CENTER for LARGE LANDSCAPE CONSERVATION

A.P.E. Project

(Assess. Protect. Evaluate.)

Final Report

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Executive Summary

This report examines the impact of linear infrastructure development on great apes and gibbons in three focal landscapes, where major linear infrastructure is being developed across their ranges: the Hoolock gibbons in India, orangutans in Sabah, Malaysia, and gorillas in the transboundary Virunga landscape.

We assessed policies affecting ape and habitat protection in these countries and identified needs to incorporate all stakeholders, especially local communities, early in the planning stages. Our spatial analyses revealed that the number, area, and impact of linear infrastructure (LI) and its subsequent human impacts are far more prolific than indicated by publicly available data sources. Our systematic literature review showed that while there is growing awareness of the impacts of LI, focused research needs to be done on the specific impacts of linear infrastructure on apes.

To mitigate the impacts of LI, we need further research and monitoring to inform best practices, including the design and construction of wildlife crossings. Biodiversity conservation should be integrated into development planning to minimize negative impacts on the environment and local communities. Sustainable development, such as green infrastructure and renewable energy, can balance development needs with the protection of wildlife and their habitats.

Our findings underscore the importance of effective policy and law enforcement, local community participation, and transparent, collaborative planning processes. Mitigation requires monitoring data to rehabilitate and restore habitats to address the direct and indirect effects of LI, fragmentation and human impacts in order to support the long-term survival of apes.

Introduction

The impacts of linear infrastructure (LI) on apes and gibbons are a growing concern for conservationists as LI proliferates globally, especially in the tropics. As human populations continue to grow, the construction of roads, railways, powerlines, and pipelines increasingly fragment habitats, creating barriers to wildlife movement and negatively impacting the ecosystem services communities rely upon.

Infrastructure development threatens apes through direct effects such as vehicle collisions, power line electrocutions, destruction and fragmentation of forests. Fragmentation reduces food sources and nesting sites, creates barriers to movement, and subsequently leads to crowding, conflict, and behavioral changes. Indirect impacts include habitat loss due to increased human settlements and secondary access roads, increased hunting pressures due to increased human access, disease transmission, environmental contamination, and human-wildlife conflict. These impacts are more threatening because even slight population declines can have catastrophic effects on apes due to their slow reproductive rates, social structures, and prolonged dependency on maternal care.

A range of policy and practical measures have been developed and implemented to mitigate the negative impacts of LI. At a national level, many countries have enacted legislation to protect apes and other critical species. At the international level, non-governmental organizations and other conservation groups, such as the IUCN species specialist groups and taskforces such as ARRC (Ape Rescue Restore and Conserve), provide guidance and oversight. The Convention on Migratory Species also supports biodiversity protection through provisions for the protection of migratory species during infrastructure development. Local and regional groups are the most critical actors during LI development. For example, in Sabah, Borneo, the multi-sectoral collaborative Humans Habitats Highway was formed to gather data, provide guidance, and engage community stakeholders in sharing their concerns during the planning and construction of the pan-Borneo highway.

National policies, though essential, have been criticized for lack of enforcement and insufficient power to protect apes from human impacts during LI development and resource extraction. When it is impossible to avoid infrastructure development in important habitats, nations must adopt and enforce polices ensuring mitigation measures to safeguard apes and other threatened species. These include cumulative environmental assessments, well-designed and constructed wildlife crossings like overpasses, underpasses, arboreal crossings, insulating power lines, and habitat connectivity planning.

Cumulative impacts refer to the combined effects of a project and other development activities within a specific region. Environmental impact assessments for single projects often fail to consider the additive effects of other projects in the area, resulting in severe and compounded negative impacts on species like apes. There is increasing pressure for individual projects to consider cumulative effects, but this is often omitted due to a lack of clarity on responsibility and funding. Cumulative impact assessments (CIAs) are essential for rigorous and effective planning. Nations should require projects to consider cumulative impacts and adopt coordinated mitigation measures to reduce their footprints. Governments can facilitate this by strategic land use planning to prevent conflicting interests.

Economic analyses are crucial in accounting for the indirect costs of linear infrastructure development, particularly to parties not directly involved in the project, such as local communities and other communities benefitting from ecosystem services protected by intact habitats. A rigorous CBA, incorporated into a project's

evaluation, can demonstrate that wildlife safeguards can save money over the long term. Therefore, cost-benefit analyses (CBAs) should be included in any feasibility study of linear infrastructure projects.

Mitigation Hierarchy

The mitigation hierarchy is a fundamental framework critical to assess and address the impacts of infrastructure, with an initial focus on avoidance, followed by minimisation, mitigation, restoration, and finally offsetting and compensating residual impacts. Through this framework, proponents can effectively evaluate and manage the potential adverse effects of infrastructure development on the environment, including protected conservation areas (PCAs), ecological connectivity, biodiversity, and ecosystem services.

Although the mitigation hierarchy is a relatively simple concept, there is some variation in its exact terminology across different jurisdictions globally. While some areas combine minimisation and mitigation into the same step, others include reduction, rectification, or rehabilitation between minimisation and compensation.

The framework's adoption has been widespread and is central to the International Finance Corporation's Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources (IFC, 2012). Many development banks, governments, and private industries have adopted this performance standard as a decision-making framework. The hierarchy facilitates cost-effective and timely project implementation with measurable positive conservation outcomes when conscientiously applied from avoid through to compensate.

According to the IFC Performance Standard 6, the mitigation hierarchy's application allows proponents to make decisions that achieve no net loss (NNL) in ecological value as a minimum or a net gain in value as an aspirational goal. In recent years, many countries have embraced biodiversity net gain (BNG) as the ultimate goal during development. In addition, the hierarchy's application ensures that project implementation is carried out with measurable positive conservation outcomes, thus enabling proponents to achieve their desired results in planning and designing infrastructure that safeguards PCAs, ecological connectivity, biodiversity, and ecosystem services.

Avoidance is the first and most crucial step in the mitigation hierarchy. It involves preventing an impact entirely, which is the most effective way of safeguarding biodiversity. Avoidance can be achieved through spatial or temporal adjustments, such as relocating activities or infrastructure away from critical habitats or scheduling construction activities to avoid breeding seasons or other sensitive times of the year. Infrastructure projects that avoid sensitive biodiversity areas may be slightly longer than the most direct route, but they will have lower ecological impacts overall and less need for expensive mitigation measures or other offsets. These slightly longer routes may also better serve local communities.

Minimisation is the second step in the mitigation hierarchy and is applied when impacts cannot be avoided entirely. Like avoidance, minimisation is a proactive step achieved through measures to reduce impacts. Minimisation measures may include short-term actions during construction to reduce soil erosion or more permanent efforts during operation to reduce contamination from pollution. Minimisation activities are often carried out under an environmental management plan (EMP) geared to reduce the project footprint. An EMP includes directives to reduce disturbance, such as preserving tree canopy adjacent to roads or a shortened construction period.

Mitigation is the third step in the mitigation hierarchy and is applied only after genuine efforts to avoid and minimise impacts have taken place. Mitigation measures are often technological or construction strategies enacted to moderate unavoidable impacts. Commonly used mitigation measures in infrastructure projects are noise and light barriers to prevent spillover into adjacent habitats, wildlife underpasses and overpasses and associated fencing to provide for ecological connectivity and minimise wildlife-vehicle collisions, and escape ramps in canals to prevent wildlife from drowning.

Restore (or rehabilitation) refers to efforts within or adjacent to the construction footprint that addresses unavoidable impacts to achieve NNL of biodiversity value or ecosystem services. Restoration involves measures to repair ecosystem structure, such as reforestation, and measures to repair ecosystem function, such as ecological connectivity. Restoration is aimed at reversing habitat degradation and typically occurs at or nearby to the site of a development project. Restoration is most effective when well-established, practical techniques are maintained and monitored for long-term success. Nevertheless, on their own, restoration measures are rarely sufficient to achieve NNL consistent with biodiversity baselines, often necessitating the pursuit of offsets.

Compensate or Offset is the final step in the mitigation hierarchy and is used for impacts that are typically outside of the footprint of a development project that cannot be avoided, minimized, mitigated, or restored on site. Offsets should be measurable and significantly “tip the scale” toward achieving NNL of biodiversity and ecosystem services. Offsets are generally characterised as i) restoration offsets that rehabilitate degraded habitats, ecosystems, or ecosystem function or ii) protection offsets that maintain biodiversity under threat of loss. Compensation usually involves payments as offsets, such as to fund and implement management plans for PCAs, support research that enhances biodiversity protection, or improve enforcement activities and infrastructure.

Community Involvement

Local communities are fundamental to the conservation of great apes and gibbons. They play a significant role in conserving wildlife and their habitats, especially in developing countries where they rely on direct access to the resources and wildlife in their territories and often hold cultural values that strive to protect biodiversity. In addition, local communities are often best suited to provide valuable information on wildlife distribution, abundance, and behavior. Engaging local communities in conservation initiatives is imperative for long-term sustainability.

Focal Landscape Policy Assessment

Introduction

National policies play a crucial role in protecting biodiversity during LI development, such as using environmental impact assessments (EIAs), establishing protected areas, and incentives for environmentally friendly practices. To adequately safeguard species, such as great and small apes, it is essential to understand a country's existing policies and identify areas for improvement. For example, some governments may have weak or inadequate policies or enforcement mechanisms for protecting biodiversity. In other cases, policies may be in place but not effectively implemented or enforced. In addition, a lack of coordination between different government agencies involved in infrastructure development can result in conflicting policies and regulations, making it challenging to protect biodiversity. More public participation and consultation in the policy-making process are also often needed. This can result in policies that better reflect local communities' and stakeholders' needs and concerns.

The Center for Large Landscape Conservation conducted an initial pilot project to assess major threats to apes, gibbons, and human communities from LI across three pilot landscapes: Northern India, Peninsular and Eastern Sabah Borneo Malaysia, and the Greater Transboundary Virunga.

We reviewed each landscape's commitment to seven international multilateral environmental agreements (MEAs) that address various facets of wildlife conservation, which could affect infrastructure development. Becoming a signatory to these MEAs shows a country's dedication to protecting wildlife on an international level, but further efforts are required within each country to translate these global commitments into more specific laws, regulations, and policies. This may involve developing national strategies, action plans, and programs that can be effectively enforced and monitored nationally. MEAs examined include:

- Convention on Biological Diversity (CBD)
- World Heritage Convention (WHC)
- Convention on Trade in Endangered Species (CITES)
- Convention on Migratory Species (CMS)
- International Plant Protection Convention (IPPC)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)
- Ramsar Convention on Wetlands of International Importance (Ramsar).

A country's participation in these international agreements signals a commitment to conservation and may suggest stronger reception to safeguarding wildlife from LI. However, focal countries must continue incorporating effective national legislation, policy, and regulations to implement these international obligations.

The following is a brief synthesis of the existing policies within these landscapes and recommendations for further enforcing and expanding policies that will protect apes during the current tsunami of LI development.

Malaysia

Malaysia is rich in biodiversity with a diverse range of flora and fauna, including endangered species such as the Bornean orangutan. Malaysia is a federal constitutional monarchy, with governance administered in 13 states and three federal territories. The country has a relatively strong governance capacity and frequently engages in knowledge transfer with other nations in the Global South to share its achievements and foster partnerships.

Malaysia is a party to six of the seven international MEAs considered in this review:

- Convention on Biological Diversity (CBD)
- World Heritage Convention (WHC)
- Convention on Trade in Endangered Species (CITES)
- International Plant Protection Convention (IPPC)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)
- Ramsar Convention on Wetlands of International Importance (Ramsar)

Malaysian policies relevant to LI development include:

National Environmental Policy 2002 - This policy aims to ensure the protection and sustainable use of Malaysia's natural resources, including its biodiversity and habitats. It emphasizes the need to ensure *'Natural ecosystems will be conserved to ensure integrity of biodiversity and life support systems as well as to conserve endangered species.'*

Environmental Quality Act 1974 (Amended 2022) - Requires approval of the Environmental Impact Assessment Report (EIA) or Proposal for Mitigation for prescribed activities. In 2022 an amendment was passed which seeks to strengthen the penalties for violating Section 34A of the Malaysia Environmental Act to ensure greater compliance with the requirements for conducting an EIA report for designated activities.

National Physical Plan (NPP) 2005- Outlines a comprehensive framework for the country's physical development. The NPP includes a section on environmental considerations, which mandates that infrastructure development must be planned and executed in an environmentally sustainable manner. The NPP aims to balance economic growth and environmental protection by promoting sustainable development practices that minimize the impact of infrastructure development on biodiversity and habitat.

National Biodiversity Policy 2016-2025 - Emphasizes the importance of maintaining and restoring ecosystem services, such as pollination and water regulation, and recognizes the need for sustainable development practices that protect biodiversity. This policy sets out a framework for empowering stakeholders, mitigating pressures on biodiversity, protecting ecosystems, species, and genetic diversity, and promoting fair and equitable distribution of benefits.

National Forestry Act 1984 and National Parks Act 1980 – Enacted to protect Malaysia's forests and national parks. These policies establish protected areas and land-use regulations, including infrastructure development, to ensure that biodiversity and habitats are not compromised. The National Forestry Act provides for the sustainable management of forests, including the protection of forest reserves, while the National Parks Act establishes national parks and other protected areas to conserve Malaysia's natural heritage.

The state of Sabah also has several laws and policies that regulate infrastructure development and environmental protection, which are significant in balancing the environment and development. The Sabah Legislative Assembly periodically updates these laws to enhance their effectiveness. Sabah-specific laws and policies include:

Environment Protection Enactment 2002 – Establishes an "Environment Protection Council" and requires approval of the Environmental Impact Assessment Report (EIA) or Proposal for Mitigation for prescribed activities prior to carrying out those activities. This mirrors the Environmental Quality Act (federal).

Sabah Structure Plan (SSP) 2033 - A long-term strategic planning document that will guide and direct the State's future physical growth and development up to 2033. The Structure Plan is "the strategic policy" for "the general directions and trends of the physical development of the State" and "the policy and general proposals" for the development and land use.

Critical verbiage from the Sabah Structure plan includes:

For "existing and future Protected Areas," there shall be "No development... shall be permitted except for eco-tourism, research, and education"; for "All other forests and wetlands outside of [Protected Areas] and [Priority Conservation Areas]," there shall be "No development" and "No net loss of biodiversity in forest conservation landscapes." (Proposal EV3-1)

"Where a highway cuts through the forest connectivity particularly if it is a national highway or strategic road; an overpass or underpass type of design shall be constructed to minimise the ecological impacts." "Highways and roads cutting through forest are regarded as one of the leading causes of dissecting forest connectivity. Being a State renowned for its rich forest resources, it is important for the State to consider implementing road technologies that can minimise the environment impact by highways and roads." (EV2-7)

"Environmentally Sensitive Areas (ESA) shall be identified and integrated into the District and Local Plans for better long-term management of the environment and natural resources." (Paragraph 14.3.3)

Malaysia recognizes the importance of protecting its environment and has implemented several national policies and initiatives to safeguard biodiversity and habitat from LI development. The government's policies and regulations demonstrate a recognition of the importance of balancing economic growth with environmental protection and a commitment to preserving Malaysia's rich biodiversity for future generations. However, recent LI development is at odds with the legislation and suggests that policies and laws must be implemented to the fullest extent to protect habitats and communities. Therefore, there is a need for greater transparency and stakeholder participation in the initial planning process.

India

India has rich and diverse biodiversity, with a wide range of ecosystems, from tropical rainforests to alpine meadows. It is home to several iconic species, including the Bengal tiger, Indian elephant, Asiatic lion, Indian rhinoceros, and Hoolock gibbon. Over the years, India has implemented significant measures to protect its wildlife. These measures include mandatory environmental approval prior to approving the development of large projects, as well as the cancellation of forest land clearing by the forest department and various other stakeholder agencies, such as the National Tiger Conservation Authority (NTCA). Additionally, in 2016, the Wildlife Institute of India (WII) produced a manual of guidelines detailing various mitigation measures that can be employed for new LI projects that cross through habitats, could impact vulnerable areas, or affect wildlife species.

In 2019, the government launched the National Biodiversity Mission to conserve India's biodiversity and promote sustainable development. The Mission focuses on conserving ecosystems, species, and genetic diversity and the sustainable use of natural resources. It also aims to integrate biodiversity conservation into sectoral policies and programs.

The Indian government has developed several policies and strategies to protect biodiversity and habitats from the negative impacts of LI development. However, the effectiveness of these policies depends on their proper implementation and enforcement. It is essential to ensure that LI development is carried out in a sustainable and environmentally sensitive manner to protect India's rich biodiversity and habitats. The government should continue to monitor and evaluate the effectiveness of these policies and make necessary changes to ensure their success.

India is a party to all seven international MEAs considered in this review:

- Convention on Biological Diversity (CBD)
- World Heritage Convention (WHC)
- Convention on Trade in Endangered Species (CITES)
- Convention on Migratory Species (CMS)
- International Plant Protection Convention (IPPC)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)
- Ramsar Convention on Wetlands of International Importance (Ramsar)

Indian policies and laws relevant to LI development include:

Wildlife Protection Act, 1972 (1991) - This central legislation aims to protect wildlife and their habitats in India. The Act prohibits hunting, poaching, and trading of wildlife and regulates the establishment and management of protected areas. In addition, the Act provides for the declaration of national parks, wildlife sanctuaries, and conservation reserves, which are critical for conserving biodiversity and habitats. The Act also empowers the government to regulate the diversion of forest land for non-forestry purposes, which includes LI development.

Forest Conservation Act, 1980 (1998) - Aims to conserve forests and wildlife by regulating the diversion of forest land for non-forestry purposes. The Act requires prior approval from the central government for the division of forest land for LI development. The Act also mandates compensatory afforestation, which requires planting trees on non-forest land to compensate for the loss of forest land.

National Biodiversity Act, 2002 - This act provided for the conservation and sustainable use of India's biodiversity and was enacted to give effect to the provisions of the CBD. It aims to regulate access to biological resources and ensure equitable sharing of benefits arising from their use. Requires LI projects to undergo a rigorous environmental assessment process, obtain prior informed consent from local communities, and implement measures to mitigate their impacts on biodiversity.

Environmental Impact Assessment Notification, 2020 - This notification requires all LI projects to undergo an environmental impact assessment (EIA) and obtain necessary clearances before approval. However, this updated legislation has been harshly criticized for diluting environmental safeguards, reducing public participation, exempting specific projects from environmental clearance, weakening the role of independent experts, and limiting the scope of public consultation. These issues may have negative impacts on the environment and local communities.

The National Wildlife Action Plan, 2017-2031 - A comprehensive strategy document that sets out the priorities and actions for wildlife conservation in India while underscoring the need for the people's support of conservation initiatives. The Plan recognizes the impacts of LI development on wildlife and their habitats and calls for guidelines for planning and designing LI projects. Emphasizes the importance of wildlife corridors, which are essential for wildlife movement across fragmented habitats.

National Green Tribunal Act 2010 - The National Green Tribunal was established as a specialized court dealing with environmental disputes and enforcing environmental laws. The Tribunal has been instrumental in enforcing the provisions of the Wildlife Protection Act and the Forest Conservation Act. The Tribunal has also directed the formulation of guidelines for constructing LI projects, which include measures to minimize the impact on biodiversity and habitats. However, criticism of the Tribunal's efficacy includes delays in judgment, inadequate stakeholder representation, and lack of transparency.

The efficacy of these policies depends on their proper implementation and enforcement. Therefore, the Indian government should continue to promote sustainable development and biodiversity conservation and ensure the equitable involvement of stakeholders.

Greater Transboundary Virunga Landscape

The Greater Transboundary Virunga Landscape is a region that spans three countries: Uganda, Rwanda, and the Democratic Republic of Congo (DRC). The Greater Virunga Landscape is a complex and challenging environment. It has rugged terrain and hosts one of the most intricate ecosystems on the planet. The complex human politics spanning three nations experiencing high poverty and internal and external civil unrest further complicates the adoption and effective implementation of environmental policies. Nevertheless, it boasts the most diverse biodiversity on the continent, with the Virunga mountain range alone supporting half the global population of mountain gorillas. Despite facing numerous threats such as habitat degradation, hunting, civil

conflict, and disease, gorillas and chimpanzees have survived in this region thanks to persistent conservation efforts that have preserved these endangered and iconic animals.

To facilitate collaborative efforts, the three countries have established the Greater Virunga Transboundary Collaboration (GVTC), a regional initiative to coordinate conservation efforts and promote sustainable development in the Virunga Landscape. The GVTC brings together government agencies, non-governmental organizations, and other stakeholders to work together on issues such as wildlife conservation, habitat restoration, and sustainable tourism development. Through this collaboration, the countries can share resources and expertise to work together to address the complex environmental challenges facing the Virunga Landscape.

Uganda

Uganda is a party to all seven international MEAs considered in this review:

- Convention on Biological Diversity (CBD)
- World Heritage Convention (WHC)
- Convention on Trade in Endangered Species (CITES)
- Convention on Migratory Species (CMS)
- International Plant Protection Convention (IPPC)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)
- Ramsar Convention on Wetlands of International Importance (Ramsar)

National Environment Act of 2019 - Provides a legal framework for protecting biodiversity and ecosystems from the potentially harmful impacts of development projects. This act requires that environmental impact assessments be conducted before any development project, and it sets out guidelines for mitigating any adverse environmental impacts. These assessments must consider a wide range of factors, including the potential impacts on soil, water, air quality, and wildlife. The act also created a *Policy Committee on Environment,* which is responsible for strategic policy guidance.

National Physical Planning Act, 2020 – This act complements the National Environment Act by requiring that plans for physical development be aligned with environmental sustainability principles. Environmental concerns must be integrated into all development plans and projects. The act also requires that environmental impact assessments be conducted for proposed development projects likely to significantly impact the environment.

National Forestry and Tree Planting Act, 2003 - This act protects, manages, and sustains Uganda's forests, including those affected by LI development. It requires the conservation of biodiversity and ecological functions of forests and sets guidelines for their use.

Wildlife Act, 2019 - This act provides for the conservation, protection, and management of Uganda's wildlife, including its habitats. It prohibits hunting, poaching, and trade in wildlife and their products and regulates activities that may cause harm to wildlife habitats, including LI development. Outlines the requirements for conducting an environmental impact assessment (EIA) for any proposed infrastructure development project in or adjacent to a protected area. The EIA must be carried out by a qualified expert and submitted to the relevant government agency for review before any development can occur.

National Wetlands Policy, 1995 - This policy provides guidelines that emphasize the need for the sustainable management of wetlands by integrating wetland conservation into development planning. In addition, it calls for the involvement of local communities in wetland management and recognizes their rights to access and utilize wetland resources for their livelihoods.

National Biodiversity Strategy and Action Plan, 2015-2020 - This plan provides a framework for the conservation and sustainable use of Uganda's biodiversity, including protecting habitats affected by LI development. It sets targets to increase protected areas, restore degraded habitats, and promote sustainable use of natural resources. EIAs are mandatory for all activities that have significant negative impacts on the environment. Developers of large infrastructure projects will be encouraged to use biodiversity offsets as part of the review of the Environmental Impact Statement (EIS). Results of cost-effectiveness, cost-benefit analyses, and other economic instruments will be used to demonstrate the benefits of biodiversity offsets over alternative biodiversity loss mitigation measures.

These policies demonstrate the strong commitment of Uganda to protecting the unique biodiversity and habitat of the Virunga Landscape. However, despite these policies, criticism of environmental protection in Uganda includes weak implementation and enforcement, limited public participation, inadequate capacity and resources, and lack of governmental coordination.

Rwanda

Rwanda is a small country located in East Africa but is rich in biodiversity, with diverse ecosystems ranging from high-altitude forests to savannah grasslands—notable wildlife species in Rwanda include mountain gorillas and chimpanzees.

Rwanda is a party to all seven international MEAs considered in this review:

- Convention on Biological Diversity (CBD)
- World Heritage Convention (WHC)
- Convention on Trade in Endangered Species (CITES)
- Convention on Migratory Species (CMS)
- International Plant Protection Convention (IPPC)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)
- Ramsar Convention on Wetlands of International Importance (Ramsar)

National Environment and Climate Change Policy, 2019 - Aims to address environmental degradation and climate change challenges by promoting sustainable natural resource management, effective environmental governance, a transition to a green economy, and disaster risk reduction. It recognizes the importance of stakeholder engagement, data, and information systems, and sustainable development principles in achieving its goals. The policy includes targets for reducing greenhouse gas emissions, increasing ecosystem resilience, and promoting sustainable production and consumption patterns.

National Land Use and Development Master Plan, 2020-2050 - The master plan is designed to provide a roadmap for the country's land-use and development policies and ensure they align with the country's environmental goals. The plan includes provisions for protecting forests, wetlands, and other ecosystems and guidelines for sustainable land use and agriculture practices. In addition, the plan highlights the need for upgrades of roadways to accommodate higher speeds.

Law N°48 on the environment, 2018 - Focuses on conserving and protecting the natural environment, including soil, water resources, biodiversity, and the atmosphere. It imposes obligations on the state, decentralized entities, and local communities to protect and promote the environment. The law also grants the power of inspection and criminal investigation in environmental matters.

National Biodiversity Strategy and Action Plan, 2016 - This plan provides a framework for the conservation and sustainable use of Rwanda's biodiversity, including the protection of habitats affected by LI development. It sets targets to increase protected areas, restore degraded habitats, and promote sustainable use of natural resources. The plan highlights infrastructure development as a “High” threat to Afro-Alpine habitats and Mountain gorillas and recommends all development projects undergo an Environmental Impact Assessment (EIA) that is biodiversity inclusive.

National Forest Policy, 2018 - This policy provides for the protection, management, and sustainable use of Rwanda's forests, including those affected by LI development. It requires the conservation of biodiversity and ecological functions of forests and sets guidelines for their use.

Rwanda has established a strong foundation for biodiversity conservation through its environmental, biodiversity, and wildlife policies and laws. However, there is still room for improvement in several areas to enhance these policies' role in biodiversity conservation and to ensure policies are adequately resourced, implemented, and monitored. To achieve these goals, several recommendations have been made. Existing environmental fines and penalties are not adequately collected and enforced, leading to a loss of government revenue and continued natural capital loss or degradation. Biodiversity considerations must be strengthened in environmental compliance and regulations for major infrastructure and capital projects.

Democratic Republic of Congo

The Democratic Republic of Congo (DRC) has one of Africa's richest and most diverse ecosystems, the Congo Basin rainforest, the second-largest tropical forest in the world. DRC is also home to a vast array of wildlife, including endangered mountain gorillas, forest elephants, chimpanzees, and bonobos.

The Democratic Republic of Congo is a party to all seven international MEAs considered in this review:

- Convention on Biological Diversity (CBD)
- World Heritage Convention (WHC)
- Convention on Trade in Endangered Species (CITES)
- Convention on Migratory Species (CMS)
- International Plant Protection Convention (IPPC)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)
- Ramsar Convention on Wetlands of International Importance (Ramsar)

DRC National Biodiversity Strategy and Action Plan, 2016-2020 - Provides a framework for biodiversity conservation and sustainable use, including the Virunga Landscape. The plan sets out strategies for the protection of ecosystems and the sustainable use of natural resources, as well as measures for managing invasive species and restoring degraded habitats to meet CBD obligations.

DRC Ministerial Decree No. 025, 2016 - Provides rules governing concession management by forest communities and advances community forestry rights in DRC, granting forest-dependent communities significantly more autonomy.

General environmental law - no 11/009, 2011 - This code provides for the protection, conservation, and sustainable use of the DRC's natural resources, including its biodiversity and habitats. It requires all development projects, including LI development, to undergo EIA and promotes sustainable development and public participation. EIA was first introduced in DRC through its mining code in July 2002 and the mining regulation that followed in March 2003. After only applying to the mining sector for several years, ESIA obligation was expanded to other fields in this law in 2011.

Law No. 14/003 on Protection of Nature, 2014 - Requires the government to consider the potential value of forest carbon sequestration services in developing the National Strategy on Protection of Nature and the National Forestry Programme. Additionally, the law urges the central and regional governments to implement policies, plans, and programs that promote economic growth, rural development, poverty reduction, and climate regulation through natural and biological resources and ecosystems.

Overall, these national policies demonstrate a commitment to protecting the unique biodiversity and habitat of the Great Transboundary Virunga Landscape from the negative impacts of LI development. In addition, they lay the groundwork to ensure that development activities are carried out responsibly and sustainably that take into account the needs of the environment and the communities living in and around the Virunga Landscape.

Conclusion

Despite existing national policies, significant gaps between national laws and practices arise from inadequate public participation and often ineffective policy and law enforcement. Several improvements can be made to the focal countries' policies and laws, including strengthening enforcement mechanisms can help ensure that

developers comply with regulations and mitigate the negative impacts of their projects on the environment and local communities.

Public participation can be enhanced to ensure that local communities have a say in the decision-making process for infrastructure development projects. This can help build trust and ensure that their needs and concerns are addressed. Increasing funding for conservation and sustainable development initiatives can support the protection of wildlife, habitats, and local communities. Biodiversity conservation should be integrated into development planning to minimize negative impacts on the environment and local communities. Promoting and incentivizing sustainable infrastructure development, such as green infrastructure and renewable energy, can balance development needs with the protection of wildlife and their habitats.

LI developers also need to conduct rigorous environmental assessments early in the project development pipeline to identify and mitigate negative impacts on the environment. Environmental Impact Assessments (EIAs) are a vital tool developers use to evaluate their projects' potential ecological effects. There are several areas for improvement in the EIA process across all of the focal landscapes:

1. **Increase Public Participation:** The public's involvement is essential in the EIA process to ensure that all stakeholders' concerns are taken into account. Public participation provides valuable information on the potential environmental and social impacts of a proposed project. The public should be allowed to comment and provide feedback to build trust and foster a sense of ownership among the public.
2. **Enhance Transparency:** Transparency is critical in the EIA process to build trust with stakeholders. The public and other stakeholders need access to information to fully understand the potential impacts of a proposed development project. Therefore, it is essential to make all relevant information easily accessible to the public.
3. **Improve Data Quality:** The EIA process heavily relies on data. Therefore, it is crucial to ensure that data used in the assessment is of high quality and scientifically robust. Data should be collected using standardized methods and be representative of the area being assessed. Data should also be analyzed objectively and transparently.
4. **Enhance Interdisciplinarity:** The EIA process should involve experts from various disciplines to ensure that all potential impacts are considered. This should include social scientists, ecologists, economists, and engineers. Experts from different fields are needed to jointly identify potential impacts and develop mitigation measures.
5. **Implement Cumulative Impact Assessment:** This evaluates the combined impacts of multiple projects in a given area. Implementing cumulative impact assessments can identify potential synergies and conflicts between projects. This helps make informed decisions on the proposed project and other activities in the area. Cumulative impact assessment should be conducted in a transparent and collaborative manner involving all stakeholders.
6. **Strengthen Enforcement Mechanisms:** The effectiveness of the EIA process relies on the enforcement of the recommendations made. Therefore, it is crucial to ensure strong enforcement mechanisms to ensure that the recommendations are implemented. This is done by developing clear and enforceable regulations and guidelines. The enforcement mechanisms need to include monitoring and reporting systems to track the implementation of the recommendations.

The above text frequently refers to the standard Environmental Impact Assessment (EIA) for simplicity. However, we advocate for the uptake of Environmental and Social Impact Assessments (ESIA), which include a

project’s potential impacts on human health, safety, livelihoods, cultural heritage, and environmental impacts. ESIA is often used for projects with significant social impacts, such as involuntary resettlement, indigenous peoples, or communities with unique cultural heritage. Overall, ESIA provides a more comprehensive assessment of a project's potential impacts and is considered a more holistic approach to environmental and social impact assessment.

Furthermore, the Strategic Environmental Assessment (SEA) assesses the potential environmental impacts of policies, plans, and programs rather than individual projects. The SEA is a systematic and iterative process that evaluates the likely significant environmental effects of policies, plans, and programs and their alternatives and identifies ways to enhance positive effects and mitigate negative ones. Unlike the EIA and ESIA, which focus on specific projects' environmental and social impacts, SEA focuses on integrating environmental and sustainability considerations into decision-making at a higher level. Therefore, SEA should be used in developing national policies and plans, especially those related to energy, transport, and land use, to better integrate environmental considerations into policy and planning decisions.

Spatial Analysis

Conducted by Claudine Tobalske

Introduction

To inform policy and management decisions, spatial analyses are being used to understand the impacts of development on these habitats. One major contributor to this impact is the construction and use of linear infrastructure (LI), such as roads, railways, pipelines, and powerlines. LI has a variety of adverse effects on apes, including physical disruption during construction, maintenance, and use, as well as the creation of barriers that bisect their habitats. LI can cause direct mortalities through collisions and electrocutions and indirectly impact wildlife through pollution and increased human access to previously inaccessible areas, leading to hunting and land conversion.

To better understand the impact of LI on ape habitats, we analyzed the forest cover and LI impact of three different ape ranges using remotely sensed imagery and public databases. Our findings indicate that the impact of LI is far greater than what is reported in these databases. In particular, powerlines and roads significantly impact ape habitats and lead to subsequent land conversion to agriculture. By understanding the true impact of human development on ape habitats, decision-makers, and conservationists can take appropriate action to preserve the integrity of the forest and protect these endangered animals.

The spatial analyses conducted for this project used publicly available data, including OpenStreetMaps (OSM), ESRI's ArcGIS Online and Living Atlas, and Google searches. Ape ranges were downloaded from the spatial data webpage of the IUCN Red List. All work was done in ArcGIS Pro 3.0.

Available data in all landscapes were found to be of varying inaccuracy for current linear infrastructure (LI) development in all landscapes, so we used land cover/land use satellite imagery to observe additional LI. We documented a significant underrepresentation of LI and other impacts in every landscape, such as forest alterations. For example, most existing roads missing from OSM appear unpaved; however, the density and width of these roads may be quite impactful on wildlife and often lead to forest removal and plantations.

India

We focused on the northeastern India section of the IUCN western hoolock gibbon (*Hoolock Hoolock*) range in the states of Arunachal Pradesh and Nagaland (31,267 km^2, Figure 1). Linear infrastructure data (roads, railroad, and power lines) were obtained from OSM; land use/land cover came from ESRI's Sentinel-2 10m Land Use/Land Cover 2021 map for India (Figure 2).

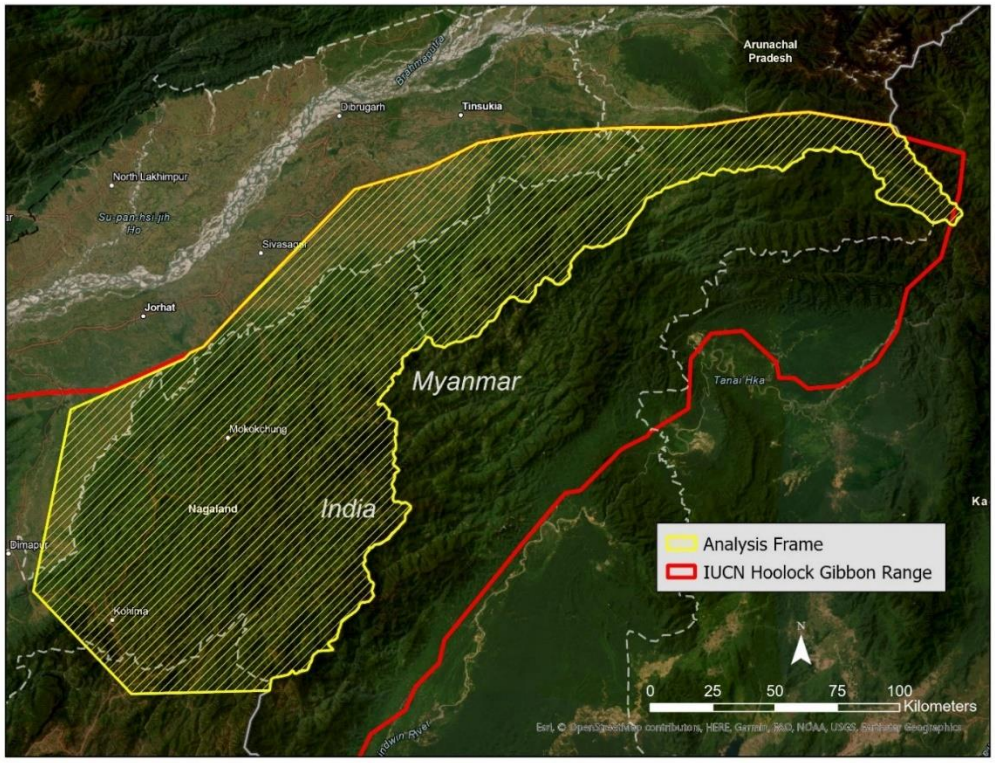

Figure 1. Focus area within the IUCN hoolock gibbon range in northeastern India.

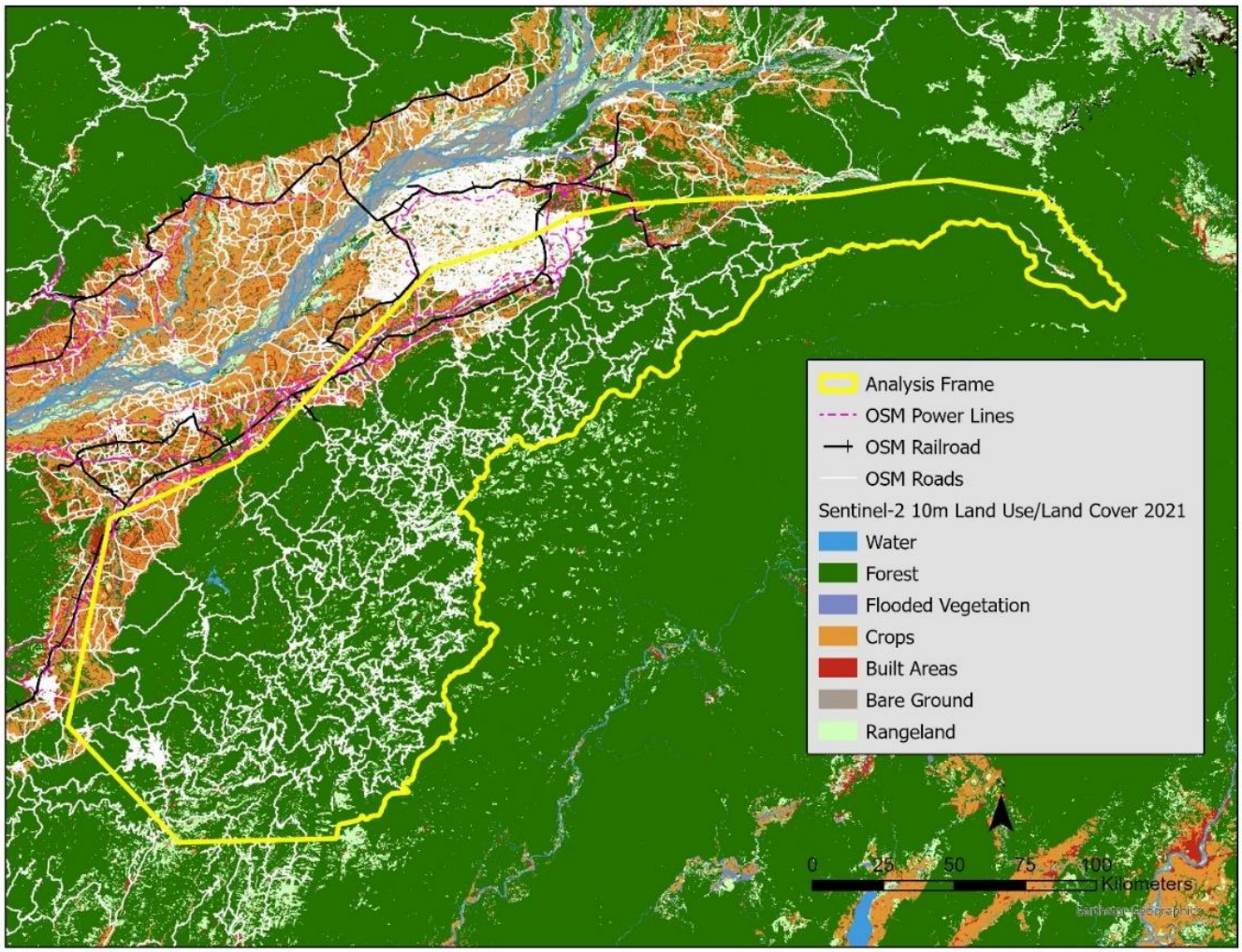

Figure 2. Human development and land use/land cover within the analysis frame.

To assess the completeness of human impact data, a regular grid of 1 km^2 cells was draped over the analysis area, and the percent forest within each cell was calculated. Of the 31,584 cells, 11,640 (36.85%) were classified as 100% forest.

116 cells (1%) were randomly selected using ArcGIS Pro's Create Random Points command and displayed atop ESRI's World Imagery background, which for the study area is a mosaic of WorldView 02 Maxar scenes at 0.5m resolution taken at various dates (to provide a cloudless cover). Each cell was visually examined and attributed with a brief description of visible forest alterations (logging, plantations) and whether or not OSM mapped any visible linear infrastructure; the imagery date was also noted.

Of the 116 completely forested cells (according to the land cover classification), only 62 (53%) presented no human impact, as apparent from imagery (Table 1). Most Maxar scenes were recent (2021 or 2022), but 38% of cells overlapped older scenes (Figure 3), so it is possible that the current human impact was underestimated; for example, a road may have been built after the imagery was taken.

Table 1. The distribution of 116 1 km² cells by human impact class, based on the visual assessment of ESRI's World Imagery. Cells with forest alterations, such as logging or plantations, typically contained dirt roads or tracks.

Human impact	Number of cells
None	62
Roads only, present in OSM	5
Roads only, missing from OSM	17
Missing forest alterations	26
Forest regrowth	6

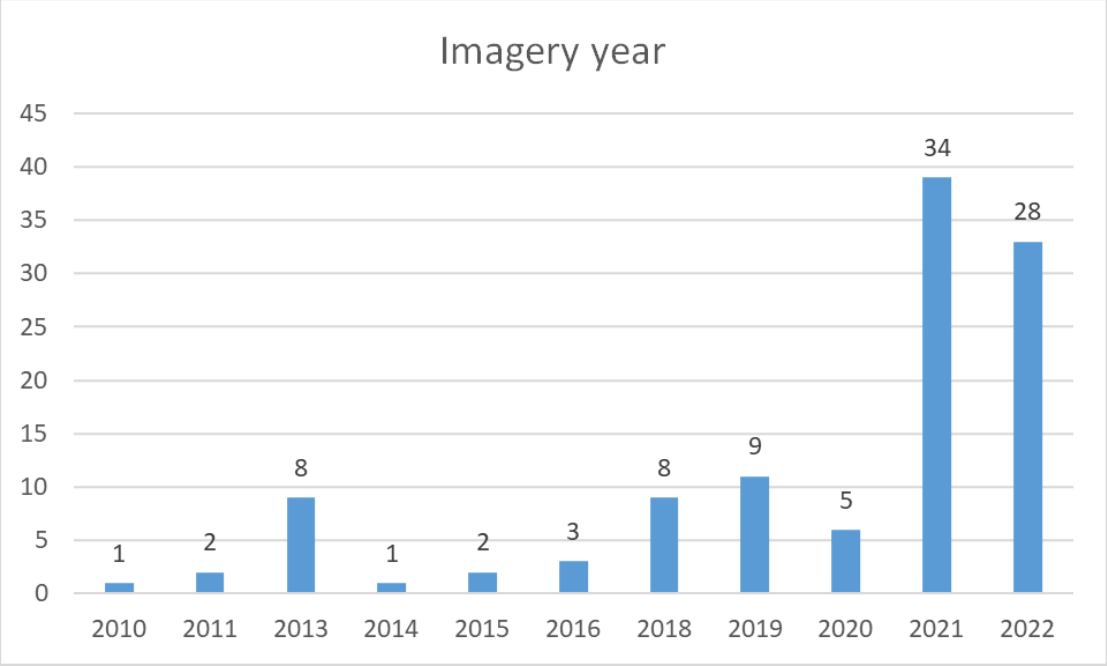

Figure 3. Distribution of 116 1km2 cells by ESRI's World Imagery year; numbers over bars represent percent.

Dirt roads or tracks were visible in most of the other 54 cells, but only 7 cells were correctly mapped by OSM (5 cells had roads only, with another 2 missing logging patches). Three cells with OSM roads were missing additional road segments. The remaining cells contained various amounts of unmapped dirt roads of various widths, some just paths, others much larger. Roads were either connected to forest alterations or paths bisecting intact forest patches. Forest manipulations, in the form of removal (logging/slash and burn) or plantations, were identified in 32 cells and ranged from small, scattered patches to prominent alterations of the natural forest; some were recent, whereas others showed regrowth.

Figure 4 shows examples of intact vs. altered cells, and Figure 5 gives a general overview of their distribution.

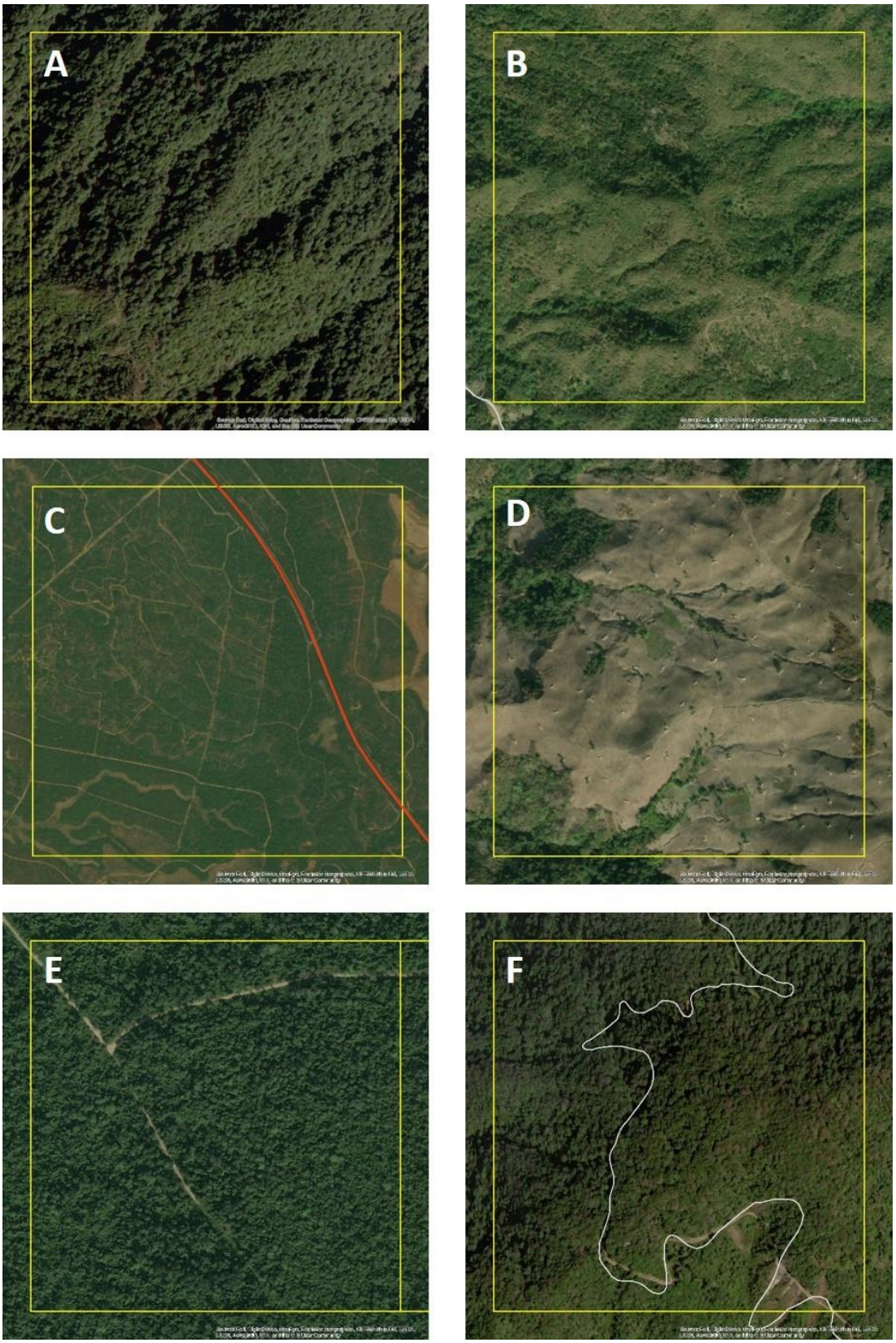

Figure 4. Examples of 1 km² cells displayed atop World Imagery. A: no human impact; B: regrowth, old logging tracks; C: intense plantation development (red line is railroad track from OSM); D: intense, new logging missing from land cover; E: dirt roads missing from OSM; F: dirt road present in OSM.

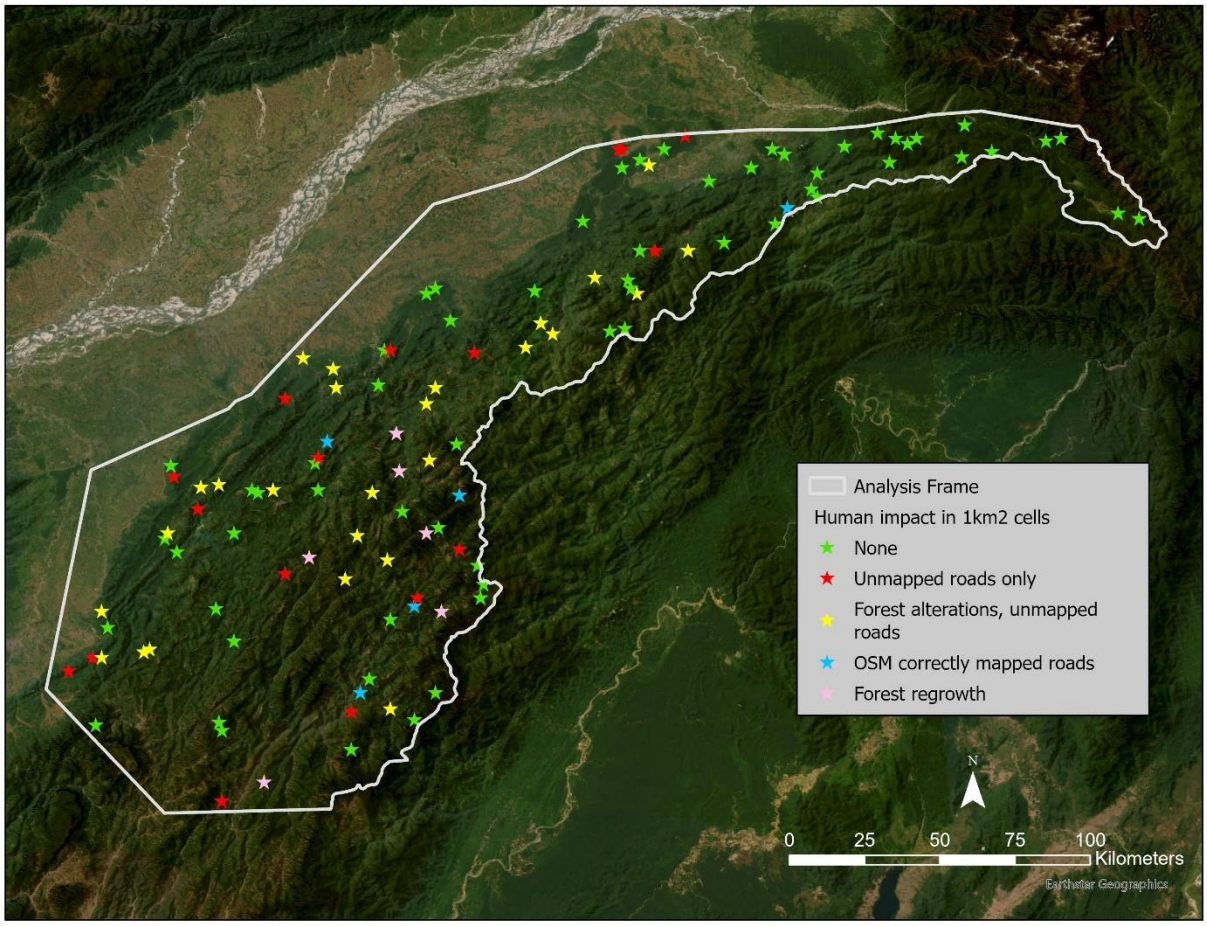

Figure 5. Location and simple classification of randomly selected 116 1 km² cells in northeastern India.

This quick and straightforward evaluation of readily available geodatasets shows the extent of human impact within the range of the hoolock gibbon in northeastern India. The study highlights the presence of unreported linear infrastructure and other impacts, such as forest alterations, that are not reflected in spatial data. For example, although most roads missing from OSM appear unpaved, they can nonetheless be quite wide and often lead to forest removal patches or plantations.

According to OSM data, railroad tracks, and power lines are concentrated in the highly developed western edge of the range, specifically in areas classified as crops and built areas (see Figure 1). However, given the predominantly hilly and forested nature of most of the range, it is unlikely that many (if any) railroad tracks are present on the ground but not in the dataset. This may not be the case for power lines, as only major, multi-line electrical networks are mapped; secondary transmission lines are likely present but not visible on imagery.

Since the land cover classification does not differentiate among forest cover types, the amount of plantation conversion within the range cannot be estimated from this dataset. As a result, many smaller, logged parcels are incorrectly classified as forested, as are areas of recent regrowth. In addition, patchy areas with a mix of

forest, agriculture, and plantations are less likely to be accurately mapped than more uniform areas, whether densely developed or remote natural forest (see Figure *6*).

Figure 6. In the transition zone between the densely developed western edge of the gibbon's range and the more remote and forested landscape that composes most of the range, this area is classified as 100% forested in ESRI's Sentinel-2 10m Land Use/Land Cover 2021 map for India. Yet, it is clearly a mix of agricultural, plantation, and naturally forested patches. None of the roads visible here are mapped in OSM.

Greater Transboundary Virunga Landscape

Within the Greater Virunga Landscape (GVL), the mountain gorilla (*Gorilla beringei*) range consists of three separate areas: Mount Tshiaberimu (subspecies *graueri*), 145 km^2; Virunga Massif (subspecies *beringei*), 455 km^2; and Bwindi Impenetrable National Park plus Sarambwe Natural Reserve (subspecies *beringei*), 334 km^2 (Figure 7). Together, the three landscapes cover only 3.5% of the GVL.

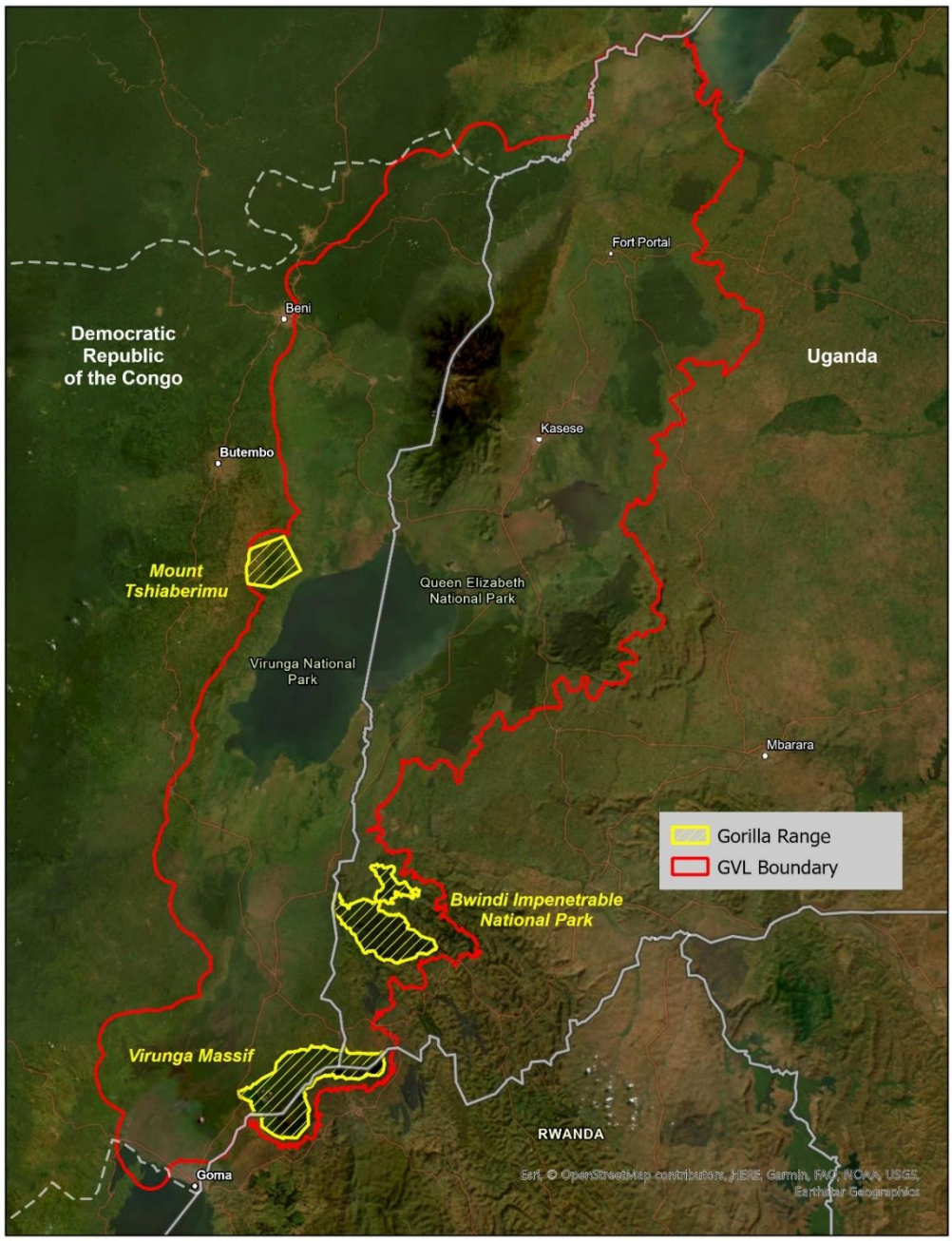

Figure 6. Location of three mountain gorilla subpopulations within the Greater Virunga Landscape, DRC/Uganda/Rwanda.

A vector land use/land cover dataset is available for the GVL, based on 2015 satellite imagery (30m pixels) and with an estimated accuracy of 90%. Although coarse, it points to significant differences among the three areas (Figure 8, Table 2*).*

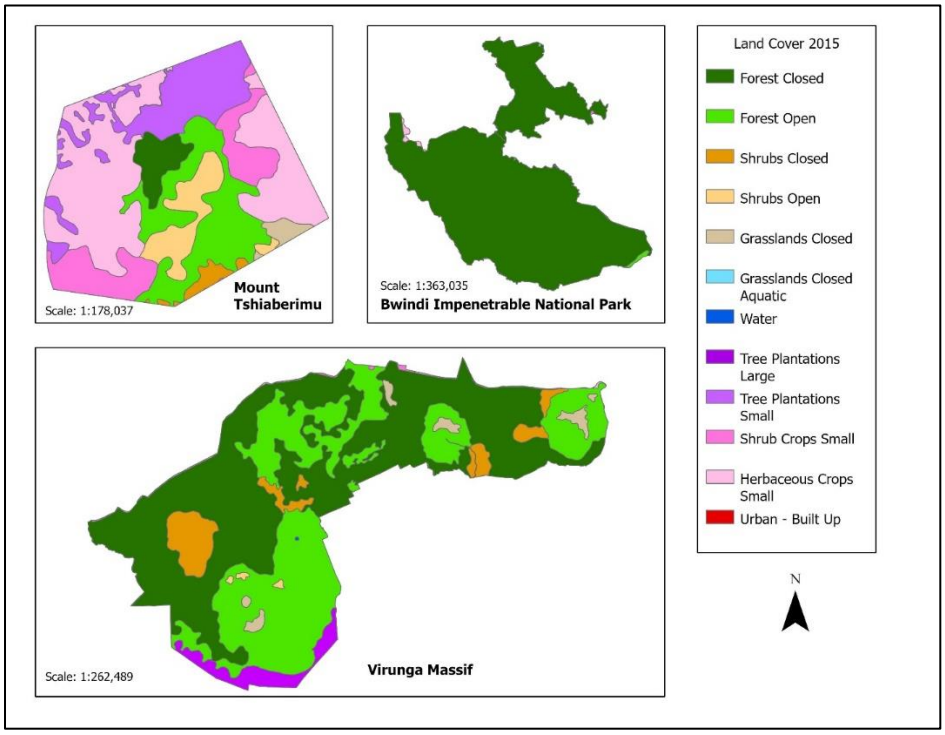

Figure 7. 2015 land use/land cover within the three mountain gorilla subranges in the GVL. Note: each landscape uses a different scale.

Table 2. Percent composition of land use/land cover classes of the three mountain gorilla subranges in the GVL.

Land cover class	Mt Tshiaberimu	Bwindi NP	Virunga Massif
Closed Forest	4.55	98.80	53.71
Open Forest	18.98	0.33	34.66
Large Tree Plantations		0.07	3.18
Small Tree Plantations	16.72		0.03
Closed Shrubs	1.82		5.9
Open Shrubs	7.75		0.24
Closed Grasslands	1.54		1.64
Closed Aquatic Grasslands		0.03	
Small Shrub Crops	12.75	0.3	0.18
Small herbaceous Crops	35.83	0.45	0.43
Urban – Built Up		0.0	0.0
Water	0.06		0.03

Based on OSM, no railroad tracks or power lines within the gorilla range exist. As with land cover, the number and density of roads vary greatly among the three areas, with a much more developed network around Mount Tshiaberimu (Figure 8). Roads add up to 356 km in this landscape, versus 47 km around Bwindi National park and 24 km in the Virunga Massif.

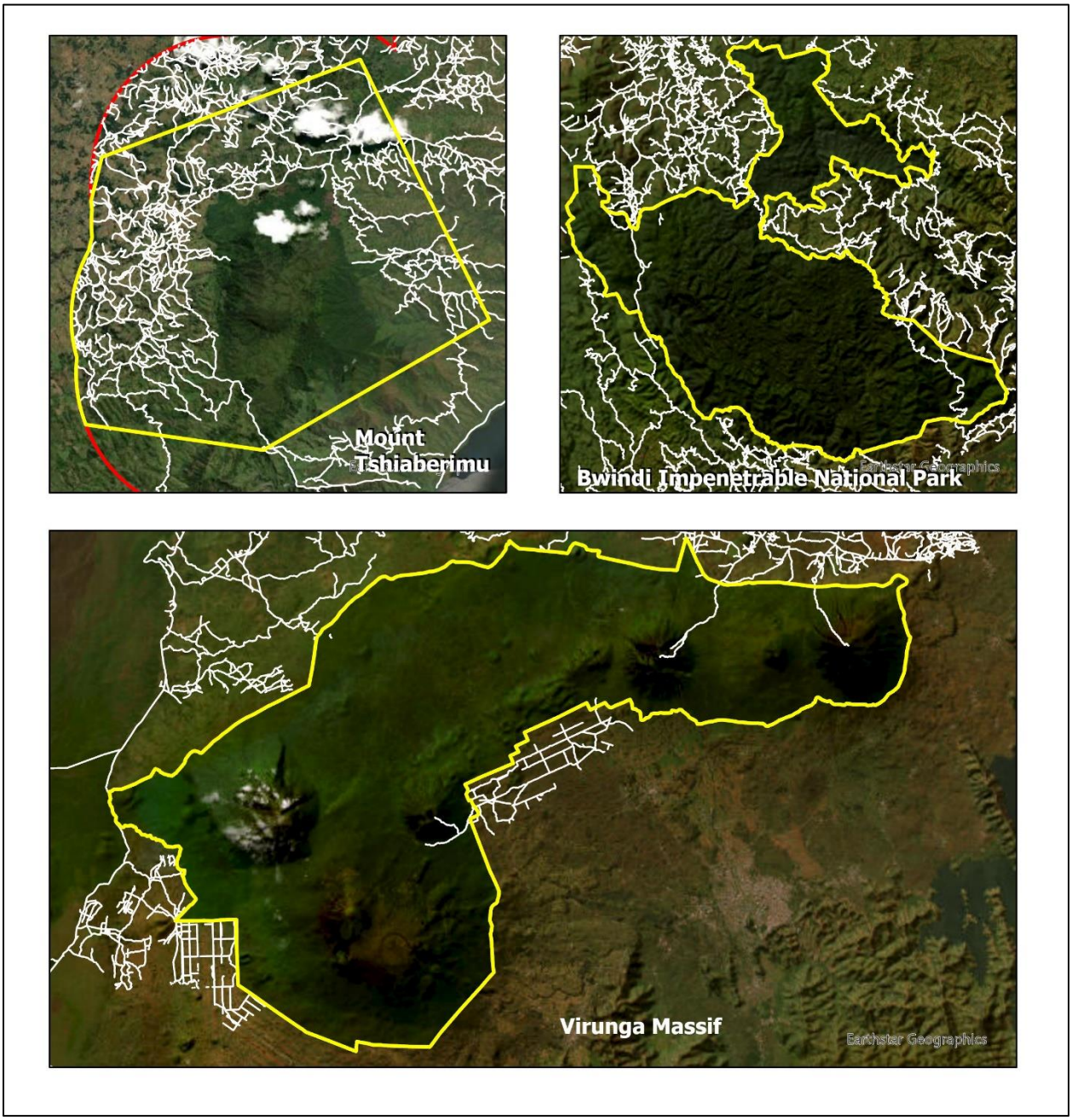

Figure 8. OpenStreetmaps road network within the three mountain gorilla subranges in the GVL. Note: each landscape uses a different scale.

Based on available data, the Mount Tshiaberimu gorilla range is much more developed than the other two landscapes. This is likely an artifact of how polygons were delineated; for Bwindi NP and Virunga Massif, range boundaries closely follow the extent of denser forest, avoiding the surrounding open areas where human activities are pervasive. They were likely digitized based on recent imagery (Figure 9).

Figure 9. World Imagery views of the transition between the densely forested mountain gorilla range and adjacent human-developed areas: Bwindi Impenetrable National Park plus Sarambwe Natural Reserve (top), Virunga Massif (bottom).

To assess the quality of available data, imagery overlapping land cover *natural* classes (i.e., omitting tree plantations, crops, and built-up areas; Figure 8) was panned at 1:5,000. Such a complete survey was possible due to the limited areas of the gorilla range.

Mount Tshiaberimu: based on imagery ranging from 06/04/2011 to 07/03/2019, the land cover layer is missing human alterations of the landscape along the border between natural and developed patches (**Error! Reference source not found.**); about 328 hectares out of 5020 (6.5%).

Bwindi Impenetrable National Park plus Sarambwe Natural Reserve: based on imagery ranging from 02/23/2011 to 07/19/2021 (the majority of the area from various dates in 2021), the road and human land use type coverage is reliable (only one small road segment about 400m not mapped in OSM).

Virunga Massif: based on imagery ranging from 07/07/2018 to 07/02/2019 (the majority of the area), the road and human land use type coverage is good, although there are buildings, roads, and paths missing from the datasets, probably because of scale (i.e., human building areas too small for land cover and paths too thin for OSM).

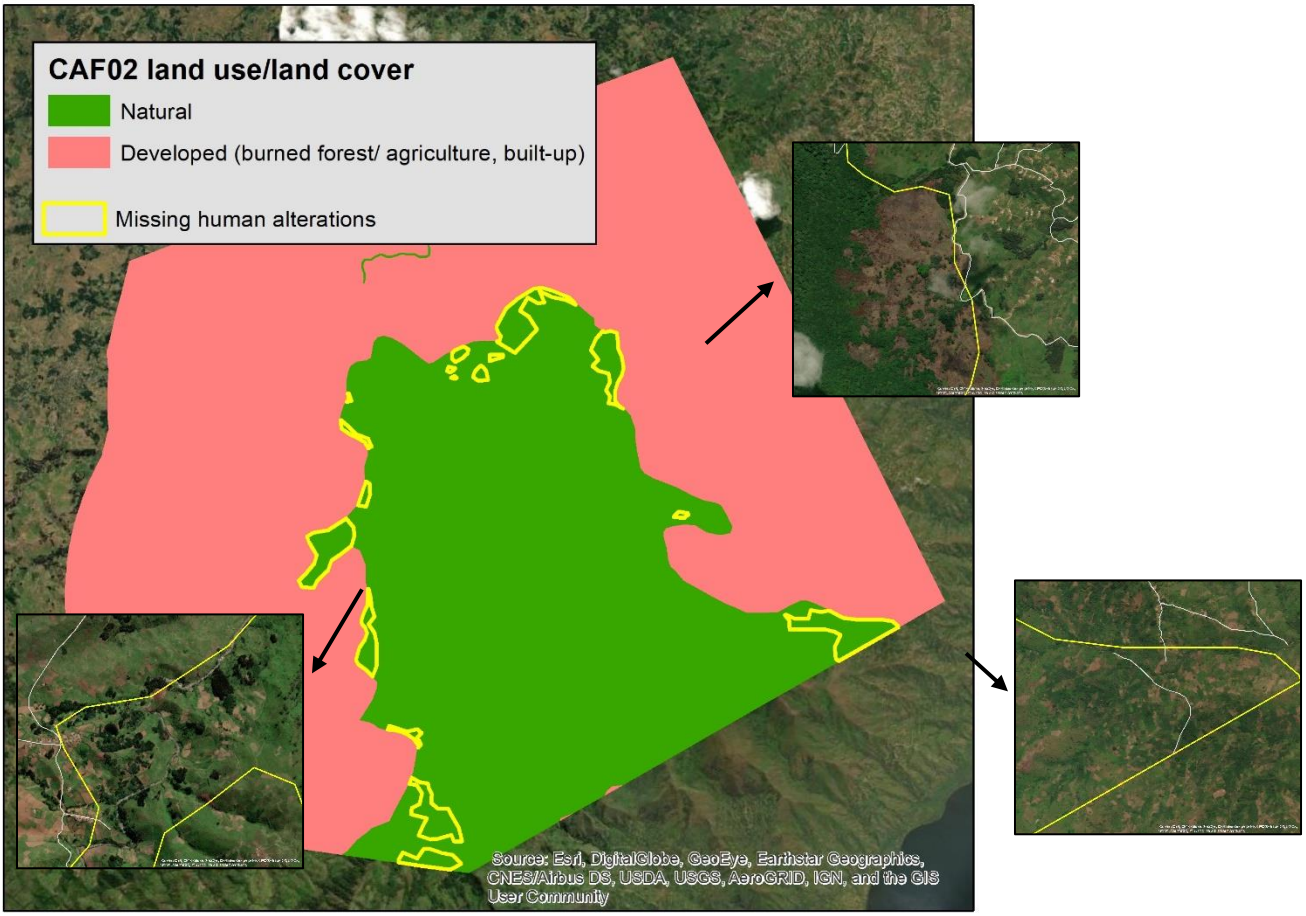

Figure 10. Missing human alterations to the natural landscape within the Mount Tshiaberimu section of the mountain gorilla range in GVL, based on the 2015 land use/land cover map.

Sabah, Malaysia

The analysis focused on the northern range of the Bornean orangutan (*Pongo pygmaeus*), composed of several patches covering 33,811 km^2 within the Malaysian state of Sabah, with the main polygon extending south into Northern Kalimantan, Indonesia (Figure 11).

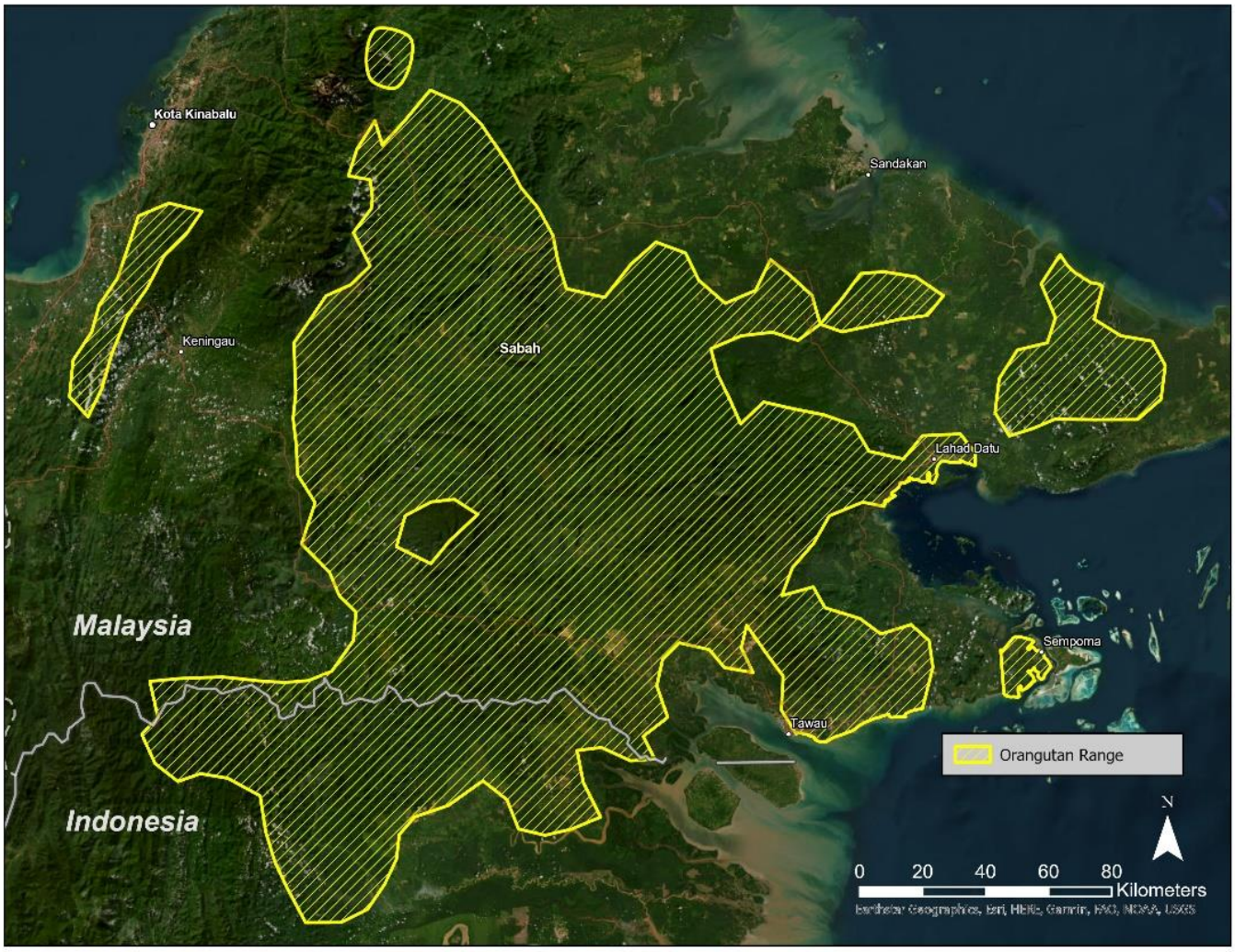

Figure 11. Orangutan range in northern Borneo.

OSM roads delineate 14,351 km within orangutan range and can be classified by type or surface cover, although the majority are not attributed (Table 3). In addition, a layer of primary logging road development was generated by the Center for International Forestry Research (CIFOR) in 2014 by digitizing roads visible on Landsat imagery (30m pixels) acquired over 1972-2010 to follow the expansion of the road network ca 1973, 1990, 2000, and 2010 (Table 4). Although its linework is not as accurate as OSM's, this dataset is a crucial component of the road network; mapped together, OSM and COFIR data show a dense network over much of orangutan range but also distinct un-roaded areas (Figure 12).

Table 3. Composition of OpenStreetMaps roads within the orangutan range in northern Borneo in terms of type and surface cover.

Type	km	Percent
Trunk/trunk link	268	1.87
Primary/primary link	245	1.71
Secondary/secondary link	218	1.52
Tertiary/tertiary link	960	6.69
Residential/living street	1805	12.58
Construction	6	0.04
Service	1065	7.42
Track	5231	36.45
Path	84	0.59
Footway/pedestrian/steps	31	0.22
Unclassified *(likely track)*	4438	30.92

Surface	km	Percent
Asphalt/paved	200	1.39
Gravel/dirt/earth/ground	25	0.17
Sand/wood/grass	14	0.10
Unpaved	4607	32.10
Unknown (*likely unpaved*)	9504	66.23

Table 4. CIFOR logging roads by Landsat imagery year within the orangutan range in northern Borneo.

Year	km	Percent
1970	899	5.35
1990	8448	50.32
2000	3714	22.12
2010	3729	22.21

ESRI's World Imagery was panned at 1:20,000 to identify roads absent from OSM/CIFOR, digitized onscreen at a scale of 1:10,000. This report is not complete at a fine scale nor exhaustive; because the best cloud-free scenes are used to generate the overall World Imagery composite, some older scenes (e.g., 06/19/2010, 04/14/2014) may be lacking more recent roads. Regardless, 1,445 km of roads were added via onscreen digitizing; these roads tend to densify the OSM/CIFOR network rather than fill in open areas (Figure 13).

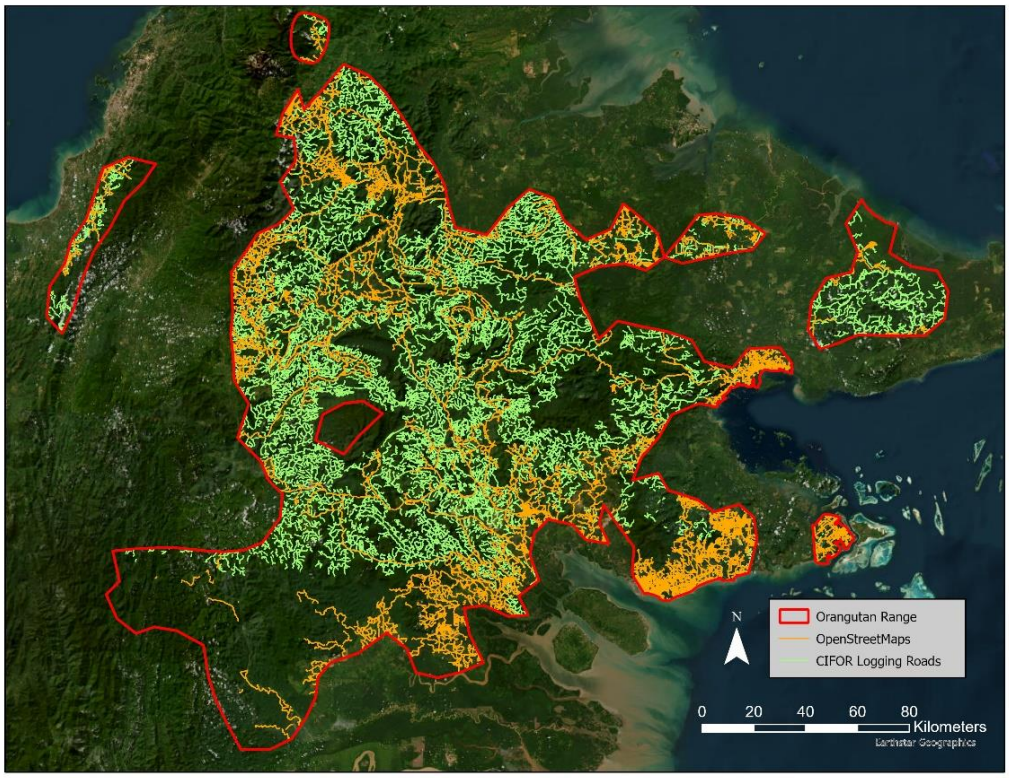

Figure 12. Road data available from OpenStreetMaps and CIFOR within the orangutan range in northern Borneo.

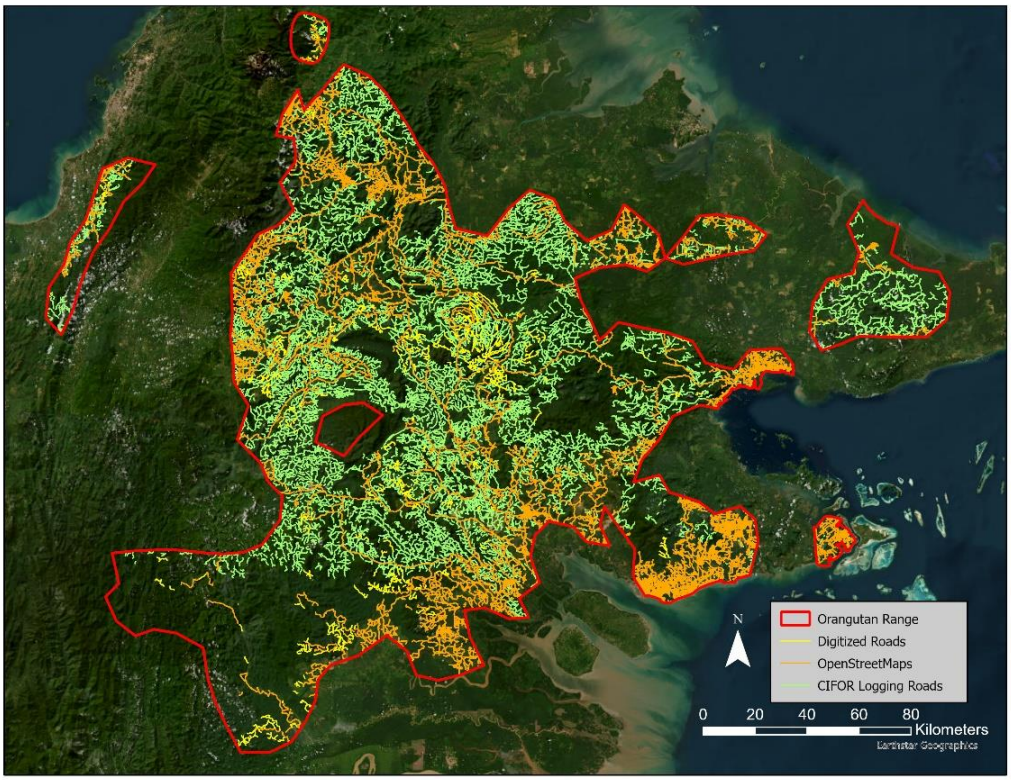

Figure 13. The final road network within the orangutan range in northern Borneo.

Other linear infrastructures, such as railroad and power lines, are either mostly absent from orangutan range or missing from OSM (Figure 14).

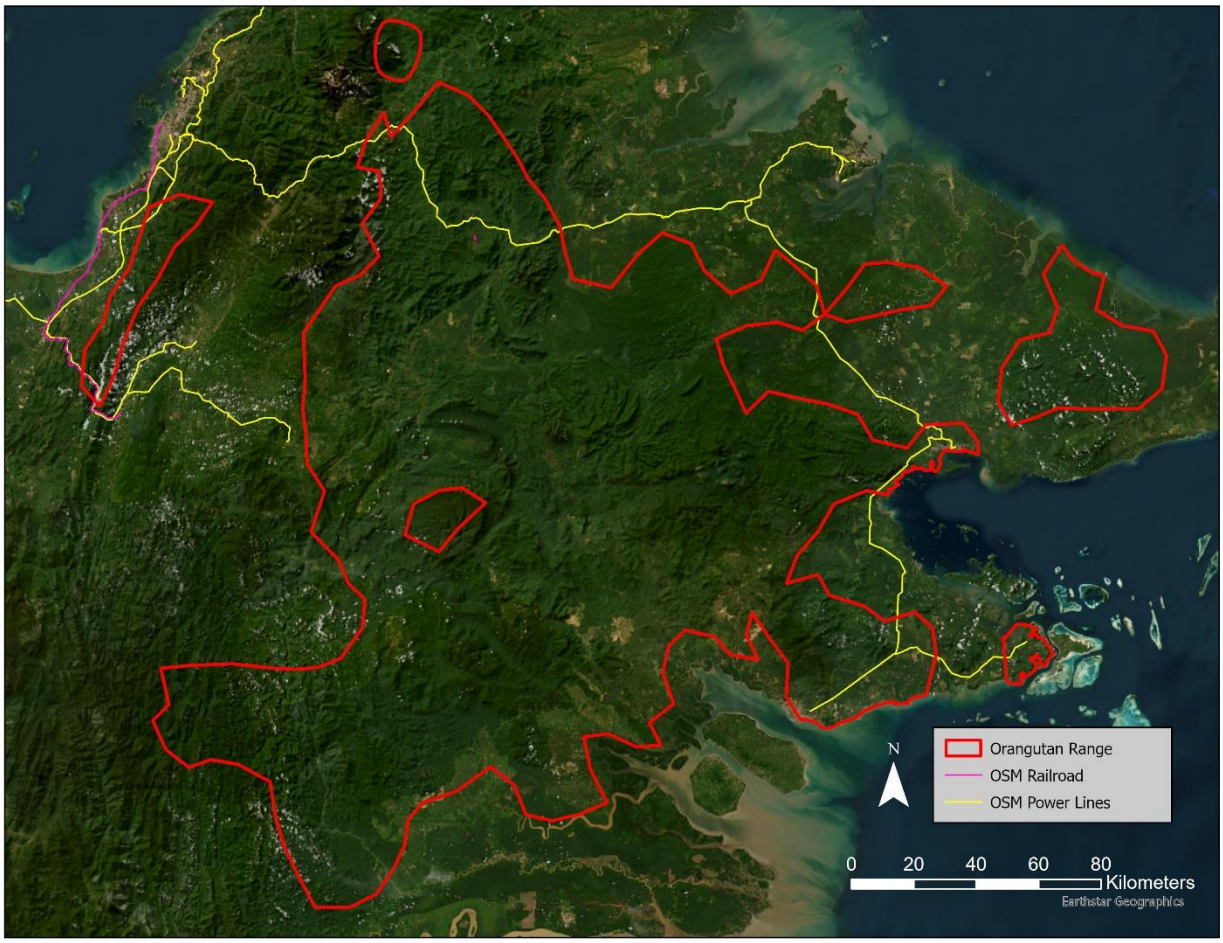

Figure 14. Railroad and transmission lines available from OpenStreetMaps within the orangutan range in northern Borneo.

Human development activities within forests of orangutan range in northern Borneo were obtained from a 2016 dataset of tree plantations created by Transparent World with the support of Global Forest Watch (GFW) and posted on ESRI's ArcGIS Online. To capture forest conversion since that dataset was produced, new logging areas (identifiable by their dense network of cleared paths) and recent plantations were identified using the World Imagery, streaming Sentinel-2 imagery: agriculture with DRA and digitized onscreen (Figure 17). Around 8,000 km^2 of converted forest occurs within the orangutan range (Table 5, Figure 16).

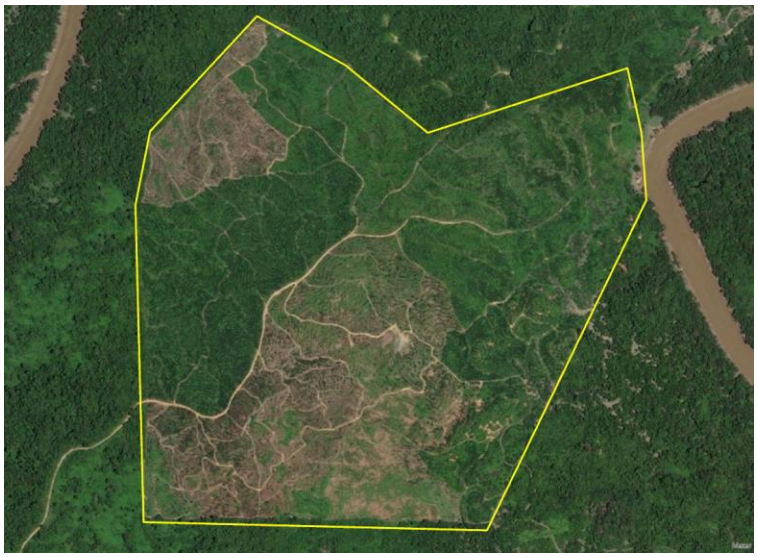

Figure 15. Recent forest conversion identified within the Bornean orangutan range using ESRI's World Imagery.

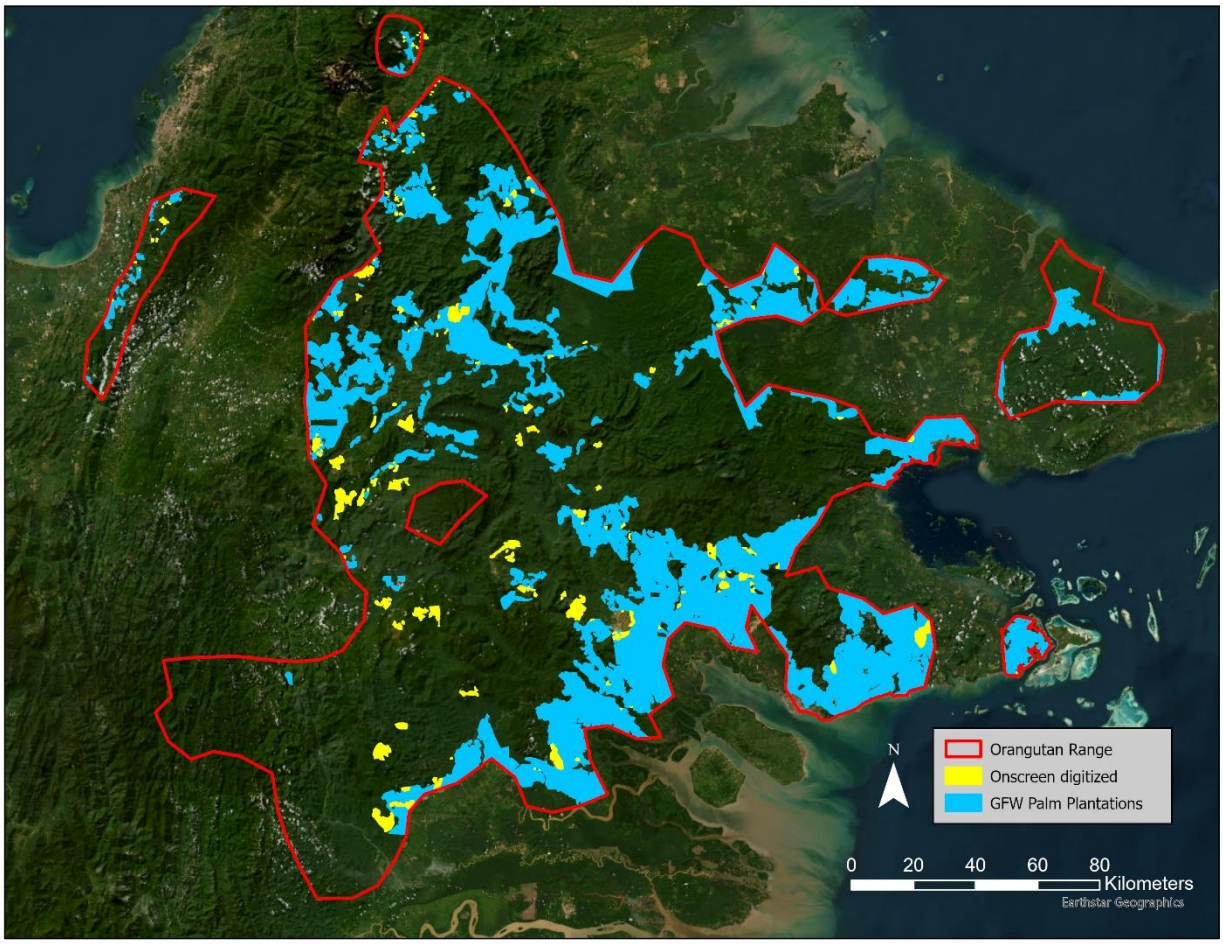

Figure 16. Converted forest within the orangutan range in northern Borneo.

Table 5. Converted forest within the orangutan range in northern Borneo.

Forest Conversion	Area (km^2)
Global Forest Watch (2016)	
• Clearing/ very young plantation	1,258
• Large industrial plantation	5,024
• Mosaic of medium-sized plantations	1,089
• Mosaic of small-sized plantations	271
Onscreen Digitized	452

Figure 17 combines road density (km/km^2, generated with the Line Density command in ArcGIS Pro) with forest conversion in a single map.

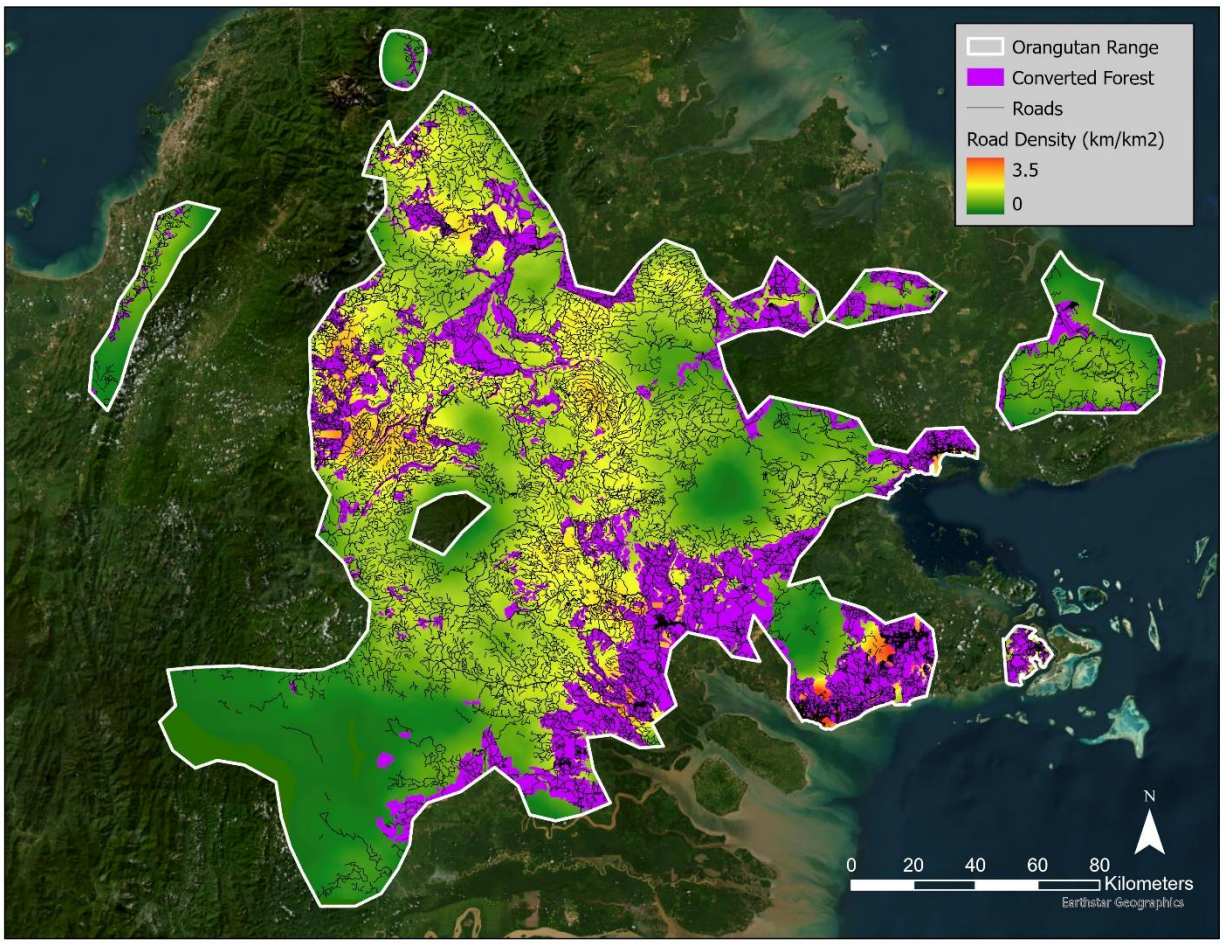

Figure 17. Road network, density, and forest conversion within the orangutan range in northern Borneo.

Recommendations:

When considering the large landscapes necessary for the survival of apes and gibbons, range maps and land use practices are important to understand for management and conservation. Spatial analyses of these areas require incorporating high quality, recent satellite imagery of LI and subsequent land conversions by digitizing these developments onto maps. Public data bases are not adequate for understanding the current state of LI in ape ranges. Procuring planned national or regional linear infrastructure can be very difficult or impossible, but would be helpful, where possible, to plan for additional impacts on apes and their habitats.

Literature Review

To accurately quantify the impact of LI on apes and effectively mitigate them requires sound scientific research and consistent monitoring. Only 20% of primate species have been the subject of studies on the impact of linear infrastructure.[1] This implies that the literature surrounding LI and apes is even smaller, as apes account for only a tiny fraction of the 504 recognized species and subspecies of primates in the world[2]. For this project, the Center for Large Landscape Conservation (CLLC) required a better understanding of the current state of knowledge on existing effective mitigation solutions that protect great apes and gibbons from the deleterious effects of LI and determine existing knowledge gaps.

We conducted a systematic examination of peer-reviewed journal articles on the scholarly database Web of Science to summarize the current state of knowledge on three modes of linear infrastructure: roads, railways, and electric transmission lines, on great apes and gibbons. The database search was conducted in December 2022. Information was extracted and compiled from sources identified in the literature review and synthesized to highlight recent research on the mitigation of impacts from infrastructure on great apes and gibbons.

The database was queried using a formulaic equation similar to recent publications with a similarly broad scope. We employed a formulaic equation to search "taxonomy," "impact," AND "linear infrastructure type." Where "taxonomy" refers to specific ape taxonomic groups, "impact" refers to the direct impact from linear infrastructure (LI), and "linear infrastructure type" was divided into three separate searches by mode: roads, railways, and electric transmission lines.

This review synthesizes peer-reviewed, published best practices for mitigating impacts from linear infrastructure on apes and identify gaps in knowledge. Our search detected all ape-related papers identified in the recent primate-focused review, *No Planet for Apes*, and a few additional papers published within recent years. [1]

Table 6. input for formulaic search

Search Topic	Formulaic Equation Keywords
Taxonomy	TS=(Ape OR Pongo OR Orangutan OR Gorilla OR Chimpanzee OR Troglodyte OR Bonobo OR Hoolock OR Gibbon OR Hylobates OR Symphalangus OR Siamang OR Nomascus NOT Human)
Linear Infrastructure	TS=("linear infrastructure" OR transport* OR road* OR highway OR motorway OR vehicle OR rail* OR train OR "power line*" OR power-line* OR powerline* OR "transmission line*" OR "high voltage line*" OR "transmission system*"))

Three hundred and seventy-five papers were identified using the Boolean logic. The search was refined to limit publication dates from 2010-2022, focusing on recent research conducted within the last decade. We utilized the analysis feature to remove irrelevant articles from research areas including: Biochemistry, Immunology, Psychology, and other areas (see appendix I for full list). Further irrelevant papers were removed based on title and abstract. Sixty-four papers remained and were divided between two reviewers. After reading, it was determined that only thirty-five papers remained relevant to the scope of this review.

All five species of the ape clade were represented within the thirty-five papers, with most papers focusing on gorillas and chimpanzees. Ten of the thirty-five papers covered multiple species of ape. Bonobos were the least represented, with only three papers.

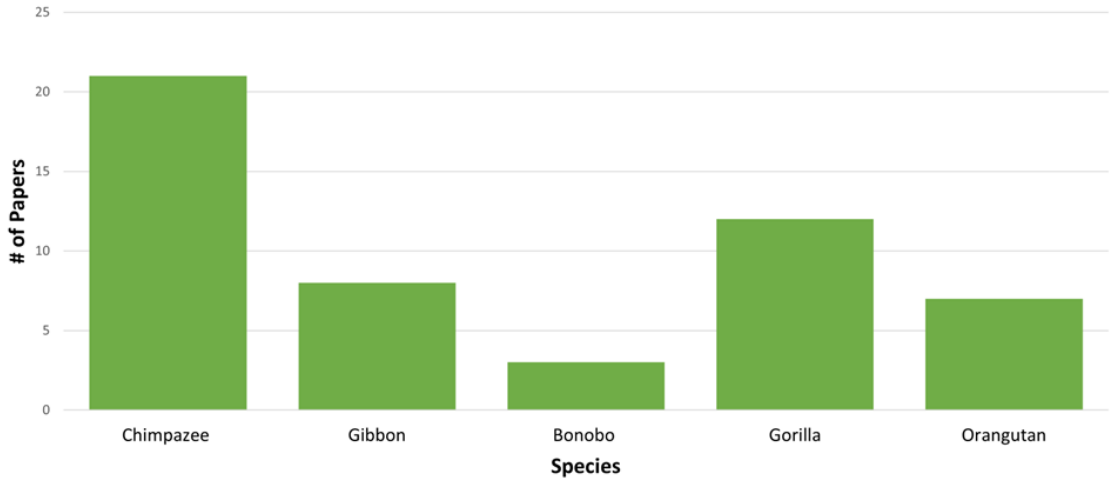

Figure 18. Number of papers per species.

Linear Infrastructure Mode

All of the papers focused on the effects of roadways on apes, and only two papers mentioned railways. Railways and trains have ecological effects on wildlife that are similar to roadways and vehicles. However, the degree of impact may differ, and the effects of railways on wildlife are not well understood. Most research has focused on evaluating the impacts of trains and railways, with little attention towards mitigation, and research projects have primarily focused on moose and bears.[3] Mitigation options exist for wildlife- train collisions, but there remains a need for further study and application of new approaches and technologies.

No papers mentioned the risk of apes being electrocuted on powerlines, despite documentation in Yi et al., 2022, which did not appear in our search likely because it does not have a registered DOI. This study described three cases of Javan gibbon electrocution in a forested area.[4] Recommendations include routing powerlines away from critical habitats, burying or insulating the lines, and installing arboreal crossing structures to dissuade the use of powerlines as crossing structures. While published research on the mitigation of powerlines for apes may be limited, the broader world of primate ecology offers a variety of solutions.[5–7] However, further

research specific to apes should still be prioritized. The exclusion of the Yi et al., 2022 paper also highlights the limitations of systematic reviews focused on traditionally published journals – information from less developed countries is available but not as easily found.

Artificial Arboreal Crossings

Seven of the eight papers which focused on gibbons mentioned the use of artificial arboreal canopy bridges as a potential mitigation measure to reduce the impact of LI on gibbons. However, canopy connection through arboreal crossings should be carefully considered. In the case of LI, which has existed in the landscape for extended periods of time, reconnection may affect behavior and disrupt existing group dynamics, an especially important consideration in territorial species such as gibbons.[8] Single rope design and horizontal ladder design were utilized by gibbons. One study had both designs installed within their study area, and the authors suggested that gibbons have a preference for single rope design.[9] Orangutans have been documented using artificial arboreal crossing structures, but only one of the seven papers which mentioned orangutans suggest canopy bridges as a useful tool for mitigating the effect of LI on orangutans. Artificial arboreal crossing structures are increasingly being used to mitigate the impacts of LI on primates and arboreal mammals. However, there is still a need for further design experimentation, testing, and analysis of their efficacy. As of 2023, only four papers quantify whether canopy bridges reduce primate-vehicle collisions.[10] Further studies should focus on proof of concept, establishing use and risks to primates and other wildlife with various designs and placement. Enhancing or reconnecting natural canopy bridges through restoration efforts with native trees should first be considered. However, reforestation takes time, and ape range connectivity may be maintained during re-growth with artificial bridges.[11]

Wildlife Crossing Structures

Wildlife crossing structures, such as overpasses and underpasses, are a well-documented and effective tool for reducing the impact of roadways on wildlife and enhancing ecological connectivity.[12] To be effective, appropriate fencing is necessary to funnel animal movements through the crossing structures. One paper in the review suggested the use of such structures to reduce impacts on chimpanzees, citing the successful usage of structures in the North American context. However, there is still a great deal of research needed to better understand if and how installation of such structures would be used by apes. Further research would need to be done to determine the best structure type, design, vegetation, and associated fencing.

Traffic Calming Measures

Traffic calming involves making physical alterations to the roadway, such as installing speed bumps, rumble strips, pullouts, wider striping, narrower lanes, and/or adding curves to the road. The main objective is to decrease vehicle speed and discourage the use of the route, thus encouraging drivers to choose a faster alternate route. Additionally, these changes can increase driver attentiveness, potentially improving awareness of surroundings, including the presence of large animals.[12] By reducing vehicle speed, increasing driver alertness, and decreasing the number of vehicles on the road, traffic calming measures can help lower the incidence of wildlife mortality.

Only three of the reviewed papers suggest the use of speed bumps as an effective, low-cost mitigation measure. This method has been proven effective in other primate species, such as the Zanzibar red colobus where the installation of speed bumps within a national park reduced road mortality from 14.5% to 3.2% .[13]

Road Effect Zone

The road effect zone (REZ) is a crucial factor in linear infrastructure ecology. The impacts of linear infrastructure often extend well beyond the actual development's footprint, which is commonly referred to as an "effect zone".[14] The REZ has been quantified for many species, but notably not for apes. In one paper reviewed, an attempt was made to estimate the REZ for chimpanzees.[15] The authors suggest that minor roads have a REZ between 4.9-5.8 km wide, while major roads have a REZ between 15.9-18.6 km wide. This is nearly three times greater than the estimated REZ for other species. As a result, REZ estimation should take place for all species of apes, as scientifically sound estimates are currently non-existent.

While direct road effect zones are due to the actual installation and use of the road, such as vehicle lights, sounds, smells, vibrations, and contamination, secondary and tertiary effects are often more important. These effects include, most importantly, increased human access to habitats and increased hunting, agriculture, and harvesting of forest products.

Better Monitoring Techniques

Monitoring the efficacy of linear infrastructure mitigation efforts after installation is crucial for several reasons. It helps to assess whether the mitigation measures have been successful in achieving their intended goals, allows for the detection of unintended consequences of the mitigation measures, and informs best practices to improve future mitigation efforts. Monitoring can help to build public support for infrastructure mitigation efforts by demonstrating their efficacy and inform decision-making regarding the allocation of resources.

A common theme found throughout the reviewed papers was the lack of monitoring during and after the development of linear infrastructure (LI), leaving the actual effects of roads, railways, and power lines unknown or only estimated for most great ape species. This may be due to the fact that any type of large-scale forest disturbance is not tolerated by apes and mitigation measures are of little use. However, in captive ape reserves and facilities, it may be possible to measure some aspects of mitigation that could be useful in natural settings, such as crossing structures of various types and materials. In habitats where LI development is confirmed for development, wildlife experts must be engaged as early as possible in the planning process in order to share expertise on species specific placement and design of crossing structures to ensure the continued health and stability of populations.

Policy Recommendations

Many papers suggest the need for national laws and environmental strategies to strengthen protection of habitat from the impacts of LI. Current systems typically require environmental impact assessments (EIA). However, this process has been criticized for due to the poor quality of assessments, lack of public participation and transparency, and conflicts of interest. To address these criticisms, nations can enforce policies to increase public participation, enhance transparency, improve data quality, enhance interdisciplinarity, implement

cumulative impact assessments, and strengthen enforcement mechanisms. These improvements can help to ensure that all stakeholders' concerns are considered and the recommendations made are effectively implemented. Most national legal frameworks require strengthening as well as enforcement of environmental laws. Designation of ecological corridors, including restoration of habitats should be considered by national governments to ensure ape viability from protected areas through working landscapes to additional suitable habitats

The Need for Ape Specific Guidance

There is clearly a need for further research to adequately inform best practices for the mitigation of the impact of LI on great apes and gibbons. Historically, literature has been heavily biased towards North American and European species. Recent decades have seen a significant increase in literature from underrepresented regions, however species specific research is lacking on how LI should be designed and mitigated, how post construction restoration should occur, and best practices for monitoring and evaluation.

Limitations of Traditional Systematic Literature Reviews

In part, this activity was used to better familiarize researchers with the existing state of knowledge related to apes and linear infrastructure. Linear infrastructure ecology spans all geographies and species, making the need for context specific research critical. However, the authors would like to note that this effort is viewed as an exercise to better build our own capacity, and is not wholly representative of the entire field of apes and linear infrastructure mitigation. Our efforts focused on papers with registered Digital Object Identifier (DOI) which are often cost prohibitive to smaller research initiatives. Additionally we restricted our searches to english published or translated papers, primarily due to time and capacity of project personnel. Non-English-language science contributes to conservation decision-making and is no less relevant that English-language literature.[16]

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Stakeholder Engagement

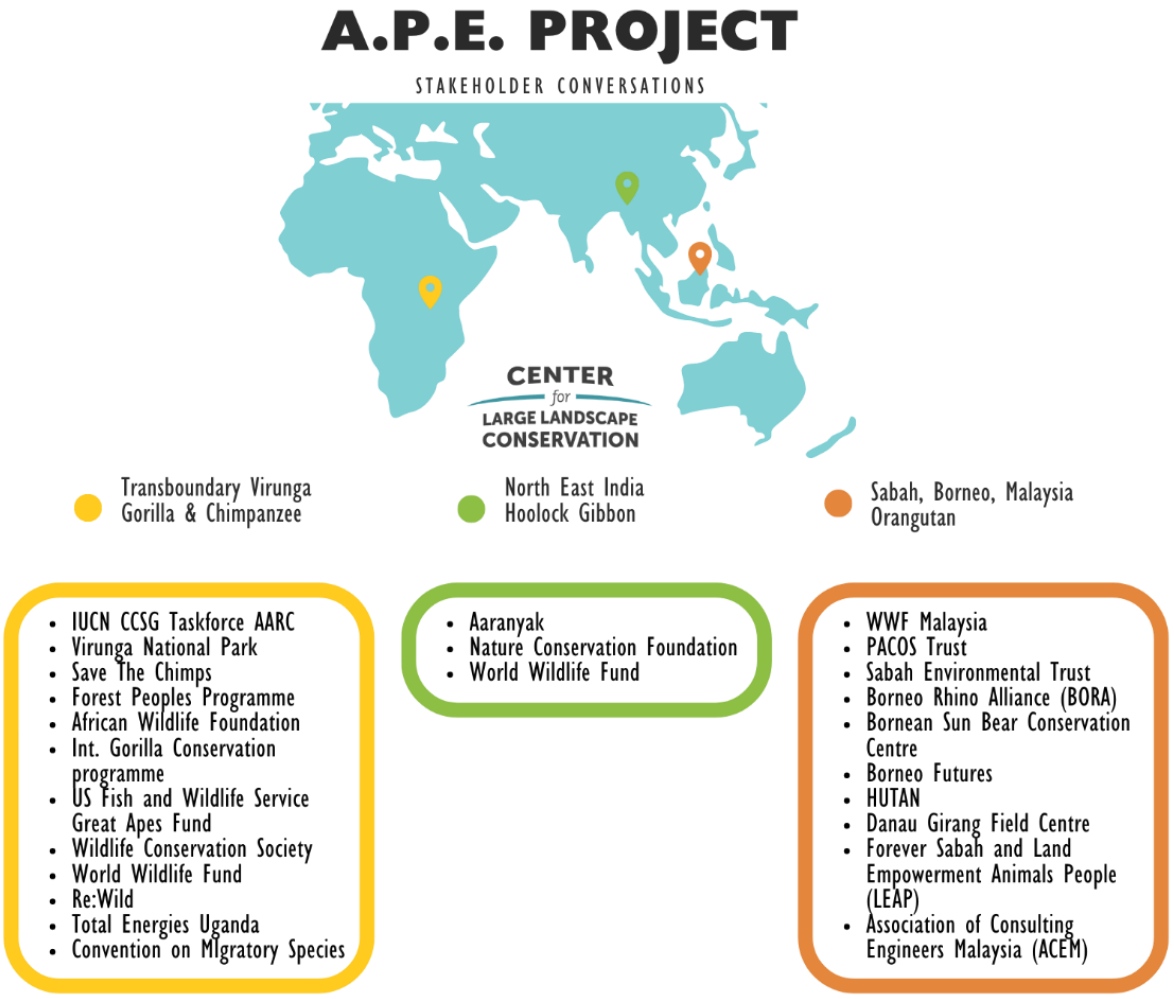

Figure 19. Institutions engaged by CLLC during A.P.E. Project

The project team would like to extend their gratitude to on-the-ground practitioners who took the time to engage in discussions about linear infrastructure development within each focal landscape. Figure 19 showcases the various institutions the team engaged with in each landscape and these conversations greatly informed many of our research methodologies and recommendations. The project team found that both the GTVL and Sabah landscapes are areas with a wealth of capacity to assist in safeguarding apes from linear infrastructure development. The Center was only able to identify a few key players engaging in linear infrastructure mitigation in the Hoolock gibbon landscape, highlighting the need for greater capacity building and creating a larger collaborative community around gibbon conservation here.

Recommendations

While policy and practical measures have been developed to mitigate the impacts of linear infrastructure on great apes and gibbons in some areas, significant data gaps exist, and much work needs to be done. Good science and monitoring are required, and conservation policies and enforcement must be strengthened across ape ranges. Local communities and their forests' integrity need to be brought into national and international conservation and LI conversations with advocacy and training.

Through conversations with on the ground practitioners, policy assessment, literature review, and spatial exercise the project team recommends the following to better mitigate the deleterious effects of linear infrastructure on apes:

- Increase public participation and enforce policies and law within focal landscapes. In many cases, government oversight agencies need more capacity and sufficient staffing to enforce and oversee linear infrastructure developments and resulting environmental degradation.
- Increase research on the effects that railways, power lines and pipelines have on apes and gibbons. There are few data to estimate the area of negative effects, beyond the physical footprint of LI, for nearly all ape species. This requires measuring ape movement, behavior and population density in relation to all types of LI across their ranges, and monitoring habitat use, population size, fitness and gene flow.
- Design, construct and monitor LI crossing structures specifically designed for apes. Initiate studies as to whether terrestrial crossings can work for great apes in Africa, and understand best practices for design, materials and placement strategies of arboreal crossings for brachiating primates.
- Restore and rehabilitate habitats where LI is constructed with an understanding of native foods, cover and the removal of invasive species to mitigate the deleterious effects of LI.
- Incorporate indigenous and local community voices into policy and planning decisions across landscapes. Understand community needs, health and culture over the long term. Reach local people and advocate for their futures.
- Consider the large landscapes necessary for the survival of ape species, and conduct spatial analyses which incorporates high quality imagery of LI and subsequent land conversions to compare with available LI data bases to ensure that the best, current maps reflect actual LI impacts.
- Monitor, regulate and support enforcement of human impacts on the landscape following LI development, such as illegal hunting and agricultural conversion, which brings apes, humans and domestic animals into closer contact. Increased loss of habitat as well as disease transmission are risks to ape survival.

Appendix I: Research Areas Removed from Literature Review

Biochemistry, Molecular Biology, Cardiovascular System Cardiology, Psychology, Immunology, Neurosciences, Neurology, Cell Biology, Pharmacology, Pharmacy, Hematology, Microbiology, Engineering or Pathology or Computer Science or Mathematics or Virology. Science Technology, Business Economics, Instruments, Instrumentation, Paleontology, Plant Sciences, Sport Sciences, Meteorology, Atmospheric Sciences, Gastroenterology, Hepatology, Linguistics, Marine, Freshwater Biology, Genetics, Heredity, Public Environmental Occupational Health, Mathematical Computational Biology, Arts Humanities, Chemistry, Endocrinology, Metabolism.

Appendix II: Citations of Papers from Literature Review

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