no agriculture encroachment), and the target species using this corridor are elephants and lions. Major threats are poaching, and human wildlife conflict. The boundary of the corridor with the community has been fenced using an electric fence - which has largely contributed to the decline of human-wildlife conflicts.

   Recommendations – i) Enhance the effectiveness of law enforcement to deter poaching at sites identified as hotspots using long-term ranger monitoring data, ii) Timely maintain the electric fence in relation to vegetation undergrowth and repair faulty sections, iii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors.

2. Bwera (Uganda & DRC) – This is transboundary savanna corridor that links southern Queen Elizabeth National Park (Uganda) to Virunga National (DRC) across the Lhubiriha River that forms the boundary between Uganda and the Democratic Republic of Congo – habitat is unmodified. The target species using this corridor are elephants and lions, and the major threats affecting the corridor are poaching, and human wildlife conflict. The corridor boundary with the community has been fenced using an electric fence to mitigate human wildlife conflict – especially from elephants. Primary economic activity for the community members is subsistence farming.

   Recommendations – i) Enhance the effectiveness of law enforcement to deter poaching at sites identified as hotspots using long-term ranger monitoring data, ii) Timely maintain the electric fence in relation to vegetation undergrowth and repair faulty sections, iii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors

3. Muhokya (Uganda) – This is a savanna corridor that measures approximately 500m at its narrowest point and is located west of lake George – habitat is unmodified. It links Kasenyi and Dura sectors within Queen Elizabeth National Park, enabling the movement of two target species (lions and elephants). The corridor boundary with the community has been fenced with an electric fence to mitigate human wildlife conflict. Major threats are narrow corridor width, poaching and human- wildlife conflict (i.e., livestock depredation, crop raiding). Muhokya is a hotspot for human -lion conflict in Queen Elizabeth National Park.

   Recommendations – i) Explore potential of expanding the corridor (e.g., land purchase, land lease) ii) Enhance the effectiveness of law enforcement to deter poaching at sites identified as hotspots using long-term ranger monitoring data, iii) Timely maintain the electric fence in relation to vegetation undergrowth and repair faulty sections, iv) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors.

4. Dura (Uganda) – This is a savanna corridor that is located north of lake George and links Queen Elizabeth National Park to Kibale National Park in Uganda. The target species are elephants and occasionally chimpanzees – habitat is unmodified.

   Recommendations – i) Mitigate human wildlife conflict using physical barriers (e.g., trenches, electric fence), ii) Enhance the effectiveness of law enforcement to deter poaching at sites identified as hotspots using long-term ranger monitoring data, iii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors

5. Kyambura - Kasyoha Kitomi (Uganda) – This is a forest corridor that links Kyambura Wildlife Reserve to Kashyoha Kitomi Forest Reserve through a narrow tract of land (forest habitat) that measures 350m at its narrowest point – habitat unmodified. The target species using this corridor are elephants and chimpanzees.

   Recommendations - i) Explore potential of expanding the corridor (e.g., land purchase, land lease), ii) Assess effects of Collaborative Forest Management (CFM) on corridor status and functionality, iii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors

6. Kyambura Gorge - Kasyoha Kitomi corridor (Uganda) – This is a forest corridor that links Kyambura Wildlife Reserve to Kashyoha Kitomi Forest Reserve along Kyambura riverine forest. The target species potentially using this corridor are chimpanzees and elephants. The corridor is largely located in the community – with the major threat being habitat loss and degradation.

   Recommendations - i) Develop habitat restoration and community engagement plans, ii) Assess effects of Collaborative Forest Management (CFM) on corridor status and functionality,

7. Kasyoha-Kitomi - Kalinzu-Maramagambo corridor (Uganda) – This is a forest corridor that links Kashyoha Kitoma Forest Reserve to Kalinzu and Maramagambo Forest Reserves. The major threat to the corridor is landuse change from natural to plantation forestry. The land use of three-kilometer corridor is currently plantation forestry (eucalyptus and pine) under the Collaborative Forest Management of the National Forestry Authority. Potential target species using this corridor are chimpanzees.

   Recommendation - i) Assess effects of Collaborative Forest Management (CFM) on corridor status and functionality ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors

8. Bwindi – Sarambwe (DRC and Uganda) – This is transboundary corridor that links Bwindi Impenetrable National Park in Uganda to Sarambwe Nature Reserve in the DRC – habitat is partly degraded on the DRC side. The target species using this corridor are mountain gorillas, chimpanzees and elephants. The major threats to the Bwindi – Sarambwe corridor are habitat loss and degradation, poaching, and civil armed conflicts that prevent protected area authorities to carry out their mandate.

   Recommendations - i) Enhance law enforcement to deter habitat degradation and poaching, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors

9. Mikeno (DRC) – This is a forest corridor that measures approximately 1.6km at its narrowest point and is located in southern Virunga National Park – habitat is currently unmodified but was heavily degraded (~ 15km2) during the civil in 2004. It connects the Mikeno and southern sectors within VNP, enabling the movement of elephants (target species). The major threats are affecting the corridor are – narrow corridor width, poaching and civil armed conflicts.

   Recommendations - i) Enhance law enforcement to deter habitat degradation and poaching, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors

10. Kisenyi (Uganda) – This is a forest corridor located within QENP and refers to the ishasha road section that is bordered by lake Edward in the west and Maramagabo Forest Reserve in the east. The Ishasha road is used by lions moving between the northern and southern sectors of QENP while avoiding forest habitat (Maramagambo Forest Reserve). The major threat is human wildlife conflict (ie., livestock depredation).

    Recommendation - i) Promote compensation schemes and community-based projects as a means to minimize the cost of living near corridors.

11. Virunga north (DRC). This is forest – savanna corridor that is located north of Lake Edward and links the forest and savanna habitats of the northern sector of Virunga National Park. Virunga north corridor is highly impacted by habitat loss and degradation, poaching, and civil armed conflicts that prevent protected area authorities carrying out their mandate. The target species using this corridor are elephants.

    Recommendations - i) Develop habitat restoration and community engagement plans ii) Enhance law enforcement to deter habitat degradation and poaching, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors. *All these recommendations assume that civil armed conflicts have been resolved and protected areas authorities are able to operate in the corridor area.*

12. Virunga central (DRC) – This is a savanna corridor that is located on the western shores of Lake Edward and links the northern and southern sectors of Virunga National Park. The major threats are habitat loss and degradation, poaching, and civil armed conflicts that prevent protected area authorities carrying out their mandate. The target species using this corridor are elephants.

    Recommendations - i) Develop habitat restoration and community engagement plans ii) Enhance law enforcement to deter habitat degradation and poaching, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors. *All these recommendations assume that civil armed conflicts have been resolved and protected areas authorities are able to operate in the corridor area.*

13. Virunga south (DRC) – This an savanna – forest ecotone corridor that is located south of Lake Edward and links the forest and savanna habitats of southern Virunga National Park. Virunga south corridor is highly impacted by habitat loss and degradation, poaching and civil armed conflicts that prevent protected area authorities carrying out their mandate. The target species using this corridor are elephants.

    Recommendations - i) Develop habitat restoration and community engagement plans ii) Enhance law enforcement to deter habitat degradation and poaching, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors.
    All these recommendations assume that civil armed conflicts have been resolved and protected areas authorities are able to operate in the corridor area.

14. Katwe (Uganda) – Measures approximately 1.3km at its narrowest point and is located north of Katwe salt lake. It connects the crater and Bwera sectors within QENP, and enables the movement of two target species (lions and elephants). The major threats are poaching and human-wildlife conflict.

    Recommendations - i) Enhance law enforcement to deter habitat degradation and poaching, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors.

15. The neck (Uganda) – Located within Bwindi Impenetrable National Park and measures approximately 800m at its narrowest point. It connects the southern and northern sectors of Bwindi Impenetrable National Park. The major threats are narrow corridor width, poaching, and human-wildlife conflict.

    Recommendations - i) Explore potential for corridor expansion (e.g., land purchase, land leasing) ii) Enhance law enforcement to deter habitat degradation and poaching, iii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors.

16. Virunga – Semliki (DRC, Uganda) - This is a transboundary corridor that connects southern Semliki National Park in Uganda to Virunga NP in the DRC. The target species using this corridor are elephants and chimpanzees. Major threats to the status and functional connectivity of this corridor are habitat loss and degradation, and poaching, and civil armed conflicts that prevent protected area authorities carrying out their mandate.

    Recommendation - i) Develop habitat restoration and community engagement plans ii) Enhance law enforcement to deter habitat degradation and poaching, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors. All these recommendations assume that civil armed conflicts have been resolved and protected areas authorities are able to operate in the park.

17. Rwenzori – Toro Semliki (Uganda) - The Greater Virunga Landscape (Rwenzori and Semliki National Parks) borders the Murchison Semliki Landscape (Toro-Semliki Wildlife Reserve) in the north separated by approximately 9km. The corridor is located in community areas. Major threat is habitat loss and degradation, and human elephant conflict. The target species using this corridor is elephants.

    Recommendations - i) Develop habitat restoration and community engagement plans, ii) Promote compensation schemes and community-based projects as means to minimize the cost of living near corridors.

18. Volcanoes – Mgahinga (Rwanda, Uganda) – This is a forest corridor that links Volcanoes National Park in Rwanda to Mgahinga Gorilla National Park in Uganda. The target species are elephants and mountain gorillas. Major threats to this corridor are poaching and potential impacts of climate change – given that it's located at high elevation.

19. Volcanoes – Virunga (Rwanda, DRC) - This is a forest corridor that links Volcanoes National Park in Rwanda to Virunga National Park in the DRC. The target species are elephants and mountain gorillas. Major threats to this corridor are poaching and potential impacts of climate change – given that it's located at high elevation.

20. Virunga – Mgahinga (DRC, Uganda) - This is a forest corridor that links Virunga National Park in the DRC to Mgahinga Gorilla National Park in Uganda. The target species are elephants and mountain gorillas. Major threats to this corridor are poaching and potential impacts of climate change – given that it's located at high elevation.

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