University of Michigan, School for Environment and Sustainability

BIODIVERSITY AND SOCIAL IMPACT ASSESSMENT AT BANKE-BARDIYA COMPLEX ALONG EAST-WEST ELECTRIFIED RAILWAY ALIGNMENT IN NEPAL

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Abstract

An electrified railway is being built east-to-west across Nepal, bisecting key ecological regions and carrying significant potential to disrupt wildlife connectivity and peoples' land relationships. We worked with WWF Nepal to analyze various social and ecological consequences of the planned railway. Specifically, we evaluated (1) where wildlife occupancy is highest in Banke-Bardiya (BB) Complex, (2) where key endangered species moved within the landscape, (3) how habitat fragmentation and human-wildlife conflict can be mitigated through effective management and railway design, and (4) village fragmentation and Indigenous rights in Nepal. To address these topics, we used Geographic Information Systems, occupancy modeling using camera trap data, remote sensing, habitat selection modeling, and literature reviews. Our results revealed high biodiversity within key wildlife corridors, the active use of these corridors by these species, and the potential for human-wildlife conflict given the proximity of wildlife to developed areas. We found that the modeled movement overlapped highly with actual wildlife movement and identified two potential best crossing locations. We strategically designed crossing structures at these points to facilitate movement of key species. We determined approaches to maintain connectivity and minimize human-wildlife conflict in general, including crossing structure standards, fencing, and habitat management techniques, as well as approaches related specifically to key species. We also proposed a Free, Prior, and Informed Consent (FPIC) protocol to support Indigenous peoples' rights prior to railway construction in BB Complex. This study has the potential to mitigate harm to both humans and wildlife, presenting a good model for future projects in achieving sustainability and development goals.

Introduction

Railway Construction Through the Terai Arc Landscape

The government of Nepal has recently made significant efforts to improve human well-being by bolstering their economic development, setting 2022 as the goal for graduating from a “least developed” to “developing country” (NPC, 2019). One of their primary methods of increasing development is increasing the connectivity and strength of their transportation infrastructure (ANZDEC, 2011). Roads account for 90% of freight and passenger traffic in Nepal (Asian Development Bank, 2017). To accommodate the growing demand for passenger and freight transport, the government of Nepal has planned to construct a 1,205 km long East-West electrified railway (Department of Railways, 2018).

The proposed railway will run through the Terai, a biodiverse lowland region of Nepal that also provides important agricultural value. The Terai Arc Landscape (TAL), a biodiversity hotspot, supports 86 species of mammals, >600 species of birds, and over 2,100 species of flowering plants (Chanchani et al., 2014). The proposed railway has the potential to harm biodiversity conservation efforts in this ecologically fragile region. The railway will likely pose significant challenges to wildlife movement, particularly for long ranging mammals such as tigers, elephants, and rhinos (Chanchani et al., 2014). Nepal’s tiger population could be significantly affected as critical tiger habitat corridors (e.g. Kamdi, Khata, and Karnali corridors) along the Banke-Bardiya Complex will be bisected by the railway (Chanchani et al., 2014). Railways and roads are a physical barrier when wildlife are unable to cross due to inaccessibility or if the railway creates conditions that cause wildlife to be unwilling to cross an accessible railway (Barrientos & Borda-de-Água, 2017). The Khata Corridor in particular provides an important linkage with the Katarniaghat Wildlife Sanctuary (KWS) in India. Linear infrastructure poses a significant threat to these corridors that are critical for the long-term survival of many species in the region. Along with the physical barrier of new infrastructure in the region, new development has the potential to alter biotic communities and reduce biodiversity (Richardson et al., 2017). Additionally, while there are many important ecological considerations, the impact of the railway’s construction on humans is an important focus as well. Human communities can benefit from the development of infrastructure such as railways (e.g. transportation use, green jobs, economic development); however, displacement of local and Indigenous peoples can occur due to construction of infrastructure across peoples’ lands (Department of Railways, 2020; Neef & Singer, 2015).

Study Area: Banke-Bardiya Complex

The proposed East-West electrified railway will run through the Terai (lowlands) of Nepal and will significantly affect this biodiversity hotspot. However, the impacts of this railway on biodiversity and Indigenous and local communities in the Banke-Bardiya landscape have not been assessed. The Banke-Bardiya Complex in the Western TAL provides essential habitat for many threatened species including elephants (*Elephas maximus*), rhinos (*Rhinoceros unicornis*), and tigers (*Panthera tigris*) (MFSC, 2015). The Banke-Bardiya Complex is of particular importance for tiger conservation as it is home to nearly half of the growing Nepalese tiger population (DNPWC & DFSC, 2018). The Complex is also home to many Indigenous and local communities in Banke and Bardiya National Park buffer zones.

Three major issues may result from the construction of this railway: (1) The proposed railway will run through areas of significant importance for biodiversity including Banke National Park Buffer Zone, Kamdi Corridor, and Khata Corridor; (2) the proposed railway will fragment villages; and (3) the structure of the railway could interfere with wildlife dispersal, threatening important animal populations including elephants, rhinos, and tigers (MFSC, 2015). Infrastructural barriers to dispersal may also present a direct danger to both wildlife and workers and commuters; elephants in Kenya have climbed steep embankments to cross railways (Cheshire & Uberti, 2016) and around 70 elephants have died in rail collisions along a single 160 kilometer stretch of track in the Himalayan Foothills of India between 1974 and 2019 (Chamling & Bera, 2020).

This study examines the social implications of the railway in Banke-Bardiya Complex, analyzes wildlife occupancy and movement in the region, proposes strategic placement of wildlife crossing structures, and finally, assesses wildlife crossing, connectivity, and human-wildlife conflict mitigation design practices.

Social Implications

Acknowledgements

The organization of this report reflects a separation of people and wildlife, indicative of another example of the nature/culture binary in action (West et al., 2006). In reality, there are other worldviews (e.g., many Indigenous) that do not see humans as separate from nonhumans, and we should remain mindful of this moving forward.

This report reflects research on “sustainable development.” Moving forward, we should acknowledge that the notion of sustainable development stems from a western worldview, which has and continues to conflict with other worldviews (e.g., many Indigenous). According to Yap & Watene (2019), for example, many Indigenous worldviews emphasize values and practices of living in harmony with the environment through ontologies of circularity rather than linear growth that often characterizes development.

Introduction

The construction of transport infrastructure can bring a multitude of benefits to people such as improved transportation use, increased jobs, and economic development. However, the displacement of Indigenous Peoples and Local Communities (IPLCs) can potentially result from the construction of infrastructure across peoples’ lands (Department of Railways, 2020; Neef & Singer, 2015). Asia holds one of the largest displaced populations in the world (Neef & Singer, 2015). Displacement due to development can result in a loss of economic, cultural, and social capital (Neef & Singer, 2015), in addition to the loss of one’s home and connections to land. In Nepal, Indigenous peoples are referred to as Adivasi Janajati, or ethnic minorities (IWGIA, 2020). There are at least 63 Indigenous groups as of 2011 (IWGIA, 2020), with 59 officially recognized (NFDIN Act). In the Terai of Nepal, the construction of the east-west electrified railway presents concern for people, due to the high diversity of IPLCs in the region, the construction of the railway through villages and across peoples’ lands, and the lack of strong land governance.

Objectives for the social impact assessment were to explore Indigenous and local community groups in Banke-Bardiya (BB) Complex, analyze village fragmentation by the railway and villages in the buffer zone, analyze Indigenous rights, and ultimately propose recommendations to minimize harm by the railway. Overall, research questions were: 1) Who lives in BB Complex, 2) Where and how will the railway impact IPLCs through village fragmentation?, 3) What rights do IPs have?, and 4) How can the negative impacts of the railway on IPLCs be mitigated?

Methods

IPLC Demographics

The population numbers of IPLC groups in Nepal were pulled from Nepal's Central Bureau of Statistics' Population Atlas (2014). To avoid highlighting caste groups, these groups were combined into a category of Local Communities, or LCs. To differentiate between caste groups and ethnic (Indigenous) groups, Indigenous groups were cross-checked according to Minority Rights Group International (2020) and the NFDIN Act. An "Others" category was created to reference IPLC groups not included in the Population Atlas but noted by other sources as discussed later. The population number representing "Others" was calculated by subtracting from the total population number in the district (Central Bureau of Statistics' Population Monograph, 2014) and the other IPLC groups' population numbers (Central Bureau of Statistics' Population Atlas, 2014).

Railway-Village Overlay

To analyze how the proposed railway line would impact people, a GIS overlay of the proposed railway line and village points (data from WWF Nepal, 2021) was conducted using ArcGIS Pro. An Intersect function was used to estimate the number of villages fragmented by the railway, and buffer zone and clip functions were used to estimate the number of villages residing within one kilometer of the railway.

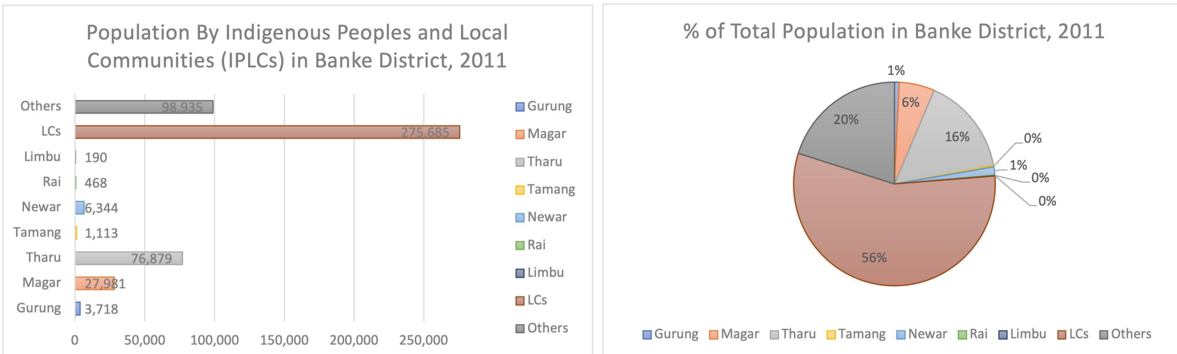
Indigenous Rights

Indigenous rights in Nepal were analyzed at the national and international level to develop a better sense of how conservation and development efforts interact with Indigenous peoples' rights to self-determination, among other rights (IWGIA, 2020; Alfonso Martínez, 1999).

Results / Discussion

Indigenous Groups in the Terai

A large Indigenous group are the Tharu in the Terai region (Figure 1). Others include Magar, Tamang, Majhi, and Gurung peoples (Government of Nepal Ministry of Forests and Environment, 2018). For the purposes of this study, the Indigenous Peoples and Local Communities (IPLC) framework is used to talk about culturally diverse groups of people and avoid the stereotyping of one “indigenous group” (Rivera Cusicanqui, 2010).



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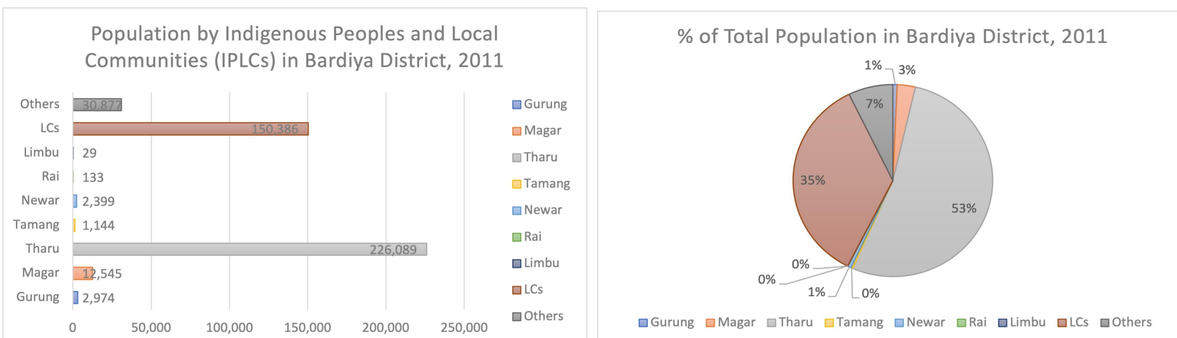


b.

Figure 1: Total population by IPLCs in Banke (a) and Bardiya (b) districts as of 2011 (Central Bureau of Statistics, 2014, Population Atlas). Population numbers for 7 IP groups are provided. “LCs” = local communities and represent the combination of 9 caste groups. Note the “Others” category, meaning the list of IPs is non-exhaustive. “Others” likely represent IP groups not included in the Population Atlas but noted to reside in the districts; “Others” likely include at least 3 additional IP groups in Banke district (Majhi, Kumal, Khonaha) and 6 additional IP groups in Bardiya district (Majhi, Kumal, Sonaha, Raji, Darai, Bote). Khonaha and Sonaha are not officially recognized by the government.

In Banke and Bardiya districts, Tharu represent the largest standalone Indigenous group, approximately 16% of the total population in Banke and 53% of the total population in Bardiya (Figure 1). In both districts, other IP groups include Limbu, Rai, Newar, Tamang, Magar, and Gurung (Figure 1; Central Bureau of Statistics, 2014). Additionally, Majhi and Kumal reside in both districts in Banke and Bardiya Buffer Zones (BZs) (Table 1; WWF, 2019). Khonaha are not officially recognized by the government but reside in Banke district in Kamdi Corridor (WWF, 2019). Lastly, Sonaha (not officially recognized) also reside in Bardiya district in Bardiya BZ (Thing et al., 2017; WWF, 2019), along with Raji, Darai, and Bote (WWF, 2019).

	Tharu	Magar	Gurung	Majhi	Kumal	Tamang	Khonaha	Sonaha	Raji	Darai	Bote
Banke BZ	✓	✓	✓	✓	✓						
Kamdi Corridor (Banke)	✓	✓	✓		✓	✓	✓				
Bardiya BZ	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

Table 1: Indigenous groups in PAs (WWF, 2019). BZ = Buffer Zone. ✓ = Group resides in PA.

Overall, there is a diversity of culturally distinct Indigenous groups in Banke and Bardiya district: a total of at least 10 IP groups in Banke and 13 in Bardiya (Table 2), along with other LCs, with Tharu representing the largest Indigenous group in Banke-Bardiya. Indigenous groups account for at least 24% of the total population in Banke and at least 58% of the total population in Bardiya. In total, as of 2011, there are approximately 116,693 Indigenous individuals in Banke and 245,313 in Bardiya.

	Limbu	Rai	Newar	Tharu	Magar	Gurung	Majhi	Kumal	Tamang	Khonaha	Sonaha	Raji	Darai	Bote
Banke district	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Bardiya district	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

Table 2: Indigenous groups in Banke-Bardiya districts. At least 10 IP groups reside in Banke district and 13 in Bardiya. This list may still be non-exhaustive, and LCs are not included here. ✓ = Group resides in the district.

Village Fragmentation

Of immediate concern are villages which the proposed railway will intersect and fragment. The proposed railway line will intersect at least 16 villages in Banke-Bardiya Complex (Figure 2). Most village-railway intersections are planned to occur outside of the Protected Areas (PAs); however, the railway will intersect at least 2 villages in Khata Corridor (Bandalipur and Ram Nagar).

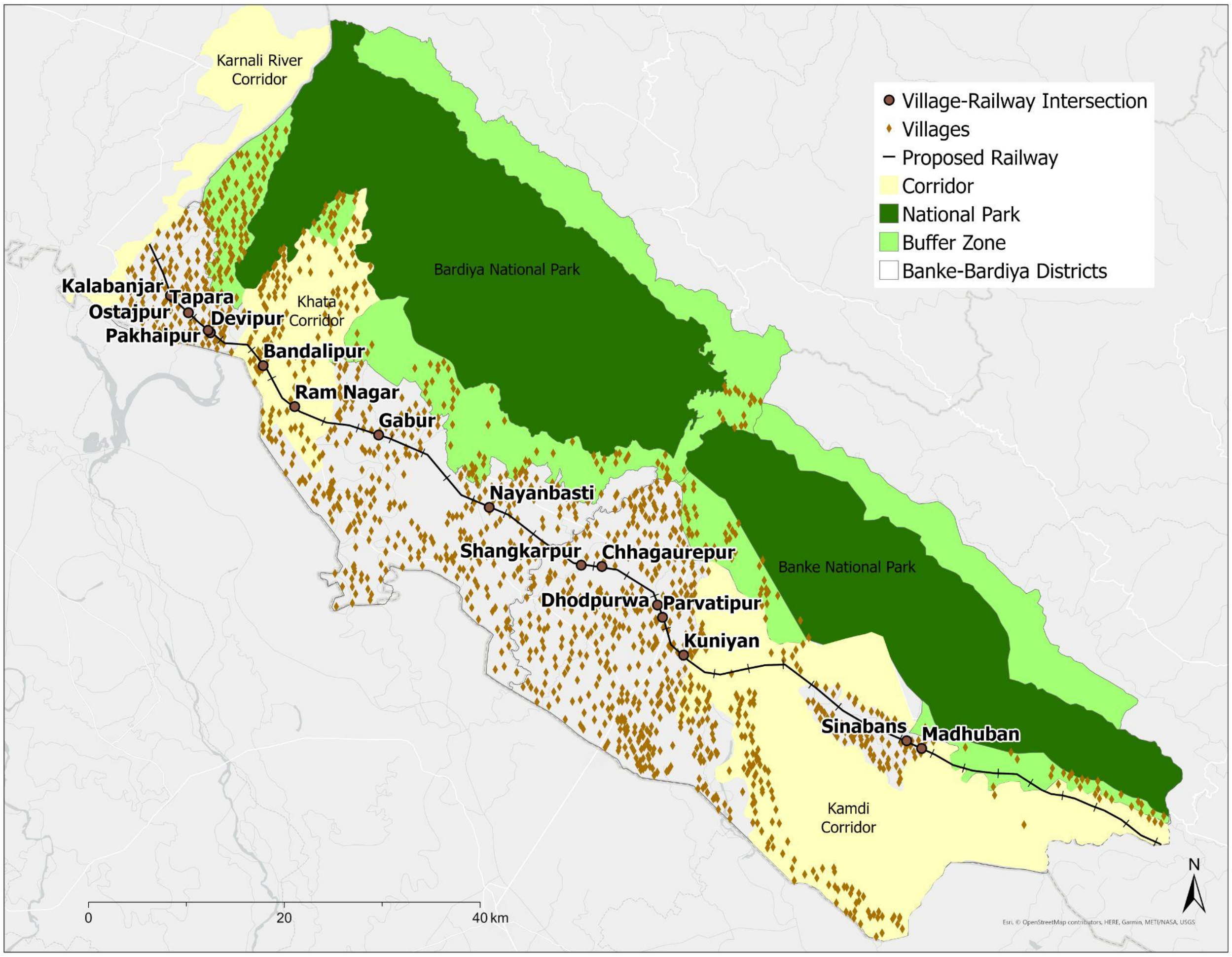


Figure 2: Proposed railway line intersecting villages in Banke-Bardiya Complex. At least 16 villages (labeled brown dots) face fragmentation due to intersection with the proposed railway. Note that 16 villages may be an underestimate due to the nature of the village data as point (rather than polygon) feature class data. Source: GIS layers by WWF Nepal. Datum/Projected Coordinate System: WGS 1984, UTM Zone 44N.

The proposed railway intersections with the 16 villages will cause village fragmentation and leave high potential for land pooling and/or to displace individuals and families from their lands and homes, affecting land-relationships in a variety of ways. In addition to the loss of one's home and biocultural connections to land (McLean, 1999), displacement due to development can result in economic, cultural, and social losses (Neef & Singer, 2015). Displacement already occurs in Nepal due to environmental variables such as flooding, landslides, and droughts, among others (National Planning Commission, 2013). There has been historical displacement during the creation of Banke and Bardiya National Parks (NPs) (Kollmair et al., 2003). In addition to displacement, fragmentation of villages can create issues in accessing community resources, reduce land value, and have health and safety impacts (FPIC &

Rights Forum, 2020). Moreover, land fragmentation can negatively affect communal governance of land (Zang et al., 2019).

Villages in Buffer Zone

On a broader scale, households in the vicinity of a railway can experience health impacts due to noise pollution (Dratva et al., 2012), or safety impacts such as from altered wildlife movement. In Banke-Bardiya Complex, there are approximately 139 villages residing within one kilometer of the proposed railway (Figure 3).

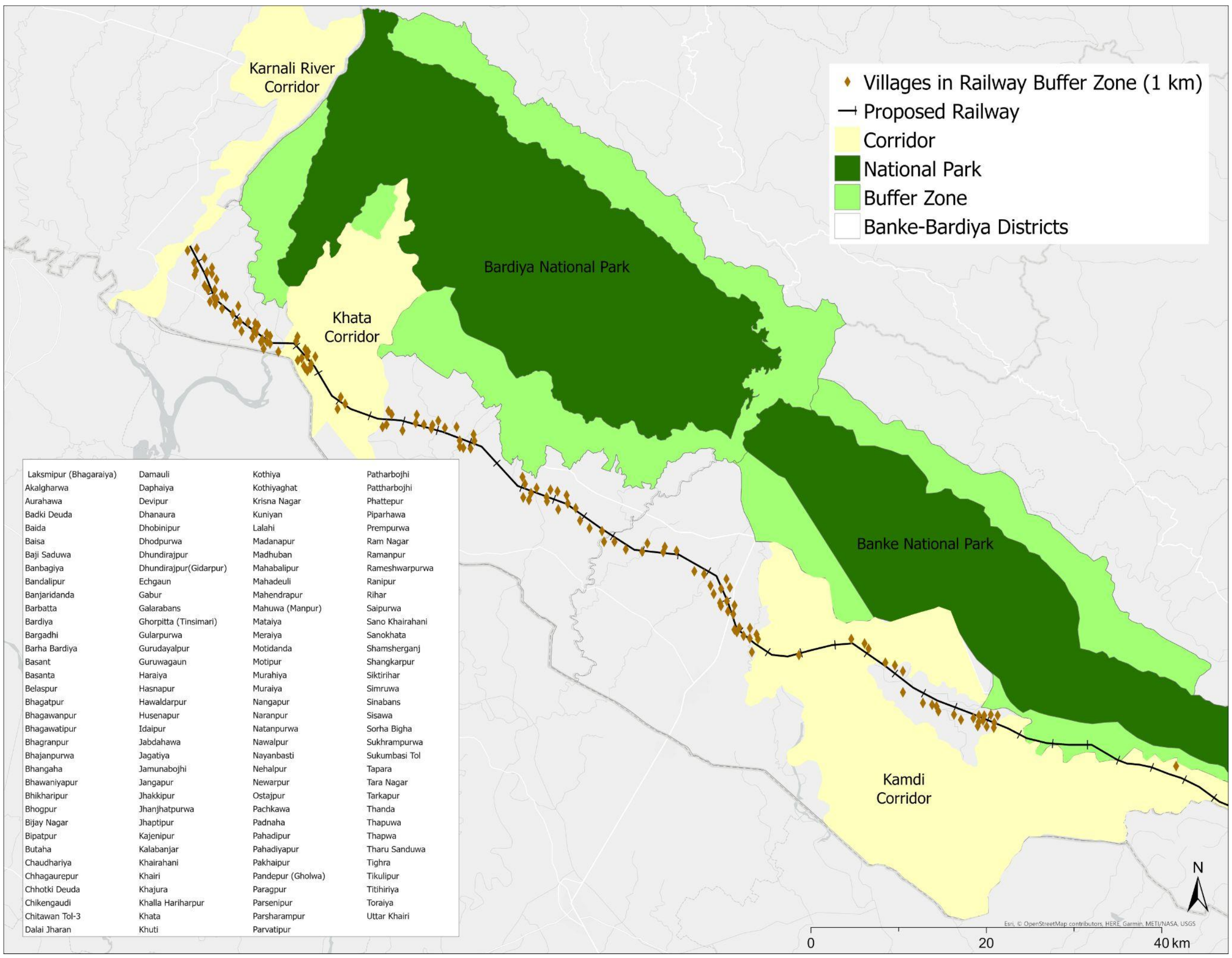


Figure 3: Villages in a 1 km buffer zone of the proposed railway in Banke-Bardiya Complex. At least 139 villages are within a 1 km buffer zone of the railway and face potential health impacts such as noise pollution. The village names are noted in the table to the bottom left (see also Appendix A). Note that 139 villages may be an underestimate due to the nature of the village data as point (rather than polygon) feature class data. Source: GIS layers by WWF Nepal. Datum/Projected Coordinate System: WGS 1984, UTM Zone 44N.

Villages within the railway buffer zone and those facing direct fragmentation by the railway present concern for IPLCs' well-being due to the impacts discussed thus far (e.g., displacement, reduced economic and cultural well-being), and so warrants attention on mitigation methods to minimize harm. The next section explores rights that are specifically afforded to Indigenous peoples in Nepal that can be used to advocate for IPLCs in Banke and Bardiya Complex.

Indigenous Rights Analysis

Internationally Recognized Rights

Two international instruments are of particular importance in relation to Indigenous rights: 1) In 1989, The International Labor Organization adopted the Convention on Indigenous and Tribal Peoples No. 169 (ILO 169), and 2) In 2007, The United Nations adopted the Declaration on the Rights of Indigenous Peoples, commonly referred to as UNDRIP. Nepal ratified ILO 169 on September 14^{th}, 2007 (International Labour Organization, 2017), and also endorsed UNDRIP the same year. The following sections explore the implications of Nepal's commitments to ILO 169 and UNDRIP and the relevance of these instruments to the railway project.

ILO 169

In 2007, Nepal was the first country in South Asia to ratify ILO 169. Once a country ratifies a convention, the convention becomes a legally binding international treaty. While the article guidelines in ILO 169 are non-binding, a country must use the convention's guidelines as a framework to implement into national policies while also being subject to monitoring by the ILO. ILO 169 specifies Indigenous rights to land and consent, among other rights.

UNDRIP

Nepal endorsed and signed on to UNDRIP in 2007 when it was adopted by the United Nations General Assembly. UNDRIP is considered the most significant progression and transformation of international human rights for Indigenous peoples--setting benchmark standards. The declaration recognizes Indigenous collective rights to land, consent, and self-determination, among other rights. Similar to ILO 169, it is considered an important instrument with guidelines that should be integrated into a country's statutes and policies to support Indigenous rights, although it is non-binding.

Specifically, Articles 28 and 32 in UNDRIP are of particular importance in the context of the railway project. The Articles declare rights to Free, Prior, and Informed Consent (FPIC) and compensation:

Article 28:

1. *Indigenous peoples have the right to redress, by means that can include restitution or, when this is not possible, just, fair and equitable compensation, for the lands, territories and resources which they have traditionally owned or otherwise occupied or used, and which have been confiscated, taken, occupied, used or damaged without their free, prior and informed consent.*
2. *Unless otherwise freely agreed upon by the peoples concerned, compensation shall take the form of lands, territories and resources equal in quality, size and legal status or of monetary compensation or other appropriate redress.*

Article 32:

1. *Indigenous peoples have the right to determine and develop priorities and strategies for the development or use of their lands or territories and other resources.*
2. *States shall consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources.*
3. *States shall provide effective mechanisms for just and fair redress for any such activities, and appropriate measures shall be taken to mitigate adverse environmental, economic, social, cultural or spiritual impact.*

In summary, UNDRIP (which Nepal is signatory to) gives rights to just compensation and that Free, Prior, and Informed Consent (FPIC) shall be obtained from Indigenous peoples prior to the approval of any project affecting their lands and territories (such as a railway).

National Rights Implementations

Indigenous rights are present in Nepal's national context after ratifying ILO 169 and endorsing UNDRIP, specifically with the new 2015 Constitution.

The 2015 Constitution states participation rights in Part 4:

> *Making special arrangements to ensure the rights of Adivasi Janajatis (indigenous ethnic groups) to lead a dignified life with their respective identities, and making them participate in decision making processes that concern them, and preserving and maintaining the traditional knowledge, skill, experience, culture and social practices of Adivasi Janajatis and local communities.*

Before ratifying ILO 169, the National Foundation for Development of Indigenous Nationalities Act, or NFDIN Act, was created in 2002 to establish a government body to uplift Indigenous peoples in a variety of social, economic, and cultural development aspects. The NFDIN body indeed developed an FPIC protocol in 2019 in collaboration with WWF (Independent Panel of Experts, 2020).

Case Study: Construction and Compensation

This section explores compensation issues surrounding the electrified railway construction that is already occurring in Chandrapur and Gujara municipalities (Figure 4), with implications for Banke-Bardiya Complex as construction continues west. One can look through an Indigenous rights lens for Chandrapur and Gujara as we highlight issues surrounding compensation of peoples' lands, although the identity of all landowners is unknown.

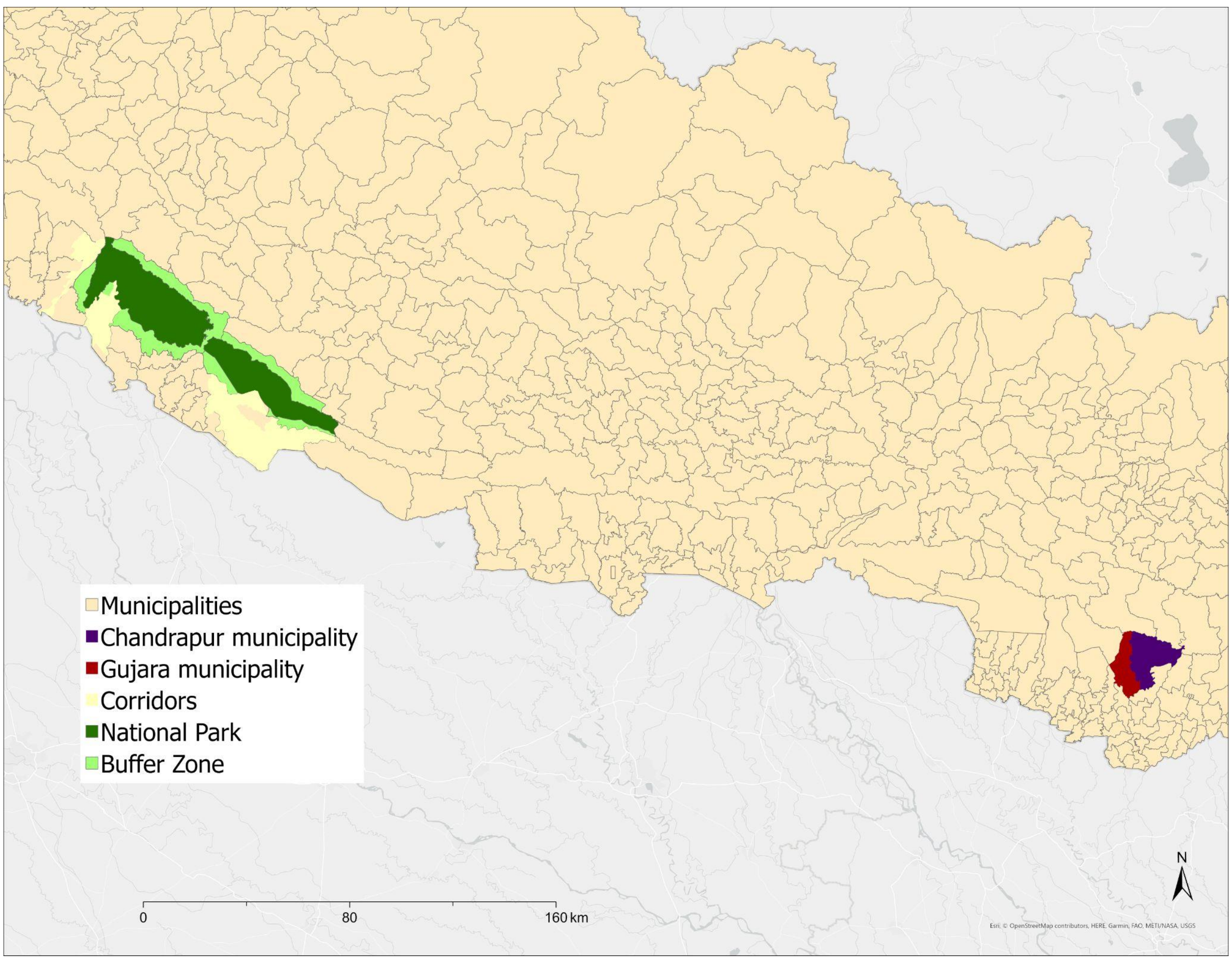


Figure 4: The electrified railway construction has occurred in Chandrapur and Gujara municipalities (purple and red, respectively)--east of Banke-Bardiya Complex, Nepal. Source: BB Complex layers by WWF Nepal; Municipalities layer by Open Data Nepal. Datum/Projected Coordinate System: WGS 1984, UTM Zone 44N.

According to Puri (2020), construction of the East-West electrified railway line—also known as the Mechi-Mahakali Electric Railway—was halted in Chandrapur municipality for over five months due to landowners protesting compensation issues after land pooling. The landowners created a “Local Struggle Committee” and demanded the Compensation Fixation Committee to 1) raise the amount compensated to landowners, and 2) reevaluate documents indicating land type, which determines the compensation amount. For instance, if land has “irrigation facilities,” the amount of compensation would be NPR 500,000 (~USD 4,222) per kattha (one kattha ~ 339 sq meters). However, incorrect records stated that some owners’ land did not have irrigation provisioning and thus were only eligible to receive NPR 400,000 (~USD 3,378) per kattha. Incorrect records, low compensation amounts, and delayed payment were some reasons that fueled the protests.

Records were eventually fixed—making local people eligible for the NPR 500,000—and fifteen of twenty-six farmers received compensation depending on their land type (Puri, 2020). The construction company promised to compensate the remaining landowners. In Chandrapur municipality, 30 bighas of land overall were acquired (one bigha ~ 6,772 sq meters).

According to Puri (2021), nine months later–after more land was acquired in both Chandrapur and Gujara municipalities–some landowners were still awaiting compensation from the Department of Railways. The Department of Railways (2020) carefully documented landowners whose land has been pooled for construction of the railway. Landowners only received compensation for 172 out of 323 plots.

While it is unclear the identity of farmers (i.e., who are Indigenous), these issues surrounding compensation indicate a misalignment with Nepal’s commitments to ILO 169 and UNDRIP, specifically regarding Article 28 if consent to land pooling was not obtained. Concernedly, there is potential for similar issues to arise in Banke-Bardiya Complex as construction continues west.

The next section explores obtaining Free, Prior, and Informed Consent (FPIC) from IPLCs prior to railway construction in Banke-Bardiya to improve compensation expectations and support consent and land rights in general. An FPIC Protocol developed by the FPIC & Rights Forum (2020) is proposed.

Recommendation: An FPIC Protocol

One important avenue to explore is obtaining Free, Prior, and Informed Consent (FPIC) from IPLCs prior to railway construction on their lands in BB Complex. FPIC is the consultation right declared in UNDRIP (Art. 32) and ILO 169 to which Nepal is signatory. Specifically, “Free” refers to giving consent without pressure; “Prior” refers to an IP group having sufficient time to make a decision before the project starts; and “Informed” refers to IP groups having all relevant information in order to make a decision (FAO, 2016).

While WWF Nepal has FPIC guidelines developed in collaboration with NFDIN (as mentioned previously), we particularly agree with the FPIC Protocol created by the FPIC & Rights Forum (2020) during a transmission line project, and believe it should be used prior to railway construction in Banke-Bardiya Complex. While a transmission line differs from the electrified railway line, we believe the Forum’s FPIC Protocol is directly applicable to Banke-Bardiya Complex due to similarities in an infrastructure being built across peoples’ lands and the right to FPIC afforded to Nepalese Indigenous communities. FPIC increases the transparency and expectations of development projects, supports the participation process and IPs’ rights, and ultimately reduces frustrations. Obtaining FPIC would uphold Nepal’s commitments to UNDRIP and ILO 169.

In Nepal, protests have occurred surrounding the lack of FPIC and compensation in regards to development projects (LAHURNIP & Accountability Counsel, 2018). The FPIC Protocol was developed by the FPIC & Rights Forum--an umbrella organization for the “Local Struggle Committees”--in partnership with IPLCs in Lamjung and Manang districts to support FPIC and compensation demands that were not adequately met during the Marsyangdi Corridor transmission line project (FPIC & Rights Forum, 2020). According to LAHURNIP & Accountability Counsel (2018), there was no meaningful consultation, FPIC was not obtained, and there were compensation, health, and safety issues, among others.

The Forum’s FPIC Protocol outlines a step by step process to obtaining FPIC and negotiating conditions through three overarching categories for both Indigenous Peoples and Local Communities (IPLCs): 1) Pre-Consent, 2) Consent, and 3) Post-Consent (FPIC & Rights Forum, 2020). We propose using the FPIC Protocol and modify it as needed for Banke-Bardiya Complex. For example, when providing information on the project to IPLCs (in their native languages), information can also include location of wildlife crossing structures (for safety reasons) and other health and safety impacts. Receiving FPIC from villages specifically intersected by the railway (Figure 2) would prove just and beneficial.

FPIC Protocol (FPIC & Rights Forum, 2020).

Conclusions

To conclude, a diversity of culturally distinct groups live in Banke-Bardiya Complex and will be impacted by the electrified railway construction as it continues being built east-west across Nepal. At least 139 villages could face health and safety impacts while residing in a 1 km buffer zone of the railway, 16 villages will be fragmented, and land will be lost due to pooling with potential for displacement. There are already compensation issues, too, where construction is occurring east of BB Complex. Since Nepal has committed to internationally recognized rights of Indigenous peoples through ILO 169 and UNDRIP, a rights approach can be used to mitigate further harm to people by the railway. Specifically, obtaining FPIC and in the process establishing clear compensation and other expectations would prove worthwhile to achieving equitable sustainability and development goals.

Limitations / Future Research

There are some limitations of our social impact assessment worth mentioning. First, we were unable to translate additional Nepalese census reports pertaining to demographic data and this perhaps resulted in the missing of some Indigenous or other groups and their population numbers in Figure 1.

Second, the village data (Figures 2 and 3) does not include population characteristics; thus, we were only able to explore the diversity of IPLCs at the district and PA level. However, the Central Bureau of Statistics (2014) offers maps showcasing the spatial distribution and density of specific groups in Banke-Bardiya Complex (e.g., Tharu). Unfortunately, a GIS version of the data was unretrievable. It would have been helpful to analyze specifically which and how many Indigenous peoples would be impacted in specific places along the proposed railway line.

Third, we recognize the potential contradiction of an FPIC Protocol when the railway line’s track in BB Complex is already proposed. If an FPIC Protocol were to be carried out prior to construction on IPLCs’ lands in BB Complex and consent was declined by a collective, the railway would likely continue being built. Nonetheless, it is important to remember that Indigenous rights advocacy does not equate to “anti-development,” and resolutions can be equitably achieved through active and respectful participatory processes outlined in the Protocol. Carrying out an FPIC Protocol is important to support Indigenous peoples’ rights and well-being, increase the transparency of the railway project, and minimize harm.

The greatest limitation has been the lack of collaboration with communities on the ground in BB Complex due to circumstances of language barriers, client priorities, time limitations, and the COVID-19 pandemic. This is problematic for a number of reasons, one being the influence we hold and project through our positions of power as western researchers, and another that their lives are being affected and not ours. More equitable research would have focused on co-production and would look like the following: 1) build trusting, lasting relationships with communities, 2) communities share their views on development of the railway, 2) communities define the problem(s), 3) communities share their stories and knowledges, and 4) in collaboration with communities, identify recommendations together (for both wildlife and people). For example, IPLCs may offer input into design measures and locations of wildlife crossing structures depending on their knowledge of local species' behavior and preferences. Future development projects should always put community collaboration and rights at the forefront. In light of this limitation, at the very least we hoped to contribute to highlighting Nepalese Indigenous rights as stated globally by the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).

In addition to collaboration with communities, future research can explore the impacts of the railway infrastructure on cultural dynamics and well-being for particular groups. For example, how loss of land and village fragmentation may affect land relationships, social organization, and relations with nonhumans (e.g., wildlife). In addition, future research can assess how changes in the social landscape would impact biodiversity in BB Complex.

It has been shown that protecting IPLCs' rights results in greater biodiversity due to peoples' knowledges, worldviews, and ways of relating to land that ultimately support their environment (Independent Panel of Experts, 2020; WWF et al., 2021). In the next section, we explore the wildlife in Banke-Bardiya Complex to develop a further understanding of how to support wildlife's well-being during construction of the railway.

Wildlife Occupancy

Introduction

Roads and railways have been crucially beneficial to humans on an individual basis as well as promoting positive societal growth. However, the rapid development of these forms of linear infrastructure has also unquestionably caused significant ecological damage (Lucas et al., 2017; Van der Ree et al., 2015). As linear infrastructure density and *per capita* travel are expected to increase over the coming decades, decision-makers must identify and mitigate the resulting damages inflicted upon wildlife (Van der Ree et al., 2015). While railway and road ecologies share some similarities, the former is still an emerging discipline and the impacts of railways on wildlife are still under exploration (Barrientos et al., 2019). The most visible impact of railways on wildlife is direct mortalities caused by train collisions (Gundersen & Andreassen, 1998; Huijser, 2012). Railway-caused wildlife mortalities can significantly impact wildlife populations, particularly for large, mobile mammals with large home ranges, and low densities and reproduction rates (Joshi & Puri, 2019; Van der Grift, 1999). Railways can also seriously affect wildlife populations in a less direct manner by acting as a movement barrier (Ascensão et al., 2019). Barrier effects can impede both regular dispersal and movement, as well as key migration routes (Ito et al., 2013; Lucas et al., 2017). Railway impacts on wildlife populations are species-specific and, as such, solutions need to be specifically tailored to species of interest to be effective.

We assessed wildlife occupancy and potential impacts of an electrified railway planned for construction in the Banke-Bardiya Complex of Nepal's western region of the Terai Arc Landscape (TAL). This 1,205 km long East-West railway will help accommodate Nepal's growing demand for passenger and freight transportation, though it will run through the biodiverse TAL (Department of Railways, 2018). Nepal's lowlands are a biodiversity hotspot and support 86 mammal species, over 600 bird species, and over 21,000 species of flowering plants (Chanchani et al., 2014). Within the TAL, the Banke-Bardiya Complex refers to two national parks (Banke and Bardiya), related park buffer zones, as well as their associated wildlife corridors. This Complex provides crucial habitat for many threatened species including the Asian elephant (*Elephas maximus*), the greater one-horned rhinoceros (*Rhinoceros unicornis*), and tigers (*Panthera tigris*) (MFSC, 2015). The planned railway will bisect the Khata and Kamdi wildlife corridors just south of the two national parks.

We assessed overall mammalian species richness throughout the Banke-Bardiya Complex in addition to species-specific occupancies, with a particular emphasis on elephants, rhinos, and tigers. It is important to determine species occupancies in the region to inform which mitigation strategies should be implemented. We next evaluated how various natural and anthropogenic covariates impacted wildlife occupancy and distributions, and the resulting conservation implications. Finally, we identified individual elephants and tigers, assessing their respective movements across the planned railway to determine the functionality and importance of the bisected wildlife corridors.

To examine species occupancy, we utilized a multi-species occupancy model to assess wildlife occupancy and the impact of natural and anthropogenic covariates within the Banke-Bardiya-Complex. The data we used for this model was sourced from camera traps deployed by WWF Nepal. We hypothesized that: (1) overall species richness and the occupancy of tigers, elephants, and rhinos would be highest in the Khata Corridor (Chanchani et al., 2014; Koirala et al., 2020; Napit & Paudel, 2015); (2) species richness would be highest in areas with flatter terrain, denser and higher vegetation, lower human presence, and areas closer to water (Easter et al., 2019; Jornburom, 2016; Sunarto et al, 2012; K. Thapa et al, 2017); and (3) individual tigers and elephants would be utilizing the Khata Corridor and traversing the location of the planned railway (Shrestha & Shrestha, 2021; A. Thapa et al., 2017). Our results can contribute to conservation efforts in this ecologically important region and help provide a template for other studies aiming to assess the impact of linear infrastructure on wildlife.

Methods

Camera Trap Data Collection and Analysis

WWF Nepal positioned motion-detecting, white LED flash, Cuddeback camera traps at 49 locations throughout the Banke-Bardiya Complex. These camera traps were situated within close proximity (max distance ~2 km) to the anticipated alignment of the East-West Railway. These traps were placed in an effort to conduct a general biodiversity assessment and determine baseline occupancy patterns near the location of the railway. At each camera trap location, two cameras were positioned facing towards each other, a paired setup. Pairing the cameras allows for both flanks of individuals to be captured by the trap, maximizing detection chances and allowing for individual identification of species with identifiable markings, such as tigers (Carter et al., 2015).

Camera traps that ran for less than eight nights were removed from the dataset resulting in 39 camera traps in our study that ran for a combined total of 1305 nights (33.5 nights, on average). The photographs in this dataset were taken between March 28, 2015 and March 20, 2020. Camera traps were distributed in the following areas: Khata Corridor (13 traps, 873 nights), Kamdi Corridor (19 traps, 313 nights), Banke

National Park (2 traps, 32 nights), Banke National Park buffer zone (2 traps, 32 nights), Bardiya National Park buffer zone (3 traps, 47 nights), and the Karnali Corridor (1 trap, 8 nights). A sampling period, or “night,” was classified as a period of 24 hours beginning at 0600 through 0600 the next day. Camera traps were active for the entirety of each sampling period (night). Photographs were considered separate detections at 15-minute intervals.

For each photograph, the entity was manually identified and the species was recorded (i.e. tiger, elephant, human, etc.). In addition to wildlife species, photos were sorted into other categories including humans, livestock, domestic dogs, vehicles, unknown, birds, small rodents (under 0.5 kg) and empty. Photos were categorized as ‘Unknown’ if the entity that triggered the camera was too close, too blurry, or too far away to confidently identify. Occurrences of these categories were removed from the dataset to isolate the wildlife species of interest to our study. Birds were removed from the study as they are not well-suited for the model used in this study and our primary focus is on the mammal community. Additionally, mammal species under 0.5 kg (all from Rodentia order) were removed from the study as they are of less interest to this study and were generally unidentifiable at the species level in the camera trap photographs.

Multispecies Occupancy Modeling

We used a multispecies occupancy model that was recently developed and used to assess mammalian richness and the impact of natural and human factors on occupancy (Easter et al., 2019). Imperfect detection occurs when animals occupy an area but are not detected by a camera. Imperfect detection can significantly affect estimates of wildlife occupancies, richness, and space use (MacKenzie et al., 2002). Occupancy models account for imperfect detection and provide probabilities of a species occurring and being detected at a location using covariate data. Our multispecies model estimates the occupancy probabilities of observed species while considering imperfect detection rates, differences between species in occupancy and detection rates, and differences in sampling factors.

The occupancy model we used was adapted by Easter et al. (2019) from the model developed by Rich et al. (2016). The model uses a species’ detection numbers to estimate the occurrence probability of that species at that location while accounting for imperfect detection. Each night that a camera trap was active was counted as a new survey at that site. The model then integrates the number of nights each trap was active to account for differences in sampling length (Tobler et al., 2015). We defined occurrence ($z_{i,j}$) as a latent binary variable where $z_{i,j}$ = 1 if the range of the species includes the camera trap site (j) and 0 if the range does not include the site. Species occurrences were assumed to result from a Bernoulli process where a species i

occurring at camera trap location *j* can be represented by: $z_{i,j}$ – Bern($\Psi_{i,j}$). As such, occurrence is dependent on both the observed occurrences at a sight and occupancy probability (Tobler et al., 2015). Additionally, detection probability also impacts occupancy probability: $x_{i,jk}$ ~ Bern ($p_{i,j,k} * z_{i,j}$) (Mackenzie et al., 2002). A single model was fitted to the whole community and individual species (Zipkin et al., 2009).

To aid in our analysis of the distribution of richness and occupancy, we grouped our camera traps into three regions: the Khata Corridor, Eastern Kamdi Corridor and the Western Kamdi Corridor. These regions were chosen because there is a close concentration of camera traps within the Khata Corridor so it would not make sense to divide these traps into regional groups. However, for the camera traps in the Kamdi Corridor, there is a clear gap between the placement of traps in the eastern and western sections of the corridor.

Occupancy Covariates

Our model included several covariates that we predicted could explain the variation in species distributions. We anticipated the following variables would affect species occupancy: mean NDVI, slope, forest height, and distance to water, built areas, crops, and roads (Jornburom, 2016; Sunarto et al., 2012; K. Thapa & Kelly, 2017; K. Thapa et al., 2017). Normalized Difference Vegetation Index (NDVI) was calculated from Landsat 8 stitched images (Path 144, Row 040; Path 143, Row 41; 30m resolution), acquired from June-November 2018 (USGS Earth Explorer, https://earthexplorer.usgs.gov/). These covered most of Western Nepal and the area covered for the camera survey. Pixels flagged as clouds or cloud shadows were removed so as not to impact NDVI averages across time in later steps. Each individual image was cropped to the size of the study area and exported for later analysis. Slope data (30m resolution) was calculated from a Digital Elevation Model (DEM) of Nepal (US Geological Survey) using ESRI's ArcGIS Pro (version 2.8.0). Forest canopy height (30m) was assessed using an integration of Global Ecosystem Dynamics Investigation (GEDI) and Landsat data for the year 2019 (Potapov et al., 2020). Other land cover categories were assessed using the Esri 2020 Land Cover map (10-meter resolution). Using ArcGIS Pro, we measured the distance of each camera trap location to water (predominantly year-round sources), built areas (human made structures), and crops. Distance to forests was not a covariate included in our study as all but two of our camera traps were located within the forest land cover category. Distance to roads was calculated using ArcGIS Pro from road network data provided by WWF Nepal. Two sets of our covariates were more correlated than would be ideal ("Distance to crops-Distance to built areas and NDVI-Forest Height). The threshold we used was a correlation coefficient of 0.6 while these two comparisons displayed correlation coefficients of ~0.7. These correlations are intuitive but as we want to assess which areas the wildlife are occurring in currently, rather than predict their occupancy in other areas, we decided to include all four of these covariates. However, if this model is to be widely implemented in a predictive capacity in the future, one variable of each of these comparisons should be removed from the model.

Detection Covariates

We assessed two detection covariates: whether the camera traps were placed on trails and the mean NDVI of their location. Animals often move along open pathways, so we created a binary variable indicating whether a camera trap was located on a trail (Kolowski & Forrester, 2017). If camera traps were placed on a human-cleared foot trail, a naturally (animal-created) cleared/worn path, or a creek bed, they were classified as “on-trail.” Vegetation density can also impact detection as denser vegetation can obstruct the range and view of the camera (Rovero et al., 2014). As such, we also assessed whether NDVI would affect detections using the same Landsat 8 images used in the occupancy covariates to calculate the mean NDVI values for 2018 (USGS Earth Explorer, https://earthexplorer.usgs.gov/). Using a paired camera setup can potentially increase detection probabilities (Pease et al., 2016). However, all camera traps in this study were paired and as such, we could not investigate whether this impacted detection.

Individual Analysis

We identified individuals of two key species of interest that possess distinguishing markings/features: tigers and Asian elephants. Though our camera traps were not active at most sites long enough to capture the full breadth of individuals that may occupy those locations, identifying the individuals in our study can provide key information regarding the movement of individuals throughout our study area. Tiger individuals were identified using their distinct stripe patterns. Elephant identification was accomplished using a combination of size, sex, scars/markings on the ears and body, and tusk features (length, size, orientation, and damage). We sorted each photograph of these species into their respective individual identification. Additionally, we recorded the camera trap locations where each individual was detected. Lastly, we cross referenced these camera trap locations to the planned railway alignment to determine if this individual would have needed to cross the railway.

Results

Camera Trap Findings

Over the course of 1305 combined nights that camera traps were active, 27 mammal species (>0.5 kg) were detected (Appendix B). Of our three primary species of interest, tigers exhibited the highest detection rate (5.52 observations/100 days) while Asian elephants (1.30 detections/100 days) and greater one-horned rhinoceros (0.92 detections/100 days) exhibited lower detection rates. Other species of interest, such as tiger prey species, were detected at high rates including barking deer (*Muntiacus muntjak*), chital (*Axis axis*), and wild boar (*Sus scrofa*). The following three species were only detected once over the course of the study: smooth-coated otter (*Lutrogale perspicillata*), four-horned antelope (*Tetracerus quadricornis*), and honey badger (*Mellivora capensis*).

Community Model

The model predicted between 4 and 14 mammalian species occupy each camera trap location. Predicted richness was highest near built areas and water, and in flatter areas (lower slope) (Table 3). All three of these covariates were found to significantly affect the occupancy of one or more species' occupancy probability. As distance to built areas and slope decrease, there is a 94% and 95% chance, respectively, that occupancy probability increases. Additionally, as forest height increases and distance to water decreases, there is a 68% and 84% chance, respectively, that occupancy probability increases. Of the two detection covariates we assessed, the placement of the camera traps on a trail impacted detection probability the most. If camera traps were placed on-trail, detection probability increased by 73% from traps placed off-trail.

	Community level covariate	Mean	Probability (+)	Probability (-)
$\alpha 1_i$	Forest height	0.128	68	32
$\alpha 2_i$	Dist. to major road	0.108	66	34
$\alpha 3_i$	Slope	-0.557	5	95
$\alpha 4_i$	NDVI	0.010	51	49
$\alpha 5_i$	Distance to crops	0.071	60	40
$\alpha 6_i$	Distance to built area	-0.509	6	94
$\alpha 7_i$	Distance to water	-0.229	16	84
$\beta 1_i$	On trail	-0.255	27	73
$\beta 2_i$	Mean NDVI	-0.337	32	68

Table 3. Mean estimates of community-level hyper-parameters of occupancy (α) and detection (β). Probabilities estimates indicate the chance that the covariate positively or negatively affects species occurrence or detection. For example, there is a 68% likelihood that as forest height increases, so does occupancy probability. Forest height, slope, distance to built area, and distance to water had the strongest impact on occupancy while the placement of camera traps on/off trail impacted detection probabilities the most of the two detection covariates.

Species Model

We found significant relationships between the occupancy of various mammal species and our covariates (Table 4). Tiger, chital, wild boar, leopard and small Indian civet occupancy probability exhibited a significant negative relationship with slope (higher occupancy in flatter terrain). Tiger and chital occupancy also exhibited a negative relationship with distance to built areas (higher occupancy closer to built areas). Lastly, Rhesus macaque occupancy was higher near water. Other species of interest, such as Asian elephants and greater one-horned rhinoceros, did not exhibit any significant relationships with our covariates. This lack of significance could be a result of a relatively low number of detections for these species.

Species	Distance to crops	Distance to water	Distance to roads	Distance to built areas	NDVI	Forest Height (m)	Slope
Asian elephant	0.10 (0.59)	-0.73 (0.65)	0.07 (0.42)	-1.08 (0.84)	-0.17 (0.35)	0.11 (0.34)	-0.79 (0.83)
Indian rhinoceros	-0.08 (0.67)	-0.11 (0.61)	0.18 (0.47)	-1.39 (1.02)	-0.13 (0.34)	0.13 (0.37)	-0.43 (1.57)
Tiger	-0.03 (0.58)	-0.28 (0.49)	0.02 (0.41)	**-1.61 (0.93)**	-0.11 (0.33)	0.06 (0.36)	**-1.49 (0.85)**
Chital	-0.09 (0.61)	0.24 (0.52)	-0.23 (0.48)	**-1.28 (0.76)**	-0.09 (0.31)	0.14 (0.34)	**-1.57 (0.88)**
Wild boar	0.06 (0.54)	0.21 (0.51)	0.2 (0.42)	-0.14 (0.63)	-0.08 (0.31)	0.10 (0.38)	**-1.71 (0.86)**
Rhesus macaque	0.36 (0.55)	**-1.37 (0.79)**	0.15 (0.38)	-0.08 (0.66)	0.17 (0.36)	0.10 (0.35)	-0.44 (0.60)
Small Indian civet	0.50 (0.56)	-0.58 (0.45)	0.02 (0.37)	-0.67 (0.57)	-0.00 (0.30)	0.24 (0.36)	**-1.15 (0.63)**
Leopard	-0.32 (0.76)	0.21 (0.61)	-0.03 (0.46)	-0.15 (0.86)	0.14 (0.38)	0.09 (0.37)	**-1.63 (1.02)**

Table 4. Mean ($\bar{x}$) estimates of species-specific covariate values for key species in the region. Standard deviations are in parentheses and bolded terms indicate 95% CI that did not cross zero.

Predicted Richness and Occupancy

Our model predicted the overall mammalian richness (species > 0.5 kg) and species' probabilities of occupancy for each camera trap location. The predicted richness at the camera trap locations ranged between 4 and 14 species (Fig. 5). Predicted mammalian richness was generally highest at camera traps located in the Khata Corridor as well as in the western region of the Kamdi Corridor (Fig. 5 & 9a). A Tukey's HSD Test for multiple comparisons found that predicted mammalian richness of the Khata Corridor ($p<0.01$) and Western Kamdi Corridor ($p<0.01$) both were significantly higher than the predicted richness of the Eastern Kamdi Corridor.

For both Asian elephants and greater one-horned rhinoceros, the only camera traps with 100% occupancy probability were in the Khata Corridor (Fig. 6 & 7). These species exhibited low occupancy probabilities in the Eastern and Western Kamdi Corridor as all camera trap locations had a less than 60% chance of occupancy for both species (Table 5 & Fig. 9b). Tigers displayed a similar pattern to elephants and rhinoceros with high rates of detection (100% occupancy probability) in most of the Khata Corridor camera trap locations (Table 5 & Fig. 8). The model also predicted lower occupancy probabilities of tigers at camera traps in the Kamdi Corridor, though one camera trap in the Banke NP buffer zone (Eastern Kamdi region) did capture one tiger detection. The Khata Corridor displayed a significantly higher occupancy likelihood of tigers and rhinos than both the Eastern Kamdi and Western Kamdi Corridors (Fig. 9c). Additionally, the Khata Corridor had a significantly higher occupancy likelihood of elephants than the Eastern Kamdi Corridor (Fig. 9c).

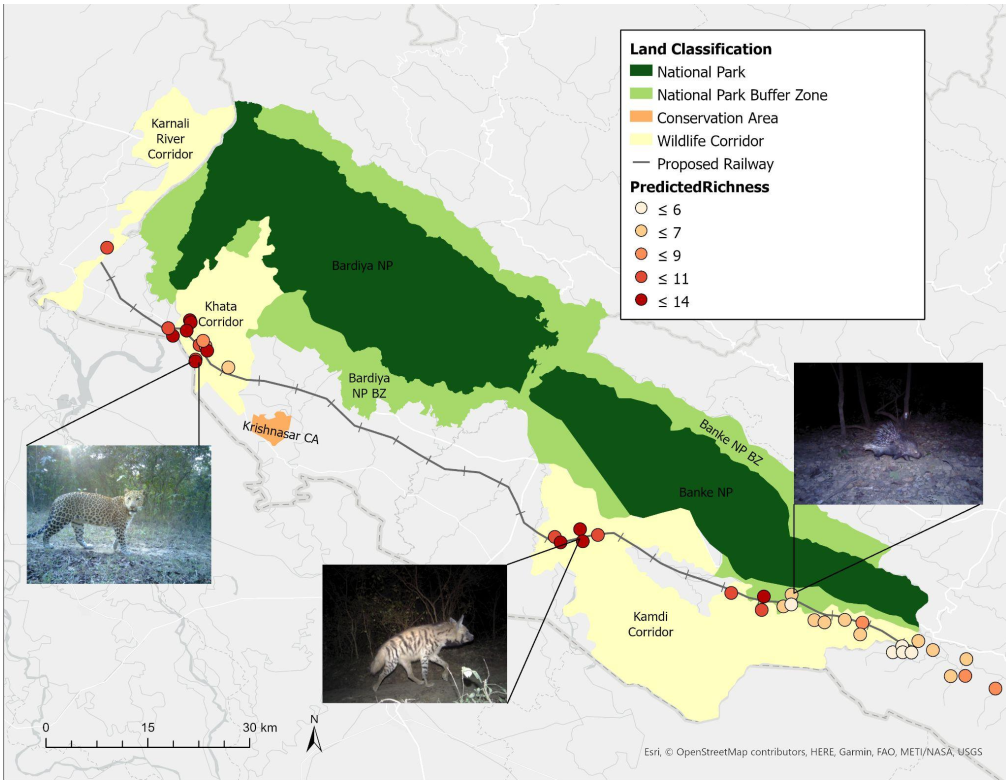


Figure 5. Predicted mammal species richness (species > 0.5 kg) at each camera trap location in the Banke-Bardiya complex. Sample camera trap images depict, from left to right, a leopard, a striped hyena and a Himalayan crested porcupine.

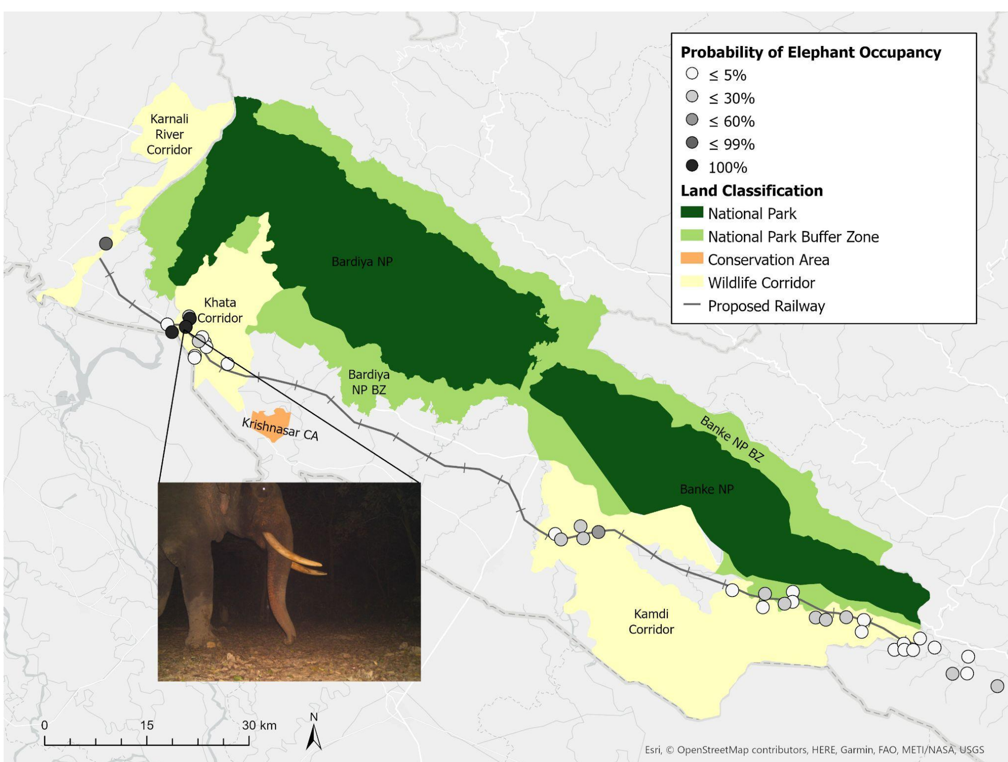


Figure 6. Probability of occupancy for Asian elephants (*Elephas maximus*) at each camera trap location in the Banke-Bardiya complex. A 100% occupancy probability indicates elephants were detected at that location.

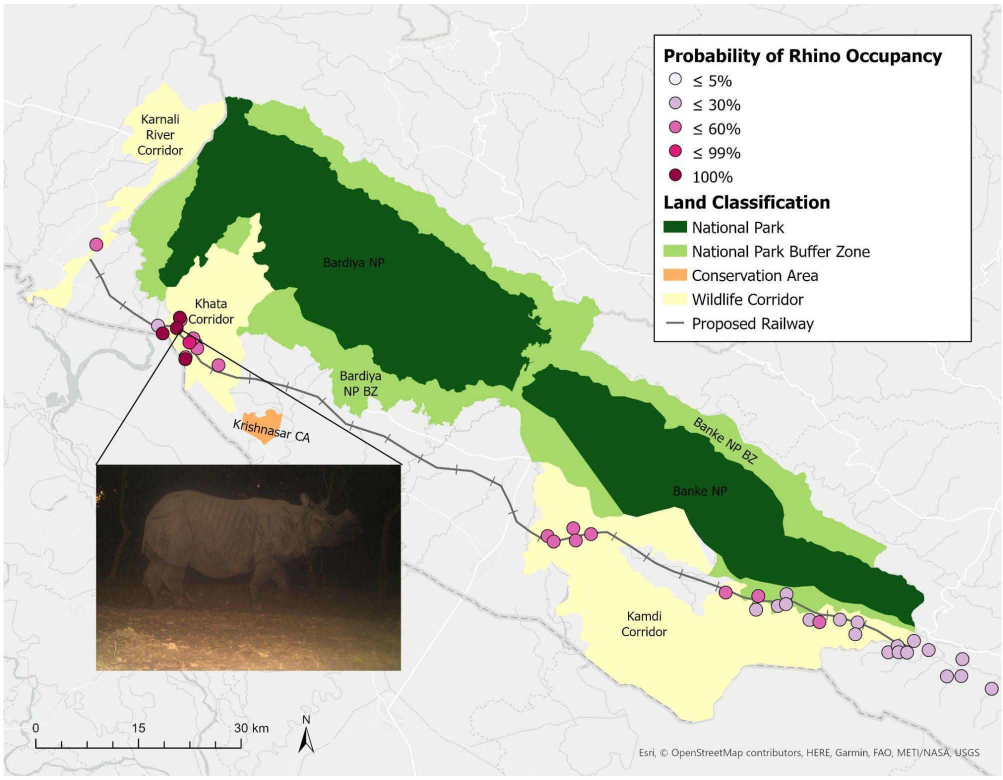


Figure 7. Probability of occupancy for greater one-horned rhinoceros (*Rhinoceros unicornis*) at each camera trap location in the Banke-Bardiya complex. A 100% occupancy probability indicates rhinoceros were detected at that location.

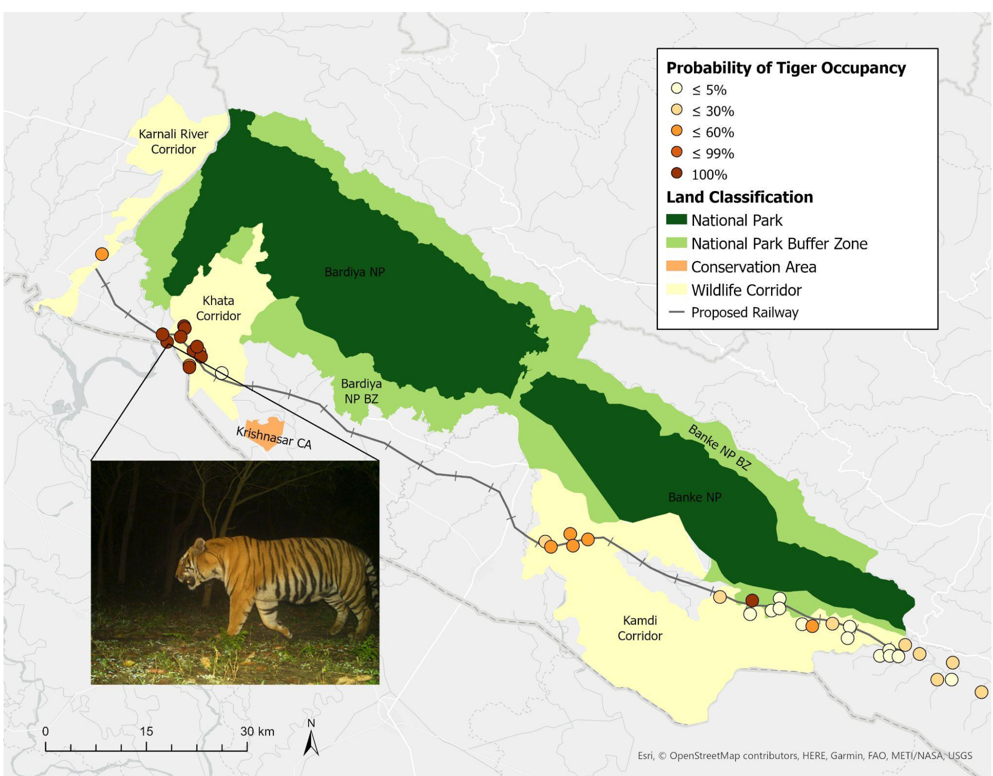
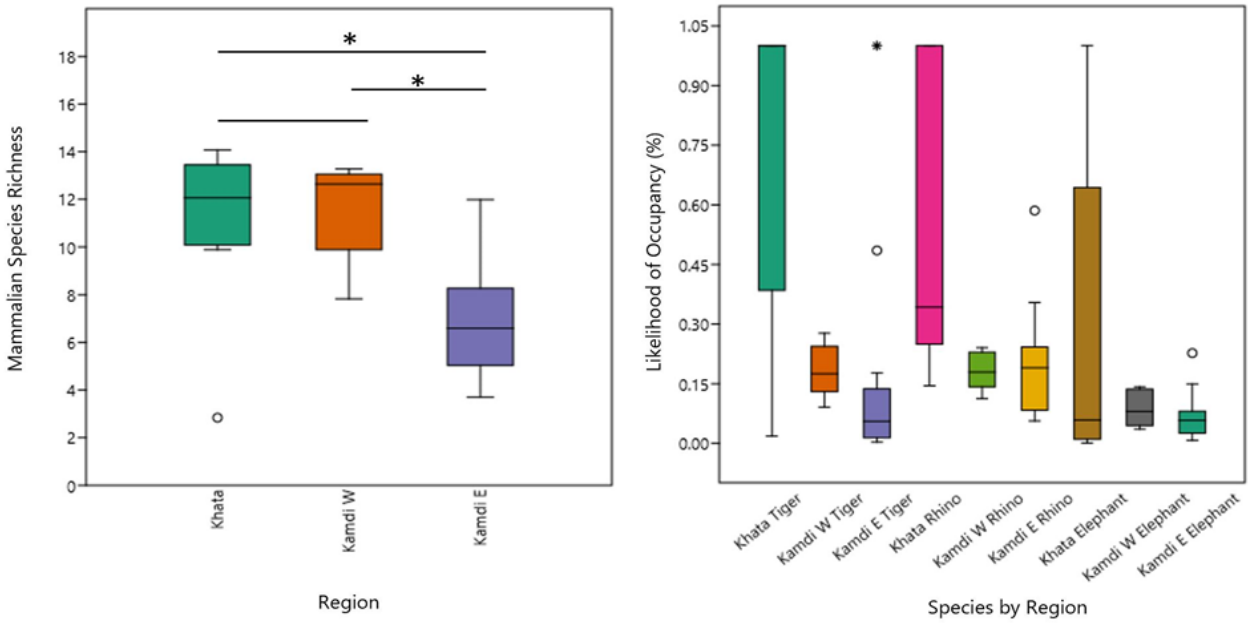


Figure 8. Probability of occupancy for tigers (*Panthera tigris*) at each camera trap location in the Banke-Bardiya complex. A 100% occupancy probability indicates tigers were detected at that location.



	Khata Tiger	Kamdi W Tiger	Kamdi E Tiger
Khata Tiger	x	*	*
Kamdi W Tiger	*	x	n.s.
Kamdi E Tiger	*	n.s.	x
	Khata Rhino	Kamdi W Rhino	Kamdi E Rhino
Khata Rhino	x	*	*
Kamdi W Rhino	*	x	n.s.
Kamdi E Rhino	*	n.s.	x
	Khata Elephant	Kamdi W Elephant	Kamdi E Elephant
Khata Elephant	x	n.s.	*
Kamdi W Elephant	n.s.	x	n.s.
Kamdi E Elephant	*	n.s.	x

Figure 9. Mean predicted mammalian richness for camera traps in the Khata Corridor, Eastern Kamdi Corridor and Western Kamdi Corridor (**a**). A one-way ANOVA revealed that richness differed significantly between the regions ($F(2, 36) = [71.13]$, $p < 0.01$). Statistically significant differences between groups are represented by an asterisk (Tukey's HSD Test). Mean likelihood of occupancy for tigers, rhinos and elephants for camera traps in the Khata Corridor, Eastern Kamdi Corridor and Western Kamdi Corridor (**b**). Statistically significant differences between the regions for each species' likelihood of occupancy were calculated using a Tukey's HSD Test and presented in a significance matrix (**c**; *=significant, n.s. = not significant).

Region	Predicted Mammalian Richness	Likelihood of Tiger Occupancy	Likelihood of Rhino Occupancy	Likelihood of Elephant Occupancy
Khata Corridor	11.33 (±2.94)	76.74% (±38.23)	51.40% (±34.87)	29.11% (±41.45)
Western Kamdi Corridor	11.71 (±2.22)	18.46% (±6.76)	18.44% (±4.89)	8.84% (±4.67)
Eastern Kamdi Corridor	7.08 (±2.39)	12.62% (±22.69)	19.43% (±12.51)	6.68% (±5.28)

Table 5. Mean (± SD) values of predicted mammalian species richness and likelihood of tiger, rhino and elephant occupancy for camera traps in the Khata Corridor (n=13), Eastern Kamdi Corridor (n=5) and Western Kamdi Corridor (n=21).

Individual Analysis

Our camera traps captured 12 tiger individuals and 9 elephant individuals, all occurring exclusively in our Khata Corridor traps, apart from one tiger in the Banke National Park buffer zone (Appendix C). Of these individuals, four tigers (3 male, 1 female) and one elephant (1 male) were detected by multiple camera traps (Appendix C). Of these combined five individuals, all were detected by at least one camera trap both north and south of the anticipated railway alignment. As such, we can infer that these individuals likely crossed the location of the planned railway as this alignment extends far to the east and west of these camera traps. We investigated these potential crossings by assessing the detection locations of all tiger and elephant individuals that crossed the railway (Figure 10). By cross referencing the detection dates and locations of these two individuals, we can visualize the animals' movements through the landscape. The general path these individuals likely took to traverse between these confirmed detection locations would require them to cross the planned railway, suggesting that at a minimum the space use of these animals would be affected by the planned railway.

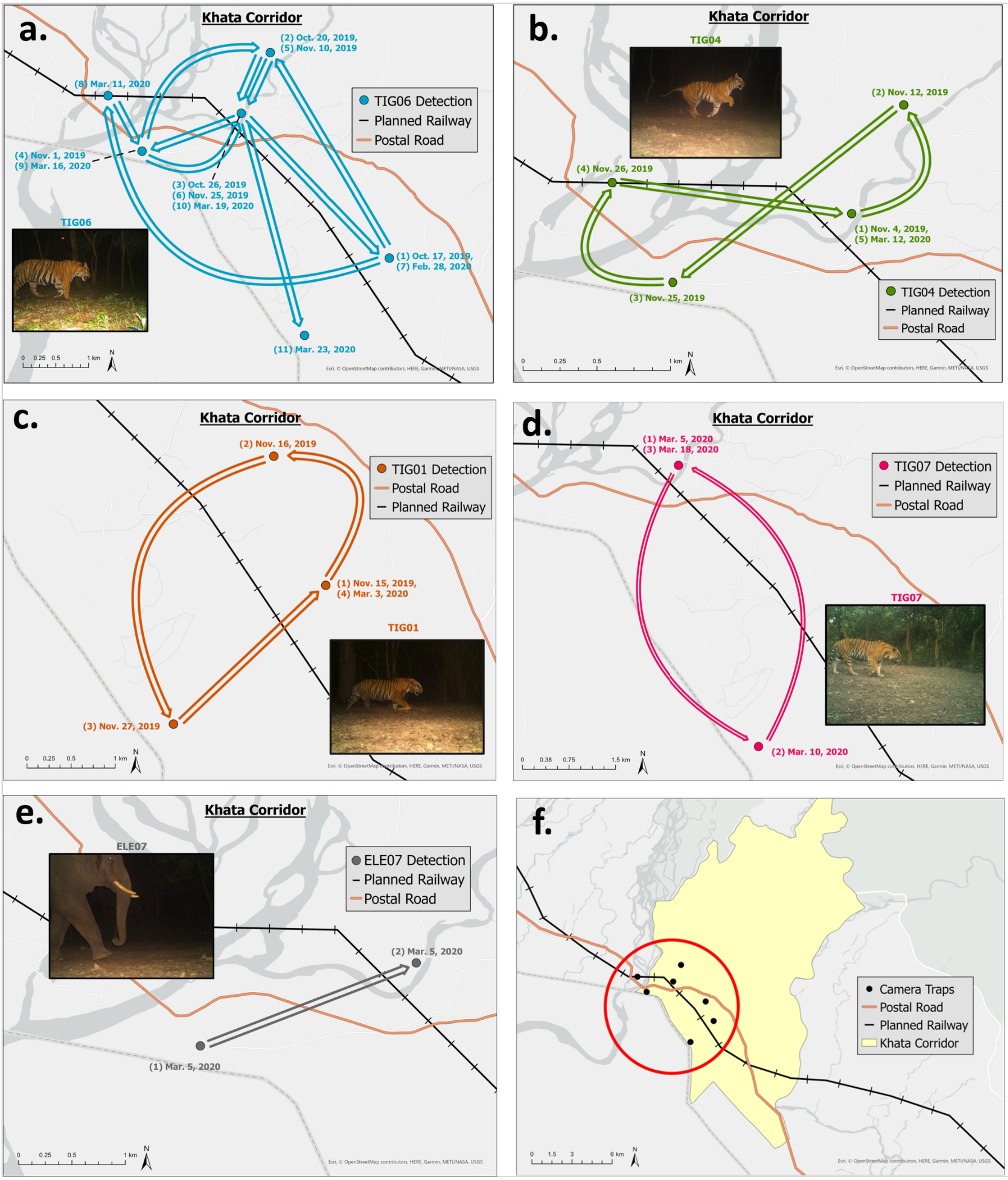


Figure 10. Dates and locations of camera trap detections of individuals TIG01 (**a**), TIG04 (**b**), TIG06 (**c**), TIG07 (**d**), ELE07 (**e**), as well as the locations of all camera traps in this figure in relation to the Khata Corridor (**f**). Arrows represent the chronological order of the individuals' locations based on the detection dates. Numbers within parentheses represent the order of the detection locations; repeat detections at the same camera trap have multiple dates listed for each detection.

Discussion

Regional occupancy and diversity estimates

Our regional analysis of the Banke-Bardiya Complex showed that the Khata Corridor had a high mammalian biodiversity with an average of 11.33 species (over the weight of 0.5 kg) predicted to occur at each camera location within the corridor. This value was comparable to the 11.71 predicted richness in the Western Kamdi Corridor. However, both values were significantly higher than the 7.08 species average expected to occur in the Eastern Kamdi Corridor. Recent data indicates that 53 mammalian species reside in Bardiya National Park, which is associated with the Khata Corridor (Koirala et al., 2020), and 34 species reside in Banke National Park (Napit & Paudel, 2015), which is associated with the Kamdi Corridor. Additionally, the composition of the mammalian communities weighing over 0.5 kg in Bardiya National Park and Banke National Park may be similar, with the differences in overall mammalian richness largely stemming from a higher richness of mammals weighing under 0.5kg in the Bardiya National Park. This theory is supported by a recent camera trap survey of Nepal's national parks that found 29 mammal species in Banke National Park and 34 in Bardiya National Park (Chanchani et al., 2014). Capturing small mammals on camera traps can be difficult as they are often not large enough to trigger the sensors (Littlewood et al., 2021), which could explain the overall richness values and gap between the two parks are lower in the camera trap study. As the Banke National Park was recently established (2010), the overall richness of the park may rise as it benefits from stronger protections for a longer period.

In addition to a high overall species richness, the Khata Corridor displayed the highest occupancy probability of our three key species of interest: tigers, rhinos, and elephants. This finding is consistent with what is currently known about the Khata Corridor. Intense forest restoration efforts within the Khata Corridor created a vibrant landscape that provides wildlife with plenty of forest cover close to a major water source (K. Thapa, 2021). As a result, there is high wildlife use, diversity, and occupancy of megafauna within this corridor. Our findings are also consistent with the current knowledge of these species' distributions in the National Parks and associated regional Corridors. The most recent nationwide tiger census found a density of 4.47 tigers/100km^2 in the Khata Corridor-associated Bardiya National Park, much higher than the 0.97 tigers/100km^2 density in the Kamdi-Corridor associated Banke National Park (DNPWC & DFSC, 2018). These data align with our and others' results of a previous tiger census that found similar density values, and a much higher presence of tigers in the Khata Corridor than the Kamdi Corridors (Chanchani et al., 2014).

While our camera traps in the Kamdi Corridor did not detect any rhinos, our traps in the Khata Corridor averaged an occupancy probability of 76.74% and a detection rate of 0.92 detections per 100 days. Previous surveys support this finding as they also detected rhinos using the Khata Corridor, but not the Kamdi Corridor (Chanchani et al., 2014). The difference in rhino presence in these Corridors is attributable to the status of rhino populations in their respective source National Parks (Mandal, 2021). In 2021, the Department of National Parks and Wildlife Conservation conducted a rhino census that found a small but growing population of rhinos in Bardiya National Park (Mandal, 2021). Notably, they did not survey Banke National Park as there is currently no established population to survey in the newer park (Mandal, 2021). However, Banke National Park should continue to be monitored for a rhino population if the park becomes more suitable to sustain a stable population.

Though we did find a significantly higher elephant occupancy likelihood in the Khata Corridor than the Eastern Kamdi Corridor, the Khata Corridor did not display a significantly higher elephant occupancy likelihood than the Western Kamdi Corridor. As such, there may be a greater overall density and occupancy likelihood throughout the Khata Corridor than the combined Kamdi Corridors. However, our data as well as previous studies suggest the elephants are found in both parks and utilize both corridors. Though our study did not detect any elephants in the Kamdi Corridor, an earlier study found elephants in both corridors (Chanchani et al., 2014), and a modeling of suitable elephant habitat in the region revealed there is plenty of suitable habitat in both corridors (Sharma et al., 2020).

Factors affecting community occupancy

In recent years, camera trap data are increasingly utilized in occupancy modeling for entire communities and specific species. These studies have assessed various environmental and anthropogenic covariates and found that the results depend on the region and species/community being assessed. The lack of impact of NDVI (our proxy for vegetation density) on wildlife occupancy contradicted our initial expectation that forests would be important for occupancy as previous research has reported (Boron et al., 2019). However, given all our camera traps were located in forests and have relatively high NDVI values, the simple presence of forests may be more important than a vegetation density metric in and of itself. This observation aligns with a previous occupancy modeling study on a mammalian community in Mozambique that found a minimal impact of NDVI on occupancy (Easter et al., 2019). Additionally, we did find a positive correlation between increasing occupancy with taller forest height, signifying that forest’s age and stage may play an occupancy role. This finding could be problematic if forest habitats in the region are degraded or older, taller trees are harvested for timber. Particularly as the construction of the railway may encourage and facilitate a higher density of humans living in the area, pressure on the local ecosystems could increase. Our model indicates that should this pressure translate into the removal of these older, taller trees, that wildlife diversity could decline. However, this potential implication should be explored further.

We found that flatter terrain (lower slope) positively affected wildlife occupancy. Previous species-specific studies in the region identified a similar trend with elephants (Sharma et al., 2020) and tigers (Kafley et al., 2016). This is an intuitive trend for the mammal community adapted to Nepal's lowland terrain. The preference for flatter slopes is likely linked to a preference of wildlife for certain food sources that are more abundant in less rugged terrain or the greater access to standing water (Wevers et al., 2021). However, the direct causal link between wildlife occupancy and flatter slope should be explored further.

Wildlife occupancy also increased closer to water sources, as has been found in many other occupancy models (Boron et al., 2019; Easter et al., 2019). However, not all studies have found this connection between occupancy and proximity to water (Rich et al., 2017). Most of our camera traps were active during the dry season, which may have made water more of a limiting factor. If we run traps during the wet season, we may see that water has less of an impact on occupancy during this period (Rich et al., 2016). Going forward, the impact of water availability on wildlife occupancy will depend on the balance between two factors: increasing human presence and climate change. Growing human communities will likely alter water resources for agricultural and residential purposes, leaving less available for wildlife (K. Thapa, 2021). Climate change is expected to result in increases of precipitation in the summer months which could mitigate some of these losses (G. Thapa et al., 2015). However, extreme climate events could also increase the variability of overall water access. Evaluating how these factors are influencing water availability in the region will be important.

While we expected to see the slight trend of higher occupancy further removed from croplands and major roads contained within our model, we were surprised by the strong increase in occupancy close to more developed areas. Most similar studies have found that occupancy increases further away from human settlements and disturbance (Boron et al., 2019; Easter et al., 2019; Li et al., 2018; Rich et al., 2017). However, the close association between these key corridors and dense human settlements has likely influenced this trend in our model. Further supporting this hypothesis, a global study on mammalian carnivore occupancy found that occupancy increases further away from roads, with one major exception being leopards in Nepal (Rich et al., 2017). These findings only highlight the importance of effective conservation and management policies in the region given the proximity of key areas for both wildlife and people.

Factors affecting species-specific occupancy

We found that tiger occupancy significantly increased in flatter terrain and closer to developed areas. A previous study on occupancy-based habitat association of tigers in the region supports our findings as their model also found that tiger occupancy increases with decreasing slope (Kafley et al., 2016). The authors of this study were similarly surprised to observe as we did that occupancy increased closer to human settlements. Again, this trend simply highlights the vital importance of these corridors for both humans and wildlife, and in particular for tigers. Prey density is a factor that previous studies have found is incredibly important for carnivores in general, and tigers specifically (Carter et al., 2019; Kafley et al., 2016; Karanth et al., 2004; Rich et al., 2017). While we were not able to assess prey density as a factor, we did find that chital and tiger occupancy were both significantly influenced by the same two covariates: slope and distance to developed areas. This overlap could indicate that tiger occupancy is influenced by the location and density of their primary prey source in the region (Upadhyaya et al., 2018).

Unfortunately, we did not find any significant relationships between elephant and rhino occupancy and any of our covariates. This absence of any significant relationships is likely due to the sparse number of total detections for both species (17 elephant detections and 12 rhino detections). However, a study that utilized elephant occurrences in the same region as our study to predict habitat suitability reported that elephant habitat suitability increases in flatter terrain, further away from roads and closer to water (Sharma et al., 2020). These data generally align with our results for the overall mammal community occupancy in the Banke-Bardiya Complex. Another study on rhino habitat suitability in Nepal reported similar findings with suitability increasing closer to water, further from settlements and roads, and in flatter terrain (Rimal et al., 2018). The one finding from this study that may be particularly unique to rhinos is that they exhibit a strong preference for grasslands over forest land cover. For both rhinos and elephants, while areas further away from human settlements may be more suitable, these corridors' locations near developed areas may not actually result in greater occupancy further away from such areas.

Study Limitations

Various limitations may have affected the applicability and significance of our occupancy modeling. First, the camera traps' placement was not random at either a macro or micro scale (MacKenzie et al., 2017). At the wider scale, the camera traps were placed in areas along the railway alignment and not dispersed throughout the region. At the smaller scale, camera traps were almost entirely placed along trails, paths, and creek beds, which can potentially affect and inflate occupancy value estimates (Kolowski & Forrester, 2017). Second, these traps were generally placed in wildlife corridors and buffer zones. Future studies should assess how occupancy trends and values differ within the national parks themselves and in entirely unprotected areas as opposed to just within these corridors and buffer zones. Determining occupancy within the parks and unprotected areas allows for a more direct comparison with corridor and buffer zone occupancy and a better assessment of the utility of these landscapes. It would also be worthwhile to determine whether placing all camera traps within forests affected values as compared to placing them in croplands, grasslands, and other land cover types.

Our model also did not meet some of the guidelines for study area size and sampling period. Our study area was large, and our sampling period was wide as camera trap data was compiled over the span of a few years. Short study periods are preferable as they ensure the closure assumptions of occupancy modeling (Mackenzie et al., 2017). However, this can be challenging to achieve for certain species with larger ranges such as large carnivores (Van der Weyde et al., 2018). Additionally, our total detections and detection rates were low for many species, including two key species of interest: elephants and rhinos. Increased sampling efforts might have improved the statistical strength and significance of our findings for these rarer species.

Finally, our study was primarily conducted during January-March, a drier time of the year in the applicable region. To gain more insight on year-round occupancy dynamics, additional data should be obtained concerning occupancy during the monsoon season in June-August given much greater precipitation and humidity during that time.

Importance of Corridors and Parks in the Region

Much of Nepal's biodiversity, particularly its mammals, are intensely threatened by habitat loss and fragmentation (Amin et al., 2018). Of the 27 mammal species detected in our study, 14 are nationally threatened (Amin et al., 2018) and 8 are globally threatened (IUCN, 2021). Additionally, the national parks and corridors in our study support flagship species like tigers, elephants, and rhinos. These areas are incredibly important for the global conservation of these flagship species, particularly for tigers and rhinos. Nepal has recently been one of the most successful countries in efforts supporting the population growth of these two species (DNPWC & DFSC, 2018; Ghimire, 2020).

Our study as well as previous research indicate that the wildlife corridors discussed in this paper, particularly the Khata Corridor, are essential for maintaining the region's biodiversity and wildlife populations. The Khata Corridor connects the Bardiya

National Park in Nepal and the Katarniaghat Wildlife Sanctuary in India. Each individual of the studied flagship species that was detected at more than one camera trap (4 tigers and 1 elephant) traveled across the planned railway alignment and utilized the Khata Corridor. For most of these individuals, only one or two confirmed crossings were found. However, TIG06 was found to frequently use the corridor with 7 confirmed crossings detected. These four tiger individuals are significant as they can ensure the population linkage between Bardiya National Park and the Katarniaghat Wildlife Sanctuary (Kenney et al., 2014). The construction of the railway could potentially block this connectivity to the detriment of these two tiger populations. A previous study confirmed our finding by detecting the same tiger individuals on camera traps located in the Bardiya National Park, Katarniaghat Wildlife Sanctuary, and Khata Corridor (K. Thapa et al., 2017). Many other studies and census efforts have confirmed the importance of the Khata Corridor for facilitating tiger movement (Chanchani et al., 2015; DNPWC & DFSC, 2018; Wegge et al., 2018). The Wildlife Movement section of our paper confirms the use of the Khata Corridor by four collared rhinoceros. Another study indicates that the Khata Corridor is functional for elephants and that they benefit from the region's landscape level biodiversity management (Shrestha & Shrestha, 2021). In addition to supporting the three flagship species' movement, our study and others also suggest that the region's national parks and corridors work in tandem to support the area's high levels of biodiversity (Ghimire, 2019).

Potential Railway Effects

Negative consequences from railways on wildlife are unavoidable. However, certain actions can be undertaken to substantially mitigate these damages. Railway design can reduce habitat disturbance and wildlife's reluctance and/or inability to cross tracks (Ito et al., 2013; Lakušić & Ahac, 2012; Lucas et al., 2017; Schulte-Werning et al., 2008). Several types of crossing structures such as culverts as well as underpasses and overpasses can encourage safe wildlife crossings (Clevenger & Waltho, 2005; Glista et al., 2009). Other mitigation examples include certain warning systems and decreasing train speed to effectively reduce train-wildlife collisions (Barrientos et al., 2019; Becker & Grauvogel, 1991; Belant, 1995). Whatever mitigation measures are utilized, they must strike a delicate balance between both encouraging wildlife movement to prevent habitat fragmentation while also dissuading unsafe crossings. For example, fencing can be employed in high-risk areas to prevent unsafe crossings while simultaneously funneling wildlife towards unfenced corridors that allow safe crossings (Smith et al., 2015).

The construction of a major railway through wildlife corridors in the Banke-Bardiya Complex is likely to greatly impact the biodiversity of the region. Though railways are generally less damaging to wildlife populations than major highways/roads, there are still significant negative impacts (Borda-de-Água et al., 2017). Habitat fragmentation preventing the flow of individuals and genes through the region as well as direct mortality caused by the trains are the two largest threats posed by the railway. Habitat fragmentation is the primary threat to mammals in Nepal (Amin et al., 2018), and its impact is likely to intensify as continuing infrastructure development has the potential to reduce habitat quality by up to 40% in the Terai Arc Landscape (Sharma et al., 2018).

We previously established that these parks contain high levels of biodiversity including many endangered species, and that the associated corridors support significant levels of biodiversity as well, including functioning as key dispersal areas for species such as tigers, rhinos and elephants. Particularly for these charismatic megafauna species that require large areas and the ability to disperse, it is essential that the railway does not act as a barrier to movement (Thatte et al., 2018). The importance of movement for these species is apparent when using tigers in Nepal as a case study. The recovery of tigers in Nepal in recent years can in large part be attributed to the movement of tigers from India into the Terai Arc Landscape and the establishment of metapopulation dynamics (A. Thapa et al., 2017). However, the continuing development of linear infrastructure in Nepal threatens to disrupt connectivity, degrade habitats, and fragment landscapes (Carter et al., 2020; Dubois, 2021; Sharma et al., 2018). Should this railway or other infrastructure reduce the functionality of the Khata, and to a lesser extent, Kamdi corridors, the tiger population in the Banke-Bardiya complex would become isolated. Preventing the flow of genes and individuals place the small-medium sized tiger population at great risk of inbreeding depression and potentially, extirpation within the next few decades (Kenney et al., 2014; Yumnam et al., 2014).

The important question then is: Will the railway act as a barrier to movement for the mammalian species in the region? The answer to this question is unclear as it varies by context and species. Barriers can either be physical obstacles that prevent crossing or behavioral, where the animal perceives a risk from the railway and thus chooses not to cross (Lucas et al., 2017). Generally, the physical barrier issue applies to smaller species such as insects, reptiles, amphibians and some small mammals, potentially including a few species at the lower end of the weight range we included in our study (Lucas et al, 2017). However, the design of the railway can also create barriers to larger species as well. A study on two ungulate species in Mongolia found that the fencing associated with railways resulted in a strong barrier to the species' movements (Ito et al., 2013). Another study found the slope often associated with railways can act as a deterrent to ungulates (Xia et al., 2007). Mammalian behavioral responses to railways depend greatly on the type of mammal. While railways may attract large mammalian predators, many large prey species often view railways as risky and avoid them (Dickie et al., 2019; Lucas et al., 2017). The East-West railway will very likely directly prevent the movement of many of the smaller mammal species in our study, and potentially some of the ungulate species in the region. However, even species whose movements remain unimpeded, potentially including predators such as tigers and leopards, may be negatively affected if the restricted movement of their prey causes declines in already low-density corridor populations (Wegge et al., 2018).

Direct mortalities caused by collisions with trains can be damaging for mammal populations, particularly threatened megafauna like elephants with large home ranges, low densities, and low reproduction rates (Van der Grift, 1999). The East-West railway's placement through these critical corridors poses a significant risk as the highest mammal mortalities from railways are often in areas where the railway bisects important habitats or migration routes (Gundersen & Andreassen, 1998; Van der Grift, 1999). One group of mammals frequently killed by train collisions are ungulates (Gundersen & Andreassen, 1998; Huijser et al., 2012). Asian elephants are one of the most studied species with regards to their collisions with trains, which is of particular relevance for our study. Railways in India are a significant concern for their elephant population, with collisions with trains accounting for 25 fatalities in Rajaji National Park from 1987-2018 (Joshi & Puri, 2019). In the Assam region of India, collisions killed at least 3 elephants over a 16-year period (Deka & Sarma, 2012). Though less studied than elephant mortalities, direct collisions also impact tigers and rhinos (Raman, 2011). At least 14 tigers have died in rail accidents in India between January 2010-January 2021 (Thakur, 2021).

Conservation Implications

The strong presence of human development and activity within the Khata and Kamdi Corridors, near the Banke and Bardiya National Parks, creates a high risk for human-wildlife conflict. The region's continued development of linear infrastructure is likely to increase the area's human population. Human-wildlife conflict is common throughout the region with depredation of crops and livestock, damage to homes, and loss of life occurring in the corridors and buffer zone areas of the Banke-Bardiya Complex (Subedi et al., 2020; K. Thapa & Tuladhar, 2021). Tigers, rhinos, and elephants are three primary drivers of this conflict (Shrestha, 2007; Wegge et al., 2018).

Promoting human-wildlife coexistence will be crucial to protecting the wildlife and humans within the Banke and Bardiya National Parks as well as maintaining the functionality of the associated corridors. To mitigate conflict with tigers and other predators, reducing livestock depredation through altering grazing methods and better fencing/penning methods, in addition to improving the current livestock loss compensation scheme, are of utmost importance (Wegge et al., 2018; K. Thapa & Tuladhar, 2021). However, conflict is unlikely to significantly decline in frequency until the prey base in the corridors/buffer zones are sufficiently bolstered so that tigers in the corridors do not resort to livestock depredation (Wegge et al., 2018). To reduce conflict with animals such as rhinos and elephants that damage crops as well as potentially lead to human casualties, various mitigation methods can be deployed. In certain critical areas close to the parks, alternative crops that are unpalatable to wildlife, such as mentha and chamomile, can be grown to reduce crop damage (K. Thapa & Tuladhar, 2021). The implementation of solar fencing, mesh wire fencing and bio fencing around crops can also reduce depredation (K. Thapa & Tuladhar, 2021). Crop damage compensation schemes can also promote coexistence between humans and wildlife (Subedi et al., 2020). Long-term efforts to monitor critical areas of conflict, bolstering community livelihoods, and promoting participatory management are essential to lasting coexistence (Subedi et al., 2020).

Designing the East-West railway in a manner that encourages wildlife movement--but not collisions--is a crucial balance needed to maintain habitat linkages and gene flow. The discussion of the conservation implications and recommendations related to the railway is located in the “Crossing Structures/Landscape Design” section of our paper.

Conclusions

Our wildlife occupancy analysis emphasizes that the East-West Railway is going to bisect a crucial area for wildlife and their movement. The railway has the potential to exacerbate human-wildlife conflict, reduce habitat connectivity, and cause wildlife mortality through direct collisions. Relatively easy and inexpensive methods to reduce these negative impacts of the railway already exist. However, more logistically challenging and expensive projects requiring greater efforts and advocacy will likely be required as well to protect this incredibly biodiverse region. The focused prioritization of funding for such projects will be necessary to preserve the functionality of key wildlife corridors in the Banke-Bardiya Complex.

We have established that the Khata Corridor supports a high level of mammalian biodiversity and that all three of our focal species move through this corridor. We have also shown the railway alignment has the potential to disrupt wildlife movement. In the next section, we use greater one-horned rhinoceros collar data to assess where wildlife are specifically moving throughout the Khata Corridor, and where this area intersects with the railway alignment. We also assess what is the “best path” for wildlife to move through the Khata Corridor.

Wildlife Movement

Introduction

Habitat for terrestrial mammals, especially those of conservation concern, has been decreasing globally in recent years (Crooks et al., 2017). These changes have occurred globally and are happening in areas that are considered biodiversity hotspots (Haddad et al., 2015). These decreases in habitat often result from the expansion of agriculture but can also be related to expanding infrastructure (Sharma et al., 2020). Human infrastructure can fragment and isolate populations due to reducing the ability for wildlife to move across these features (Holderegger et al., 2010). This can have a profound effect on endangered species, especially those who rely on seasonal movements or migrations to access suitable habitat during different seasons (Wilson et al., 2016; Zeller et al., 2020). Infrastructure can also lead to increased mortality of wildlife due to collisions with vehicles traveling on roads or trains on railroads (Yamashita et al., 2021).

There have been many recent attempts to balance development with the conservation of wildlife. One of the many ways to preserve wildlife movements is to use wildlife crossing structures that help maintain natural wildlife movement past roads or railways and reduce mortality of wildlife when crossing these features (Glista et al., 2009; Jennings et al., 2020). However, an important question for managers is where to place such features. One approach is to use GPS collar data from wildlife to identify how and where wildlife is currently moving and determine where they would most frequently intersect with the road or railway (Loraam & Downs, 2015). This approach can be a helpful starting place, but fails to account for how the landscape influences where wildlife move (Liu et al., 2018).

Beyond understanding how landscapes influence movement, one can model how wildlife may move within the landscape. A common method is using resistance surfaces, which can model how difficult it is for an animal to move through a landscape (Zeller et al., 2012). Each cell value within these raster surfaces represents resistance to movement. Some studies created these surfaces through model coefficients (Zeller et al., 2015). Resistance surfaces can then be used to either simulate individual-based movement (Avgar et al., 2013; Hauenstein et al., 2019), identify corridors of movement (Cushman et al., 2013; Koen et al., 2014), or find best paths through the environment based on resistances (Flesch et al., 2009). Many studies are beginning to utilize step-selection to identify habitat suitability and create movement models (Zeller et al., 2019). Using resistance surfaces will be helpful to identify where wildlife may move through an area in the absence of movement data. It can also account for seasonal variations and how this will change a landscape's resistance to movement.

Understanding how different aspects influence wildlife habitat choice is critical to creating an accurate resistance surface. Many studies have found that large herbivores prefer habitats that have high normalized difference vegetation index (NDVI), which is associated with areas of high productivity or vegetation density (Hansen et al., 2009; Singleton et al., 2010). Using NDVI serves as an important proxy for vegetation density (Purevorj et al., 1988). Along with vegetation, wildlife often will prefer areas close to water (Ryan et al., 2010). Using normalized difference water index helps measure wildlife proximity to water (Xu, 2006).

However, many of these studies focus on wildlife found within the United States and have few implications for critically endangered species (Suraci et al., 2020). This section focuses on the Greater One-Horned Rhinoceros (*Rhinoceros unicornis*), an endangered species found within a biodiversity hotspot in the lowlands of Nepal and Northern India. This area highlights an important conservation issue by connecting corridors between protected lands in both Nepal and India that are threatened by the construction of a new railway connecting the east and west ends of Nepal. This portion of our study aims to understand how habitat selection can be used to explain wildlife movement. We wished to determine if modeling habitat resistance to movement would overlap with where greater one-horned rhinoceroses intersected a proposed railway. We expected that the modeled movement would align with their current movement because the rhinoceroses would likely choose the least costly route through the habitat.

Research Objectives

Our wildlife movement focused on the Greater One-Horned Rhinoceros in the Khata corridor and aimed to complete the following objectives:

1. Determine exact paths where rhinos will cross the planned railway location.
2. Predict rhino movement across the study area compared to the location of the planned railway.
3. Determine where optimal wildlife crossing structure locations are based on exact and predicted rhino movement.

Methods

Data Collection

Data was provided from WWF-Nepal of four Greater One-Horned Rhinoceroses found within the Banke-Bardiya complex of Nepal. They were located around the Khata Wildlife Corridor, which connects western Bardiya National Park with Katarniaghat Wildlife Sanctuary in Northern India (Figure 11). Data was recorded hourly (unless errors occurred with the GPS collar) and recorded location (latitude, longitude), temperature, velocity, altitude, and time. This data was collected between November 2014 and December 2016.

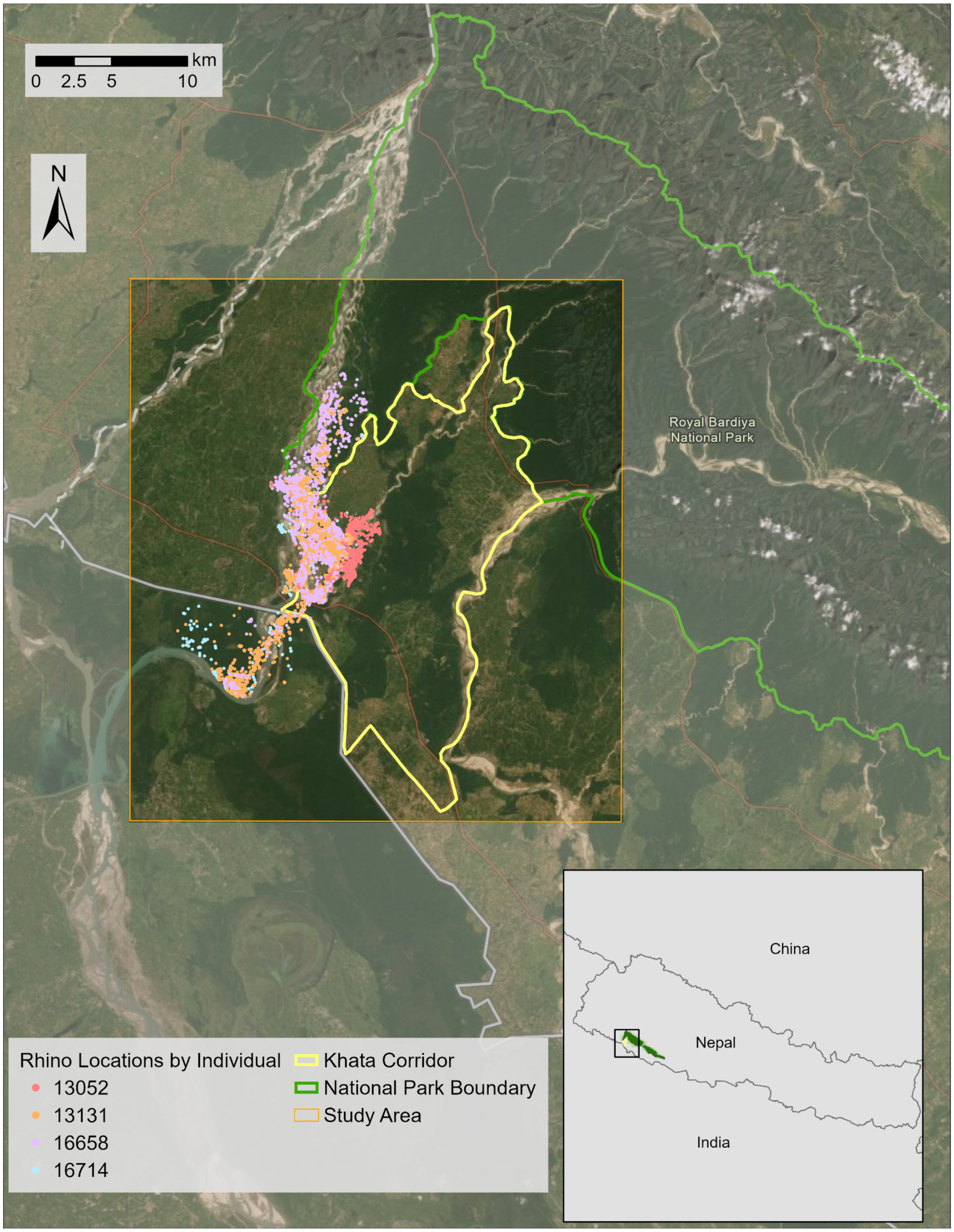


Figure 11. The study area is the area that encompasses the rhino locations and the Khata Corridor. The corridor and National Park data was provided by the World Wildlife Fund of Nepal and the international administrative boundaries came from the Database of Global Administrative Areas (GADM). The study area was digitized to incorporate areas of rhinoceros locations and to incorporate the entire Khata Corridor. The basemap is from ESRI.

Environmental Variables

A variety of environmental variables were gathered to assess the habitat preferences of the rhinoceroses. The normalized difference vegetation index (NDVI) is a proxy for vegetation greenness and density and normalized difference water index (NDWI) is a proxy for wetness, or in this case proximity to wet areas. These two variables were generated using Landsat 8 imagery from Google Earth Engine. Images were collected spanning the time of the rhinoceroses being collared from 2014 to 2016 and were from path 144 and row 40 which covered most of Western Nepal. Pixels flagged as clouds or cloud shadows were removed so as not to impact NDVI or NDWI averages across time in later steps. Each individual image was cropped to the size of the study area and exported for later analysis. Google Earth Engine was used to acquire 30m SRTM elevation data for the study area. This data was transformed into slope and aspect using respective tools from ESRI's ArcGIS Pro (version 2.8.0). Land cover data was downloaded from 2015 of the region from 100m Copernicus Landcover data in Google Earth Engine. Pixels containing agriculture areas were selected and converted to polygons in ArcGIS. A distance to agriculture raster was created from these polygons with an initial cell size of 1m. This raster was then re-sampled to 30m using bilinear interpolation within the *raster* package in R. A distance to roads raster was created in a similar way, using a roads feature covering major roads through the study area. The list of environmental variables considered and their associated information are included in Table 6.

Environmental Variable	Units	Variable Description	Cell Size (m)	Source
NDVI	unitless	Vegetation density index	30	Landsat 8
NDWI	unitless	Water coverage index	30	Landsat 8
Aspect	Degrees	Aspect of the pixel	30	SRTM
Slope	Degrees	The slope in a pixel	30	SRTM
Distance to Roads	Meters	Distance to nearest road	1	WWF Nepal
Distance to Agriculture	Meters	Distance to agriculture from Copernicus Landcover data	1	Copernicus
Landcover	Unitless	Landcover category from Copernicus	100	Copernicus

Table 6: The environmental variables associated with the greater one-horned rhinoceros' movement in Western Nepal. All of the data, except for the initial roads layer, was downloaded using Google Earth Engine. They were cropped to the geometry of the study area. The slope and aspect were derived from 30m SRTM data. The distance rasters, slope, and aspect were processed in ArcGIS Pro. NDVI is a greenness index that correlates to vegetation density.

Analyzing Wildlife Crossing

Before conducting habitat resistance to model likely areas of crossing the railway alignment, the telemetry data was used to identify where the rhinoceroses were already moving across the landscape. This provides a useful qualitative assessment of the model performance and can help validate the modeling technique when predicting possible crossing locations. The *wildxing* package (Bastille-Rousseau et al., 2018) was used to identify where the rhinoceroses most frequently crossed the planned railway. We used a railway line feature provided by World Wildlife Fund Nepal and provided a location where the alignment would pass through the area. The line segment was divided into 50 equal segments, each segment was 700 meters long. The telemetry data was used to create tracks and found which segments had the greatest proportion of crossings.

Step-Selection and Creating Resistance Rasters

Telemetry data was processed using the *amt* package in R (Signer et al., 2019). This package takes points with timestamps from telemetry data and creates 'tracks'. Each track has a starting node and ending node based on consecutive timestamps. Tracks were resampled to ensure an equal interval between observations, which was set to have a rate of 60 minutes and a tolerance of 15. Random false paths were also created. These false paths shared the same starting node as the true path, but had a randomly generated step length and turn angle, creating a new location not chosen by the rhinoceroses. Each false path represents a potential point that the rhinos could have moved to, but didn't. It compares a chosen location to locations that were not chosen, allowing which environmental variables contribute to a location being selected. The pixel values from the beginning and end of the track were extracted from the environmental variable rasters. To ensure that the NDVI and NDWI matched as closely as possible, these values were matched based on whichever Landsat image was closest to the date of the GPS fix. To correct for differences in magnitude between lower values like NDVI, ranging from -1 to 1, and Distance to Roads or Agriculture (greater than 0 to infinity), the values were rescaled inside of the data frame after being extracted from the raster.

Once the environmental data was associated with each true and false track, a conditional linear regression was used to assess how the environmental characteristics influenced the habitat selection of the rhinoceroses. The regression was done with the *amt* function fit_issf, which was a wrapper for the clogit function in the *survival* package. The equation for the regression was:

$$case \sim NDVI \ + \ NDWI \ + \ Slope \ + \ Aspect \ + \ Distance\ to\ Roads \ + \ Distance\ to\ Agriculture \ + \ Landcover \ + \ stata(Rhino\ ID)$$

The case was whether each step was a 'true' step or a 'false' step. The unique idea was a string that allowed each true step and associated false steps to be evaluated together.

Once the step-selection was completed, the resistance raster for movement was created from those results. First, the NDVI and NDWI were averaged across three seasons from the Landsat rasters. The seasons were the monsoon season, spanning from May to August. The early dry season is from September to January, and the late dry season is from February to April. The continuous environmental variables were rescaled using the rescale function in *raster*. These variables were extracted into a data frame, where each row corresponded to the same cell. The land cover raster was resampled using the nearest neighbor method to go from 100m resolution to 30m resolution. Land cover types that were significant from the step-selection were re-classified as 1, so that they could be multiplied by their respective covariate. Each significant land cover type had their own row, so that they could be differentiated. Once each row had all the cell values for the environmental variables, they were multiplied by their covariates and added together. They were then exponentiated because the conditional linear regression from the step-selection function returns a log-likelihood of habitat selection, but our aim was to produce a positive likelihood of habitat selection. The habitat selection was then rescaled to fall between 0 and 100, with 100 being very likely to be selected and 0 being unlikely to be selected. To turn this into a habitat resistance model, we found the inverse by subtracting 100 by the likelihood of habitat selection. These values were then put into a raster of the study area by season. There will inevitably be some correlation between the step-selection and least-cost paths due to having the same base data. However, this will not impact where the best path through the environment will be.

Least-Cost Paths

The three seasonal resistance rasters were then used to identify the least-cost paths to get between three core areas of where the rhinos were. These core areas were digitized in ArcGIS Pro based on the northern, southern, and eastern-most areas that they were found from their GPS positions. Least-cost paths were identified across the seasons using Linkage Mapper (v. 3.0.0). Linkage Mapper identified the least-cost paths connecting these areas based on Euclidean distance and resistance values. Along with calculating resistance, it identified corridors of least resistance and habitat connectivity through Circuitscape (McRae et al. 2008).

Results

When evaluating the overlap locations for the collared rhinos along the railway alignment, they all crossed along the same segment which was in a small forest patch along the river (Figure 12). Each rhino crossing along the same area indicates this is an area likely of focus for wildlife crossing structures. The step-selection function resulted in identifying which environmental variables had significant impacts on habitat selection by the greater one-horned rhinoceroses (Table 7). The greenness index (NDVI) (coefficient: 1.079) and wetness index (NDWI) (coefficient: 0.842) both had highly significant positive impacts on habitat selection by rhinos (p-values: $<2e-16$). This means that rhinos moved to areas that were wetter and greener, indicating habitats that have vegetation and are near water sources. Slope had a negative association with habitat selection (coefficient: -0.034, p-value: 0.0005), so rhinos avoided areas with high slope. Rhinos also selected habitats further from roads (coefficient: 0.333, p-value: <2e-16) and closer to agricultural areas (coefficient: -0.096, p-value: 1.61e-7). The landcover types that had a positive impact on habitat selection were closed forests of deciduous broad leaf (coefficient: 0.238, p-value: 4.21e-11), evergreen broad leaf (coefficient: 0.456, p-value: <2e-16), and unknown closed forests (coefficient: 0.141, p-value: 0.0036). Land covers negatively associated with habitat selection included herbaceous vegetation (coefficient: -0.208, p-value: 4.41e-6) and shrubs (coefficient: -0.532, p-value: 0.013).

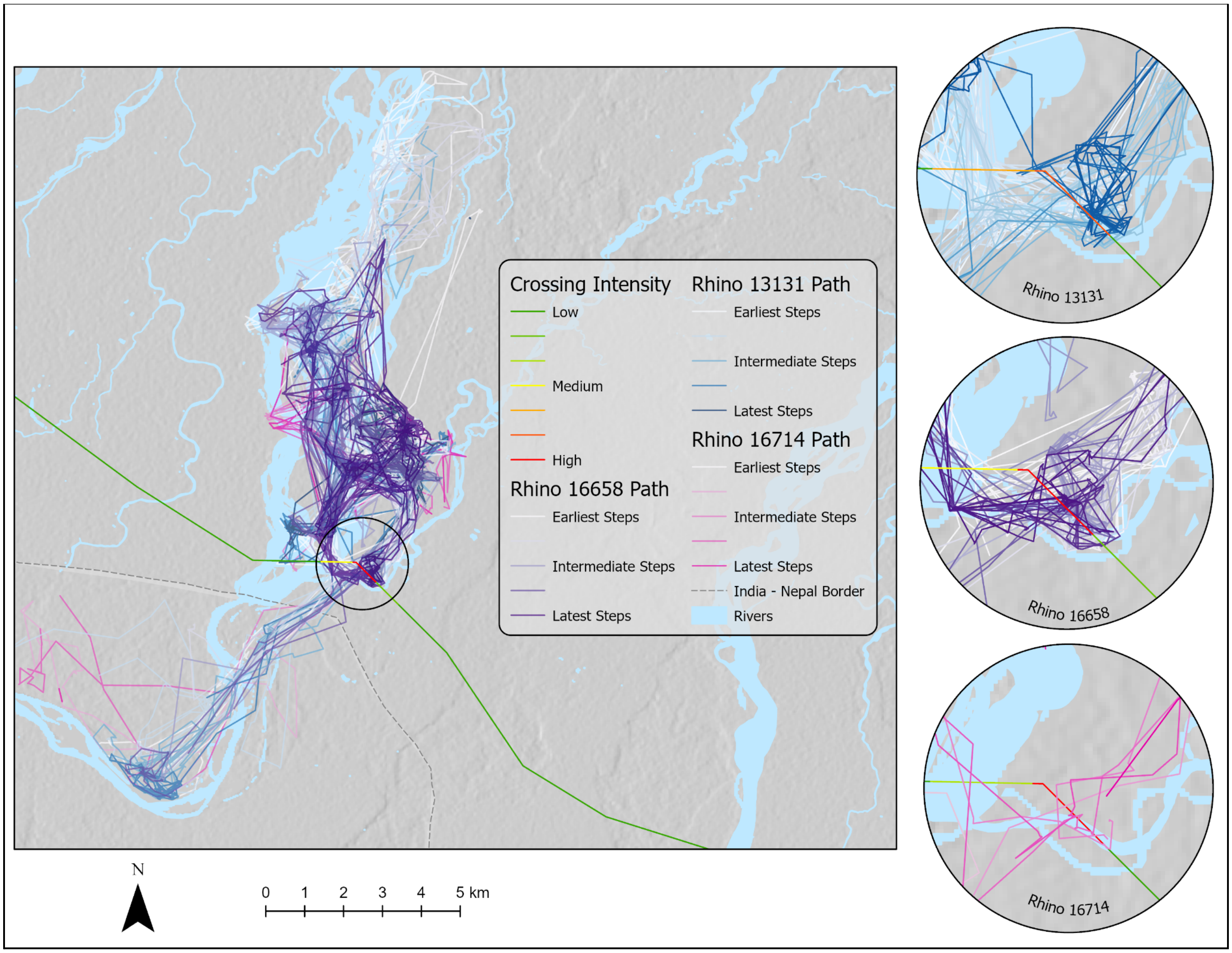


Figure 12: The paths rhinos took across the proposed railway are based on the GPS movement data. The less saturated colors show where the rhinos moved early on when they were colored and increase in saturation later into the study period. The railway layer shows where the rhinos crossed the railway with the greatest frequency.

The monsoon season resistance had a mean resistance value of 83.446 and a standard deviation of 9.544, while early dry had a mean resistance of 99.362 and a standard deviation of 0.403 (Figure 13). Additionally, the late dry season had a mean resistance of 99.488 and a standard deviation of 0.322. Overall, the monsoon season had an overall lower resistance across the landscape, likely due to having higher values of NDVI due to the large amounts of agricultural areas within the study area, along with hydrological changes that occur when there is less rainfall during the dry seasons. Another important note on the large values of resistance: due to having more randomly generated ‘false’ locations, the model will naturally favor higher values of resistance. However, this is consistent across the seasons. This allows for comparison of resistance to movement across the three seasons. The least-cost paths per season can be seen throughout the Khata corridor in Figures 14 and 15.

Variable	Coefficient	Hazard Ratio	Standard Error	p-value
NDVI	**1.079022459**	2.942	0.06102	**<2e-16**
NDWI	**0.841794714**	2.321	0.05967	**<2e-16**
Slope	**-0.03358781**	0.967	0.009618	**0.000479**
Aspect	-0.000342185	0.9997	0.008774	0.968891
Distance to Road	**0.332850778**	1.395	0.0277	**<2e-16**
Distance to Agriculture	**-0.095901821**	0.9086	0.01831	**1.61E-07**
Bare / Sparse Vegetation	**-0.690860878**	0.5011	0.2428	**0.004433**
Closed Forest, Deciduous Broad Leaf	**0.23795324**	1.269	0.03607	**4.21E-11**
Closed Forest, Evergreen Broad Leaf	**0.456091339**	1.578	0.04552	**<2e-16**
Closed Forest, Evergreen Needle Leaf	-11.74762663	7.91E-06	94.31	0.990062
Closed Forest, Unknown	**0.140654079**	1.151	0.04822	**0.003532**
Herbaceous Vegetation	**-0.20845177**	0.8118	0.04541	**4.41E-06**
Herbaceous Wetland	-0.022619863	9.776	0.05648	0.68879
Open Forest, Deciduous Broad Leaf	-1.08625474	0.3375	1.013	0.283412
Open Forest, Evergreen Broad Leaf	-12.01965979	6.03E-06	627.1	0.984707
Open Forest, Unknown	-0.082507462	0.9208	0.06289	0.189553
Water	0.050760019	1.052	0.1461	0.728224
Shrubs	**-0.532202244**	0.5873	0.2142	**0.012953**
Urban / Built	-11.52345362	9.90E-06	378	0.97568

Table 7. The step-selection results indicate which variables have a significant impact on habitat selection.. The analysis was done using a conditional linear regression that is built into the *amt* package in R. Environmental variables that had a significant result are highlighted in bold, where the coefficient is significantly different from 0.

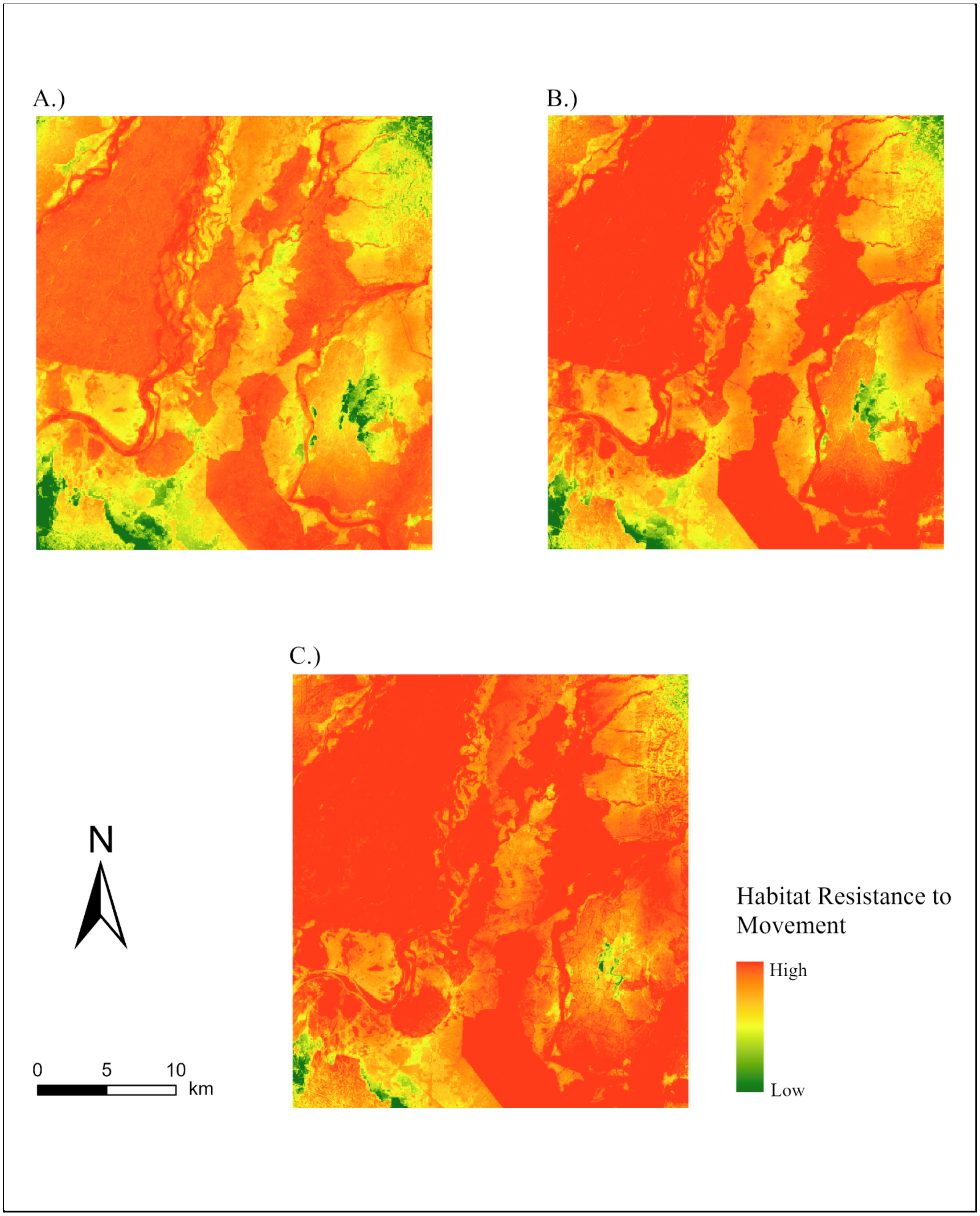


Figure 13: Rhino movement resistance across the different seasons within the study area. Each habitat resistance raster was created by combining the significant environmental variables from the step-selection covariates. The seasons within the figures are: A.) Monsoon, B.) Early Dry, C.) Late Dry.

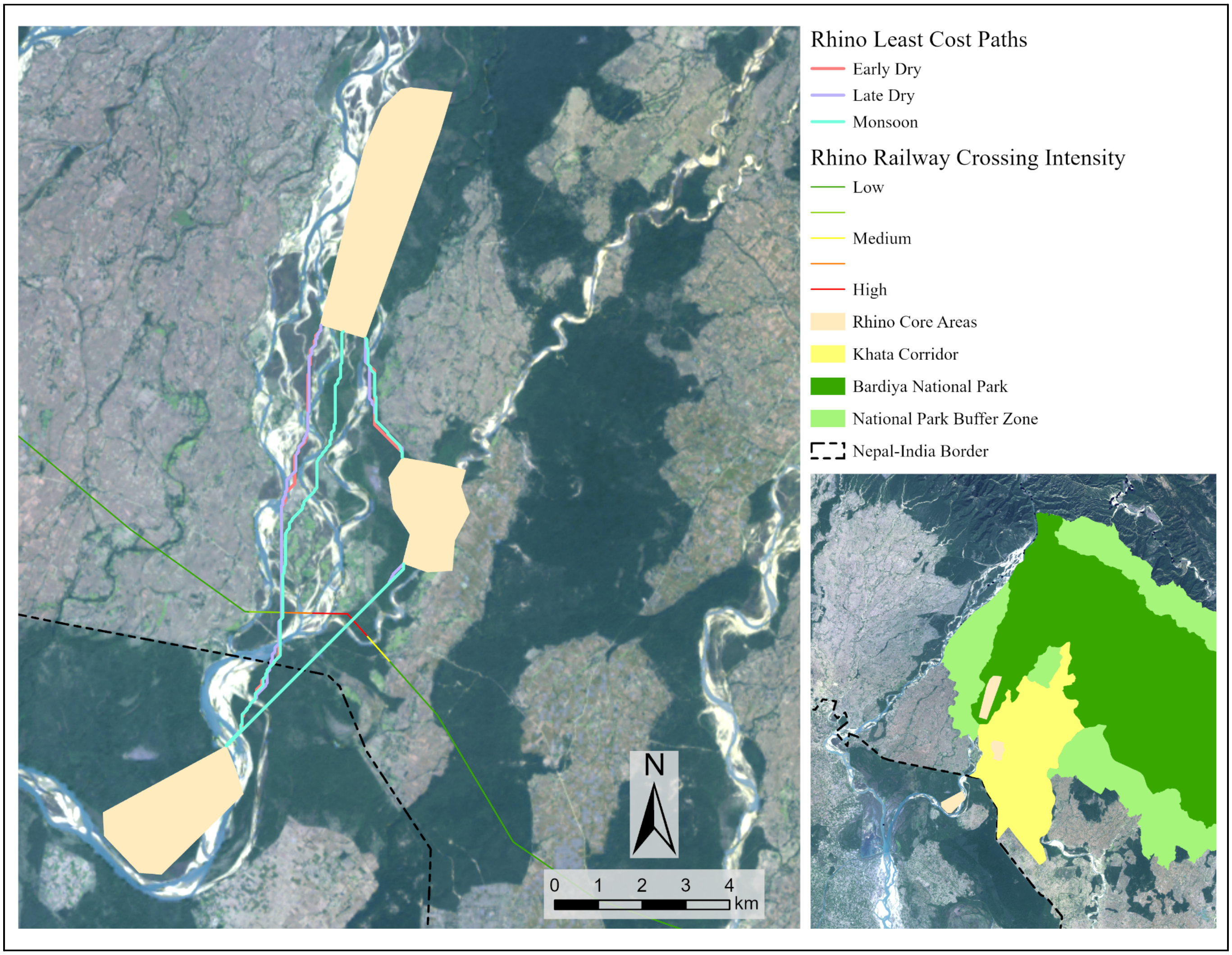


Figure 14: Least-cost paths across the rhino core areas. The rhino core areas were digitized based on the northern, southern, and easternmost areas where rhinos had a GPS collar hit. The railway crossing intensity was determined using the *wildxing* package in R, using the rhino collar data to identify segments of the railway most likely to be crossed by the rhinos.

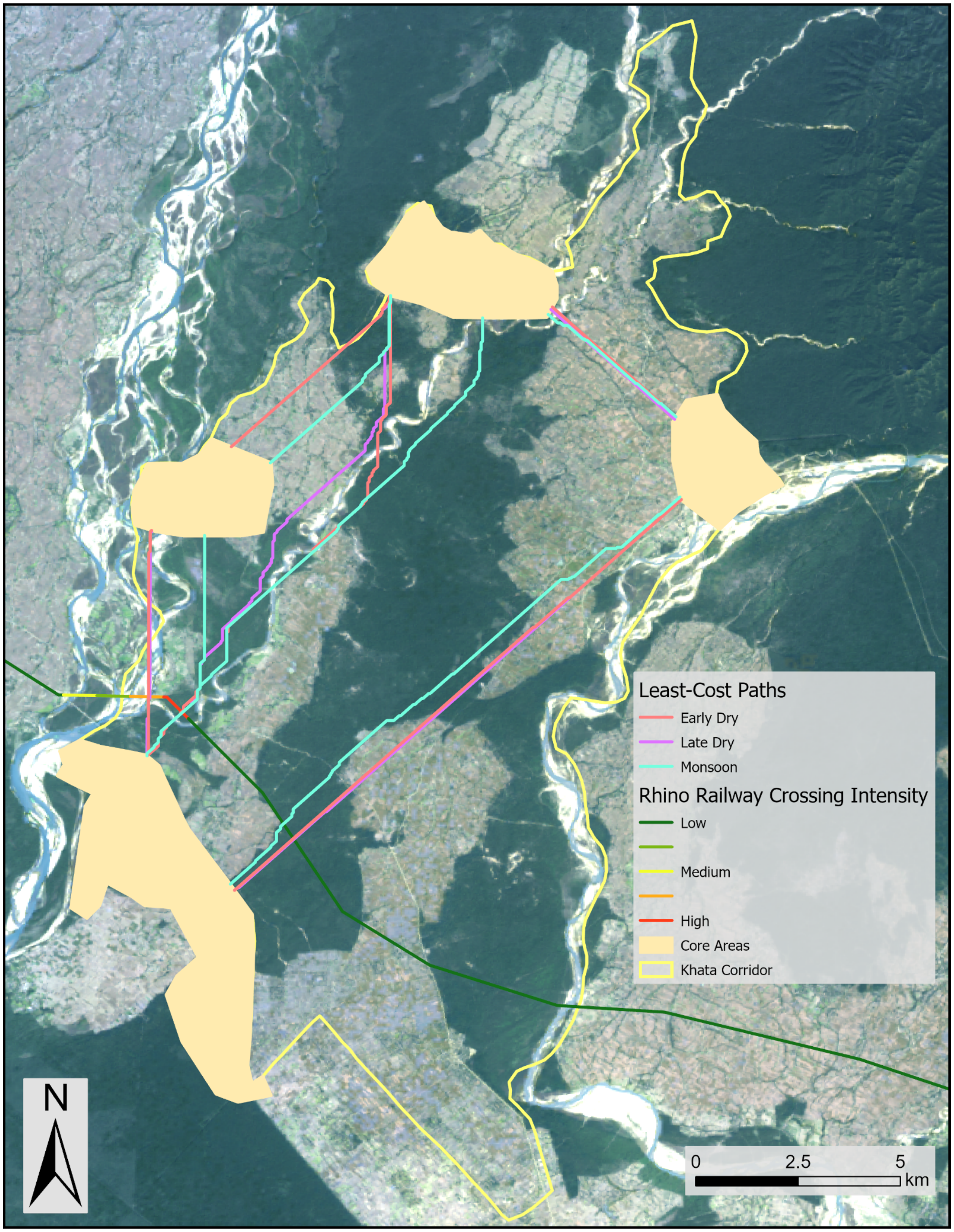


Figure 15: The least-cost paths through the central part of the Khata Corridor. The southern core area is a portion of the Katarniaghat Wildlife Sanctuary in Northern India, while the Northern core area touches the southern tip of Bardiya National Park. The West core area is an area where the rhino collar locations were and the east portion was used to identify how wildlife may move coming from that area of Bardiya National Park.

Discussion

Rhinos were found to prefer areas that had low slope, high vegetation abundance, were near wet areas, further from roads, and closer to agriculture. Rhinos are also associated with multiple land cover types, including two types of closed forests, but tended to avoid shrubs or herbaceous vegetation. This also aligns with other important large mammalian herbivores that prefer areas that have lower slopes and land cover types with abundant vegetation (Coe et al., 2011; Bose et al., 2018). This is likely due to having abundant food and important resources for these animals.

In our study, rhinos appeared to prefer to be near agriculture, especially near closed forests. Forested areas near agriculture can serve as refuges, allowing wildlife to disperse into agricultural areas (Naughton-Neves et al., 2002). The rhinos could be using these areas near agriculture because they serve as a potential food source. These areas can also provide refuge from predators, especially tigers in this area due to their avoidance of developed areas and persecution when they intrude (Sarkar et al., 2017). Wildlife use of agricultural areas can have negative impacts on local farmers as wildlife can eat or damage crops, leading to potential for human-wildlife conflicts (Baldwin et al., 2014). This can lead to killing or removal of these species when they are seen as ‘pests’ (Hill, 2015; Baldwin et al., 2014). There can also be negative health outcomes from ingesting insecticides or herbicides. These areas can also be hard to move through because of fences limiting or stopping movement (Maida et al., 2020; Osipova et al., 2018).

Rhinos preferred areas that were further from roads. This can prevent rhinos from crossing these features and further limit their movement. Being further from roads can often be a way of avoiding vehicle collisions or other negative interactions with using roads. Wildlife may prefer distance from roads to avoid vehicles and possibility of mortality (D’Amico et al., 2015). However, there is an important debate as to the level at which roads are avoided by wildlife. There are times that roads can be beneficial as a means to more easily traverse a rugged landscape, though often they are small and unpaved roads (Dickson et al., 2005). By avoiding roads, the rhinos show they prefer to be away from infrastructure and places of potential vehicle collisions. Placing railway crossing locations away from roads will help ensure that wildlife will use these structures and be able to avoid less desirable habitat.

The resistance surfaces show clear distinctions and changes between the seasons. This is most likely accounted for in the differences in greenness and wetness (NDVI and NDWI) across the seasons. These fluctuations are especially evident in agricultural areas outside of Bardiya National Park. The fields are fallow in the dry season and are much less desirable habitat for rhinos. Due to decreased access to food in agricultural areas, it is likely that rhinos would avoid them. Also, there are many changes in hydrology during the different seasons. With decreases in NDWI, and by extension water along the surface and water flow in rivers, wildlife will often search areas for more accessible water. These rhinos often use areas of perennial and seasonal water sources, indicating the importance of access to water (Ojah et al., 2015). While seasonal changes to vegetation and hydrology can decrease the movement of rhinos through these areas, it is important to note that these areas also become less desirable for rhinos to stay in. Seasonal movement from wildlife and altered habitat use is common to find adequate food and water sources that flux seasonally (Thomas et al., 2021). It is important then to understand how seasonality will change routes of movement.

Creating resistance surfaces from models has benefits and drawbacks. Habitat resistance itself is a relative term that can be used to describe different processes. It can describe how energetically costly it is for wildlife to move through an area (Shepard et al., 2013) or take a more holistic view of habitat selection to inform likelihood of moving into and through an area (Zeller et al., 2012). Our method used habitat selection as the primary basis for determining resistance. This highlights that rhinos will prefer desirable habitat and choose to inhabit or move through these areas. It also can be helpful to visualize how landscapes change seasonally related to how wildlife will move through.

The least cost paths did appear to change across the different seasons within the study area (Figures 14 and 15). This shows that there are important seasonal considerations when evaluating wildlife movement and infrastructure crossings within this area. Importantly, the least cost paths crossed the same railway segment of highest intensity determined by the actual rhino movement. This indicates that our method of identifying the least cost path can be used as a means of estimating potential locations where wildlife could cross and identify locations for a crossing structure. This can be a suitable method when no field data has been collected in an area but previous habitat selection models have been conducted on a species of interest. It is important that this work begin with empirical estimates of habitat selection or other wildlife movement metrics to properly understand dynamics of focal species.

Identifying proper locations for wildlife crossings has important conservation implications for the rhinos in our study. Connecting important core areas of rhino habitat allows rhinos to follow the seasonal patterns that were identified in the resistance surfaces. This also allows for proper gene flow within the population of our study area. Also, identifying wildlife corridors for one species can facilitate the movement of other species that also follow seasonal changes (Coe et al., 2015). Along with facilitating other species, there can also be facilitation of predators within these areas (Dickie et al., 2019; Foster et al., 2020). Our study did not include estimates of predator density or how crossing structures could facilitate predation. It is important to consider the design in these areas to ensure that prey and predators can move across the railway safely.

Our analysis highlighted the importance of placing wildlife crossing structures of intact forested areas going through the Khata Corridor. These areas will provide an ideal location to place these structures because they provide suitable habitat for wildlife to move through. While the exact location within these areas depends on the railway alignment, this study provides a good starting point.

Overall, our study identified which environmental characteristics within our study area impact habitat selection. Choosing habitat can have strong implications for movement and change with seasonal variations. We show that creating resistance rasters from habitat selection can reveal important relationships across a study area to identify where rhinos would likely move through a landscape. Based on the movement modeling, we identified two key areas along forest patches in the Khata Corridor. One is along the Girwa River, south and west of Bardiya National Park. The other is in the center of the Khata Corridor. This approach can be a useful empirical method for assessing potential wildlife movement in the absence of extensive GPS collar data.

Recommendations

With the effectiveness of the least-cost path analysis (Figures 14 and 15), this model can be used to identify important areas to prioritize placing wildlife crossing structures. The rhino movement data (Figure 12) and the least-cost paths intersected with the proposed railway along the same segment. This forest fragment along the Girwa River, along the western portion of the Khata corridor, will be a critical area to place a wildlife crossing structure. Prioritizing the river areas will be especially beneficial to rhinos and other species who use these riparian areas. Another important area to focus is along the forested patch that runs through the Khata corridor (Figure 15). This patch will likely be another important area to build a crossing structure due to the likelihood of wildlife using this route when moving between Bardiya National Park and protected areas in Northern India.

Having outlined a method for identifying optimal wildlife crossing structure locations and used it to suggest crossing locations for rhinos, the next section will highlight how to design these structures. It is important to not only place them in an area of high utilization by wildlife, but also design them in a way that will be enticing to use. We will focus on how the wildlife crossing designs and other mitigation strategies can be optimized for three focal species: rhinos, elephants, and tigers.

Crossing Structures / Landscape Design

Introduction

The Terai Arc Landscape is a highly successful example of landscape-level conservation. Critical to its success are the wildlife corridors that connect separate protected areas in Nepal and India. More than 30 different species have been recorded utilizing the Khata Corridor alone, including all three of our target species (Thapa & Thuladhar, 2021). There is even some evidence to suggest that tigers are permanent residents of the Khata Corridor (Wikramanayake et al., 2010). Yet linear infrastructure development threatens to curtail the value of wildlife corridors and fragment the Terai. The new East-West electrified rail line is no exception. In order to safely and effectively maintain connectivity for Indian elephants (*Elephas maximus indicus*), greater one-horned rhinoceros (*Rhinoceros unicornis*), and Bengal tigers (*Panthera tigris tigris*), a regional system made up of multiple strategies across scales that work together to ensure permeability and safety is appropriate.

The detrimental effects of railways play out across multiple physical and temporal scales. Chemicals, sediment, sound, and vibration all disrupt ecological processes during construction (Asian Development Bank, 2019; Barrientos & Borda-de-Água, 2017). Although railways present some environmental advantages to roads – lessened emissions and smaller physical footprints among them – they still obstruct species migration and dispersal (Borda-de-Água et al., 2017). The steep slope, fencing and unfamiliar terrain that often border railways can prevent wildlife from crossing (Ito et al., 2013; Xia et al., 2007). They also cause direct mortality when species are hit by trains, electrocuted by overhead wires, or trapped in the rail bed (Santos et al., 2017). Additionally, noise, vibration, pollution, direct human presence, and signs of human presence – such as debris and machinery – can all create an expanded zone of unsuitable habitat around rail verges. Finally, railways are homogenous strips that can be exploited as pathways by predators, generalists, and invasive species, causing changes to the habitats they cross (Barrientos & Borda-de-Água, 2017). The best way to prevent these effects is to avoid building infrastructure through sensitive areas in the first place. Nepal has already taken this approach for another portion of the East-West rail project by rerouting it around Chitwan and Parsa National Parks, as opposed to the original alignment that cut through the interior of both (United States Agency for International Development, 2021). If avoiding corridors connected to the Banke-Bardiya Complex is not possible, however, careful consideration of the design and operation of the railway and its surroundings is necessary. Since rail impacts play out across multiple scales, we must consider mitigation efforts at multiple scales to form a comprehensive plan. Additionally, proposing strategies at multiple scales can engage individuals and organizations from local to international levels in conservation efforts. Therefore, we reviewed scientific and popular literature for strategies to mitigate the East-West Rail Alignment's potential impact on wildlife across three spatial scales: individual crossing structures, the entire rail alignment, and the region. We then applied strategies from these scales to each of the three target species individually. From there, we translated this into a series of graphics to better communicate the information.

Research Questions

Our review intended to address the following questions:

1. What measures can be taken to minimize wildlife mortality on railways?
2. What measures can be taken to maintain wildlife connectivity even as railways are constructed?
3. Which crossing structures are appropriate for large, wide-ranging wildlife species?
4. What general design standards make crossing structures more effective?
5. What general design standards minimize human-wildlife conflict in communities surrounding the railway?
6. What design standards maintain connectivity and minimize human-wildlife conflict for each of the three target species specifically?

Crossing Structure Design

At the local scale, crossing structures are an important tool for locations where animals will cross the railway frequently and in high numbers. Large mammals in particular can experience high mortality without effective crossing measures, especially where railways cross migration routes or important habitats. According to Barreintos & Borda-de-Água (2017), mortality is generally highest along rail lines with a moderate amount of traffic, because lines with a high amount of traffic will scare wildlife away completely and act as an impermeable barrier. Noise, vibration, pollution, and human presence all reinforce this barrier effect. The remaining fragmented habitat is also often changed due to the conditions, pollutants, and species a rail corridor may introduce (Barrientos & Borda-de-Água, 2017). An effective way to reduce both mortality and the barrier effect is to build crossing structures.

Not all crossing structures are created equal, however. It is important to carefully consider the design and scale of these structures. Whenever pedestrian infrastructure is designed, its success depends on how well it accounts for the needs and preferences of people. Paths that are too wide and indoor spaces with roofs that are too tall may feel exposed and intimidating, while those that are too narrow or too short may feel cramped and even claustrophobic. A lack of vegetation along pathways may uncomfortably expose pedestrians to the elements, but too much vegetation or the wrong types of vegetation may make them feel unsafe. The material that makes up the walking surface, the absence of water on pathways, the ambient noise, smells, and temperature, the general appearance of infrastructure and its surroundings, and the amenities that can be found along a path are all also important considerations as to whether people will be willing to walk a pedestrian path. Similarly, wildlife crossings succeed or fail in part due to their consideration of the needs and preferences of the wildlife. In Banff National Park in Alberta, Canada, grizzly bears (*Ursus arctos horribilis*), black bears (*Ursus americanus*), wolves (*Canis lupus*), cougars (*Puma concolor*), elk (*Cervus canadensis*), and various smaller species all used crossing structures to cross the Trans-Canada Highway, though each species exhibited different preferences for crossing location, type, dimensions, and materiality. Here, the fact that many crossings of different types and specifications are available mitigated the impact of the Trans-Canada Highway on connectivity and prevented any individual crossing from becoming an ecological trap or sink (Stewart et al., 2020). Meanwhile, a study of crossings at the A4 motorway in the Lower Silesian Forest in Western Poland found that both wolves and their associated prey species showed a clear preference for overpasses rather than underpasses (Myslajek et al., 2020). Finally, camera traps near underpasses constructed under the Narayanghat – Ramnagar and Ramnagar – Jugedi sections of the Narayanghat-Muglin Road in Nepal detected seven mammal species, but only wild boar (*Sus scrofa*) and a single common leopard (*Panthera pardusfusca*) actually crossed (Paudel et al., 2020, pp. 190-191). This indicates that wildlife were largely unwilling to use the crossings, though the local population sizes of different species were likely also a factor.

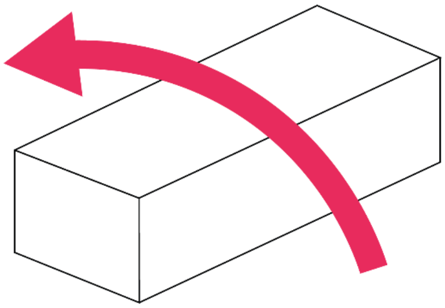
Crossing Types

Figure 16 shows four main categories of wildlife crossing structure. Overpasses are generally highly effective, as they are open and feature the ambient atmospheric conditions of the environment around them. Even the largest and most skittish species will cross them (Carvalho et al., 2017, p. 32; Barrientos & Borda-de-Água, 2017). Yet overpasses are also expensive and have a significant footprint, potentially subjecting more habitat to construction and causing further hydrological issues. The raised rail embankment, overhead electric wires, and lowland terrain of the Terai make an overpass unfeasible in the case of the East-West Railway. Therefore, we will focus mainly on culverts, underpasses, and bridges in this report. Culverts, either designed specifically for wildlife use or adapted from existing drainage infrastructure, can be important paths for small to medium-sized animals (Bissonette & Adair, 2008; Asian

Development Bank, 2019). In anticipation of the effects of climate change, the Asian Development Bank (2019) recommends upgrading culverts to larger, more open arch structures – a change that could also make them useful crossings for larger species (pp. 23-25). In the Terai, where the monsoon season already brings extreme flooding and the new railway embankment may exacerbate hydrological issues, these upgrades are especially important. Underpasses, typically larger than culverts, provide a more cost-effective alternative to overpasses, though some species may be more reluctant to use them. Standards for underpass design are discussed in the next paragraph. Finally, bridges or viaducts can be similarly effective as overpasses in some areas. These structures often have the advantage of already being necessary for infrastructure crossing water or other obstacles. However, they are sometimes built specifically with wildlife connectivity in mind, as with 0.25 km to 1 km highway "flyover" bridges used in India (Asian Development Bank, 2019).

CROSSING TYPES

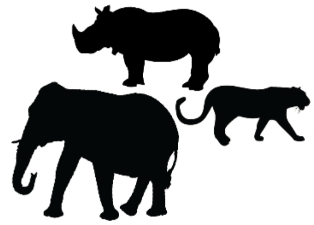
Overpass



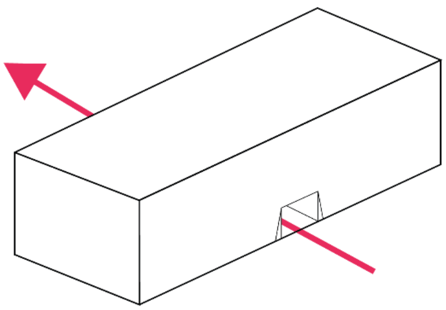
Brings wildlife over infrastructure

Open air, better for skittish species

Vegetative cover possible



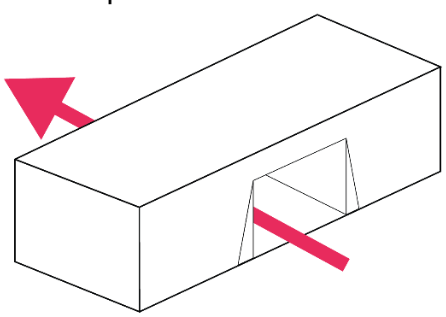
Culvert



Can be adapted from existing drainage infrastructure

Prone to flooding; dry ledges necessary

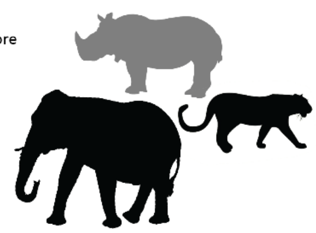
Underpass



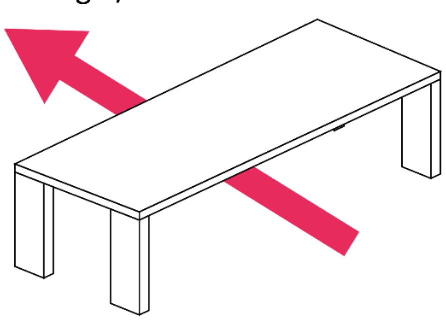
Larger than culverts; appeals to more species

May still be too enclosed for some species

May flood; dry ledges may be necessary



Bridge / Viaduct



Open air, better for skittish species

Vegetative cover possible

Waterways may flood; high ground necessary

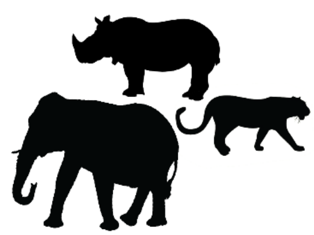


Figure 16. Four categories of wildlife crossing structures and the likelihood of their use by the target species. Based on information from Carvalho et al., 2017; Barrientos & Borda-de-Água, 2017; Asian Development Bank, 2019.

Underpass Design

According to Carvalho et al. (2017), there are several common features for successful wildlife underpasses. Generally, most terrestrial species prefer underpasses that are not flooded, not heavily used by people, spacious, gently sloped, and not significantly different from the ambient conditions around them. Entrance conditions determine whether or not an animal will approach a crossing, while the interior conditions and the visibility out the exit determine whether or not the individual completes the journey. Floor materials that are abrasive or difficult to traverse such as brushed concrete or riprap should be replaced with soil or organic substrate wherever possible. Openness, calculated by multiplying the height and width of an underpass and then dividing by its length, is a particularly important factor in whether or not large mammal species will use an underpass (Asian Development Bank, 2019). Minimum openness index values have been previously estimated for tigers and Asian elephants and will be mentioned in the sections concerning each individual species. It is important to recognize that, while there are certain general crossing standards, species may vary in their preferences. In many cases, sizes, shapes, contexts, cover conditions, and materials that appeal to some species or taxa repel others (Gannett, 2018). For example, carnivores in Banff National Park preferred underpasses associated with drainage systems, while ungulates tended to avoid them (Clevenger & Waltho, 2001). For this reason, specific guidelines concerning each of the three target species are outlined individually later in this report. Interactions between species could also have an effect. Clevenger & Waltho (2001) theorize that the difference between carnivore and ungulate passage usage in Banff may indicate that predators deter prey from using structures. In some cases, poorly designed crossings may be used by predators to ambush prey (Gannett, 2018). However, it is possible to design crossings that strike an acceptable balance between the needs of various species and do not create an ecological trap for prey species. At the A4 motorway in Poland, wolves and their prey both used the same crossings at similar times of day – though both showed a clear preference for overpasses than underpasses (Myslajek et al., 2020). Figures 17 and 18 diagram general guidelines for the entrances and interiors of successful underpass crossings in detail. Though this is discussed in more detail in the profiles of each of the target species, it is worth mentioning that adult rhinoceroses and elephants face little, if any, risk from tigers. However, calves are threatened if separated from their mothers (Dinerstein, 2003).

CROSSING ENTRANCES

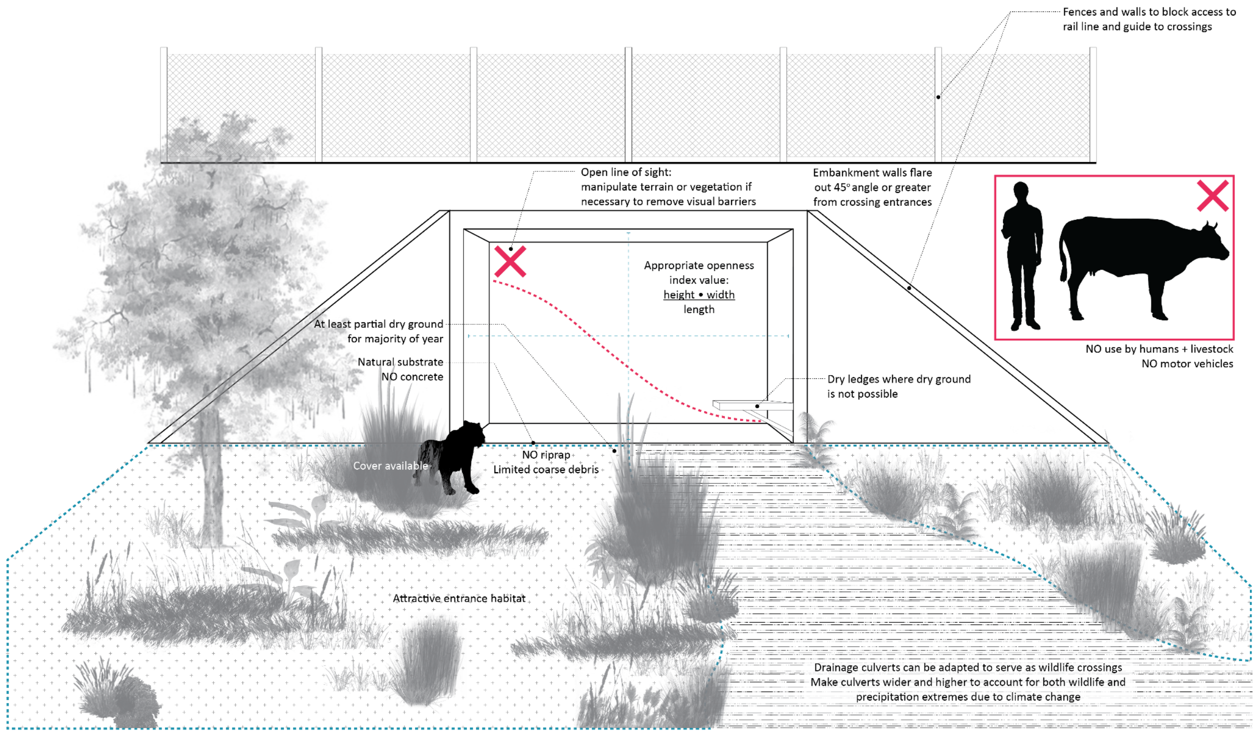


Figure 17. General design guidelines for the approach conditions and entryways of crossings. Preventing use by humans and livestock is important – Clevenger & Waltho (2001) found that carnivores were reluctant to use crossings with high levels of human activity. Fences are discussed in more detail in the Rail Alignment Scale section. Based on information from Carvalho et al., 2017; Asian Development Bank, 2019; Baofa et al., 2006; Yanes et al., 1995; Lucas et al., 2017.

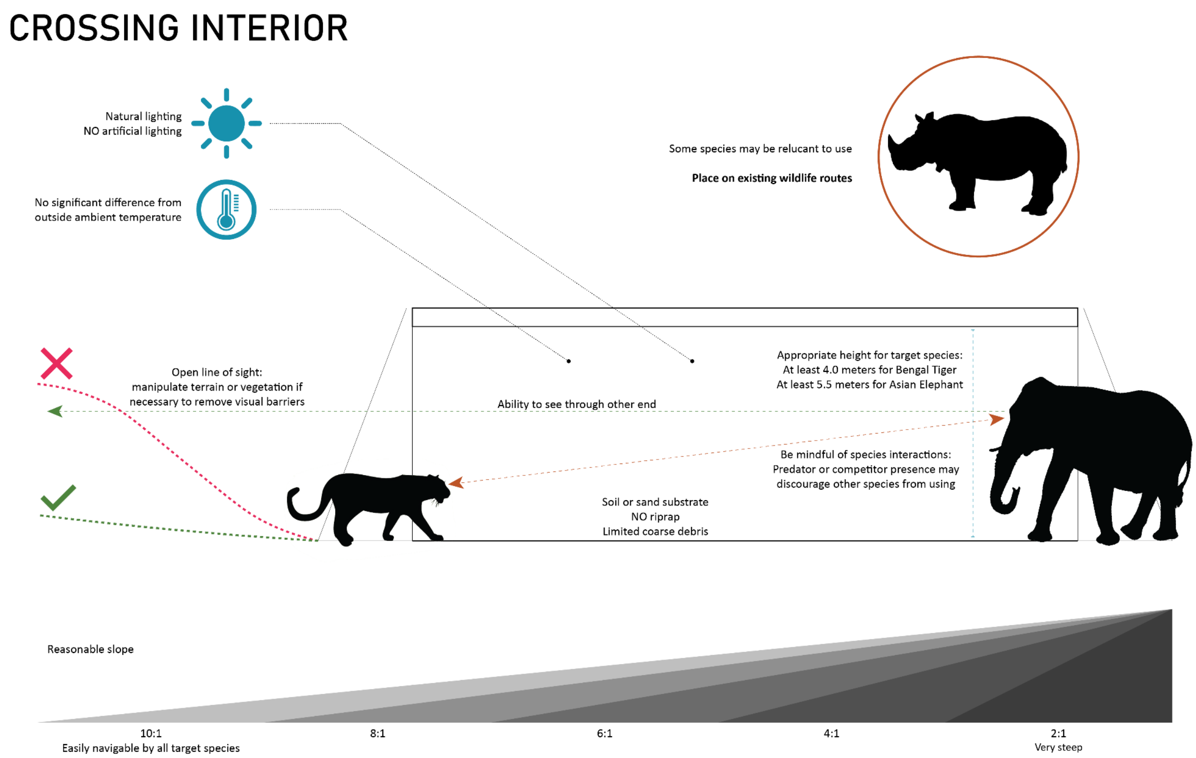


Figure 18: General design guidelines for the interior of crossings. Placing crossings on existing migration routes, as well as using fencing, can increase the likelihood that skittish species will use them. Visibility is especially important for herbivorous species. Based on information from Carvalho et al., 2017; Asian Development Bank, 2019; Lucas et al., 2017.

Rail Alignment Scale

At the scale of the railway, creating a system of strategies that work together ensures that wildlife can cross the alignment safely and that resources are used effectively. Though Bengal tigers, greater one-horned rhinoceros, Indian elephants, and other wildlife in the region may have some overlap in their habitat usage, species and even individuals utilize the landscape differently and will be compelled to cross the railway at different times and places. Additionally, conditions vary significantly with the seasons and from year to year. As the climate changes, this variability may become more extreme, further complicating connectivity. Finally, differing human land uses will attract or repel wildlife across or around the rails. For example, train-elephant collisions on the Siliguri-Alipurduar railway in West Bengal, India, peaked during the cultivation season as elephants crossed the rails to raid crops (Roy & Sukumar, 2017). This is a dynamic environment where no one technique for mitigating mortality and maintaining connectivity is appropriate alone. Even after mitigation techniques are put in place, continued monitoring will be necessary. If unexpected mortality hotspots or connectivity issues emerge, adjustments will have to be made.

Railway Construction and Operations

Foresight, training, and scheduling offer simple mitigation strategies. Construction is disruptive to ecological processes and introduces pollutants. Building durable infrastructure that accounts for expected future traffic volumes prevents the ecological damage that would result from reconstruction in the future (Asian Development Bank, 2019). However, care must still be taken to minimize the extent of the infrastructure's footprint. Even when accounting for future traffic volumes, the less space taken up by infrastructure and its verges, the better. Once built, reducing vehicle speed and regularly maintaining the tracks can both reduce noise/vibration pollution (Lakušić & Ahac, 2012; Schulte-Werning et al., 2008). Reduced speed can also mitigate mortality and the barrier effect imposed by infrastructure, particularly in areas of high habitat value or low visibility (Becker & Grauvogel, 1991; Belant, 1995). Speed limits are already widely utilized in conservation, such as with boating regulations in sensitive marine areas (Gannett, 2018). At Rajaji National Park in India, slowing trains to 30-35 kilometers per hour reduced collisions with elephants by giving operators enough time to see an elephant and bring the train to a stop (Joshi & Puri, 2019). Other successful techniques here also focused on train operators, including radio warnings that elephants were nearby, training focused on recognizing animal movement from a distance, and clearing vegetation at known crossing points to allow for greater visibility. The authors also noted that highly visible signage identifying known crossing points could further reduce collisions. Additionally, Roadside Animal Detection (RAD) systems, which activate in response to wildlife approaching infrastructure (Gannett, 2018), could be adapted to trigger warning signals along the track or send alerts directly to the operator.

Rail mortality occurs most often at times of day or times of the year when animals are the most mobile. For example, Santos et al. (2017) write that moose (*Alces alces*) in Alaska are more often hit at dawn, dusk, or night time than during the day, and in winter more than in summer. Meanwhile, trains in Rajaji National Park most often collide with elephants during the late dry season, when the animals must cross rail lines in search of water (Santos et al., 2017). Temporary closures are a simple but effective mitigation measure. All three target species are at least partially nocturnal (Smith, 1993; Von Houwald, 2015; Joshi & Puri, 2019), so limiting rail traffic to daytime hours is one option. Nepal has used similar techniques in the past; after lifting a nightly travel ban, Bardiya National Park experienced a significant increase in vehicle collisions with wildlife (Asian Development Bank, 2019). Seasonal operational changes are also an option. Rhinoceroses become more mobile during the hot dry season as they expand their mean home ranges to compensate for limited resources (Dinerstein, 2003). They may also seek out higher ground, such as the 7-15-meter-tall railway embankment, during the monsoon season (Thapa, 2005). While spikes in train-elephant collisions in some areas relate to water availability in the hot dry season, those in other areas coincide with agricultural cultivation as elephants cross railways to raid crops (Roy & Sukumar, 2017). Some evidence suggests that droughts in the hot dry season also prompt tigers to enter areas they would normally avoid (Rauniyar, 2021). Decreasing traffic volumes on the East-West railway seasonally could be effective. Alternatively, nightly closures could go into effect seasonally and be lifted for the rest of the year. However, the appropriate season for taking these actions would not be homogenous along the entire alignment. Speed reductions that go into effect seasonally for sections of the track where collisions are more likely would account for habitat and seasonal heterogeneity. Additionally, species-specific warning signals that mark likely collision points at certain times of year could be seasonally activated, preventing operators from becoming habituated to them (Asian Development Bank, 2019). It is worth noting that this type of signal, while less accurate, is much easier to maintain than previously mentioned RAD systems.

Crossing Placement

Even the most well-designed crossings will likely go largely unused if they are not sited correctly. One of the underpasses below the Narayanghat-Muglin Road Section studied by Paudel, Devkota, & Lamichhane (2020) was not successfully crossed by any of the observed species, likely because it was not placed along an existing game trail (pp. 192-193). There are many potential methods for choosing where to place crossings. According to Bissonette & Adair (2008), placing crossings based on linear home range distances would both ensure maximum permeability for wildlife and minimize collisions, as relatively short daily wildlife movements determine the permeability of a landscape (pp. 485-486). Table 8 shows crossing spacing sizes based on the average linear home ranges of Asian wildlife species (Asian Development Bank, 2019).

Species Group / Taxa	Mean Home Range (km^2)	Spacing (km)	Passage Structure Size	Species Included
Small ungulates	1.7	1.3	Medium	Barking deer
Mustelids	2.0	1.4	Small	Civets, marten
Small felids	7.8	2.8	Medium	Leopard cat, Asiatic golden cat
Large ungulates	12.2	3.5	Large	Sambar
Bears	13.7	3.7	Medium	Asiatic black bear, sloth bear
Large bovids	27.0	5.2	Large	Asiatic water buffalo, gaur
Large felids	60.8	7.8	Large	Common leopard, tiger
Large canids	116.6	10.8	Large	Asiatic wild dog
Asian elephant	184.0	13.6	Very Large	Asian elephant

Table 8: Wildlife crossing spacing recommendations based on average linear home range data. Table produced by Asian Development Bank (2019).

While this might be feasible for crossings serving small wildlife species, it would be an expensive option for large species. Additionally, animals do not make decisions based on linear home range distances alone. For example, elephants may require crossings to be much more closely-spaced than their linear home range would suggest due to their high use of certain habitats (Asian Development Bank, 2019). Bissonette & Adair (2008) concede that short sections of road often account for the majority of wildlife mortality, so focusing mainly on these hotspots can be effective. For road wildlife crossing projects, mortality hotspots can often be clearly identified using actual collision data, as the roads already exist. In contrast, since the railway has not yet been built through the Banke-Bardiya complex, hotspots will need to be predicted. In our wildlife occupancy and wildlife movement studies, we explored a few ways of doing so. These are mentioned in the sections specific to tigers, rhinos, and elephants below.

Fencing

At mortality hotspots, it is just as important to prevent access to the rails as it is to maintain connectivity through crossings. In fact, when it comes to roads, crossings do not prevent collisions unless fencing is also used. Yet fencing the entirety of a linear infrastructure project is expensive and creates a damaging ecological barrier. The same analysis used to identify crossing spots is appropriate for placing sections of fencing as well. Given that the target species for this project are all large-bodied and mobile, a few long sections of fence strategically placed in conjunction with the crossing structures will be significantly more effective than many short sections along the rail line (Spanowicz et al., 2020, pp. 1212, 1217; Smith et al., 2015). Fences should be adequately high and strong in order to assure that animals are not able to jump over them or break through them. Additionally, escape methods such as one-way gates or returning ramps should be included to prevent animals from becoming trapped on the rails between fences (Carvalho et al., 2017, p. 34). Information on fencing placement and escape methods is shown in Figures 19 and 20. The sections concerning the target species include more specific fencing standards for each.

Additional Strategies

In *Methods to Monitor and Mitigate Wildlife Mortality in Railways*, Carvalho et al. (2017) outline multiple tools other than fencing and crossing structures. These are diagrammed in Figure 19. Sound signaling (audio cues that warn wildlife that a train is approaching) and sound barriers (audio effects that repel wildlife from the railway) are two available options. Stationary audio systems that are either motion activated by wildlife or triggered by approaching trains can be installed near the tracks, or the trains themselves can be fitted with a front-mounted system (Barrientos et al., 2019; Lucas et al., 2017). Ultrasonic tones and train horn blasts have been effective in some cases, though their success depends on the species. Another promising option is the use of recorded wildlife warning calls. One project in which multiple animal warning calls were played through stationary speakers activated by approaching trains was effective at preventing wildlife mortality without animals becoming habituated to the signal over time (Carvalho et al., 2017, pp. 34-35). As it does not prevent wildlife from crossing when trains are not around, sound signaling is an important option for potential and realized mortality hotspots where crossing structures are not feasible. Stationary systems installed in these areas can use warning calls of various species, including those of the three target species. In those hotspots near human settlements, an ultrasonic tone may be used instead to avoid noise pollution, although it is worth noting that not all wildlife species may be able to hear the tone. Train drivers using the horn to warn wildlife is a good additional emergency tactic, but is not highly effective on its own. Flashing lights or reflectors may be combined with sound signals to encourage a faster escape response, given the higher likelihood of wildlife crossing the rails at night. (Babińska-Werka et al., 2015; Lucas et al., 2017). If used, lights should be relatively dim to avoid blinding or stunning the animals (Carvalho et al., 2017, p. 35). These lights should be cool-toned in order to ensure the animals see them, but only turn on when a train is approaching in order to avoid contributing significantly to light pollution.

Olfactory repellents, often in the form of synthetic predator substances, can repel animals or make them more alert to danger (Andreassen et al., 2005; Kušta et al., 2015). This method has reduced wildlife-rail mortality in parts of Europe, but with varied efficiency (Carvalho et al., 2017, p. 34). It is worth noting that olfactory repellents wear off relatively quickly compared to the lifespan of other deterrent methods, and therefore would require frequent reapplication. For this reason, they may be best used as a temporary measure to prevent conflict during construction and mitigate unexpected mortality hotspots that may arise once the railway is in operation.

RAIL SYSTEM MITIGATION STRATEGIES

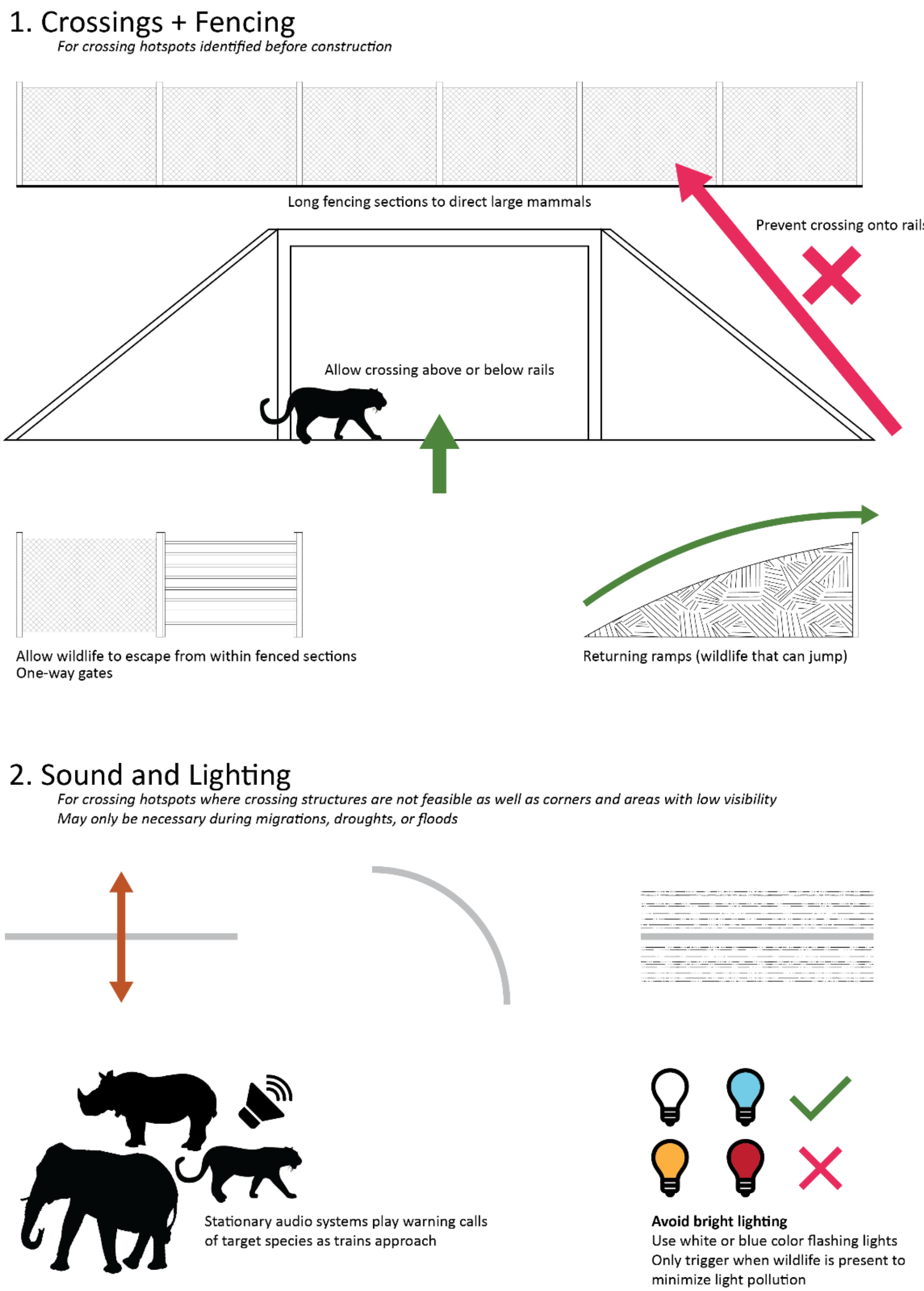


Figure 19: Strategies for mitigating mortality and fragmentation along the length of the railway. Based on information from Spanowicz et al., 2020; Carvalho et al., 2017; Joshi & Puri, 2019.

Above all, continued monitoring and analysis is important. The wildlife occupancy analysis carried out as a part of this project provides a useful baseline for understanding the movement and habitat usage of the target species and some of their associates prior to construction. How this changes during and after construction is an important subject of further study. Additionally, while crossings and mitigation methods are often placed at realized mortality hotspots on preexisting linear infrastructure (Spanowicz et al., 2020), these recommendations for the rail line through the Banke-Bardiya Complex are based on predictions of where those hotspots will be. Continued monitoring is necessary in order to identify unexpected mortality hotspots and adjust the system of mitigation strategies as necessary. Monitoring is also necessary to determine whether fences and other mitigation methods are working as intended and how the finished railway may be impacting habitat composition and water availability in surrounding habitats (Carvalho et al., 2017, p. 25).

Regional Scale

At the regional scale, habitat and water management are necessary to ensure positive and safe relationships between people and wildlife. Though the system scale mitigation methods detailed previously will help to reduce the barrier effect imposed by the rail line, railways have impacts far beyond the space directly occupied by the rails. According to Barrientos & Borda-de-Água (2017), noise, vibration, pollution, direct human presence, and signs of human presence (such as debris and machinery) can all create an expanded zone of unsuitable habitat around rail verges. Additionally, since railways are homogenous strips that can be exploited as pathways by predators, generalists, and invasive species, they will cause changes to the habitats they cross (Barrientos & Borda-de-Água, 2017) and could even become attractive corridors for elephants that have been blocked from other corridors by fences and changes in land use (Chamling & Bera, 2020). Railways elevated on an embankment will also affect the flow of water through the landscape, potentially drying out some habitats and concentrating water in others. The steep rail embankment, along with crossings, fences, and other mitigation strategies, are likely to direct wildlife into new areas, including agriculture and villages. Figure 20 outlines regional scale mitigation strategies based on habitat management, topography manipulation, and fencing.

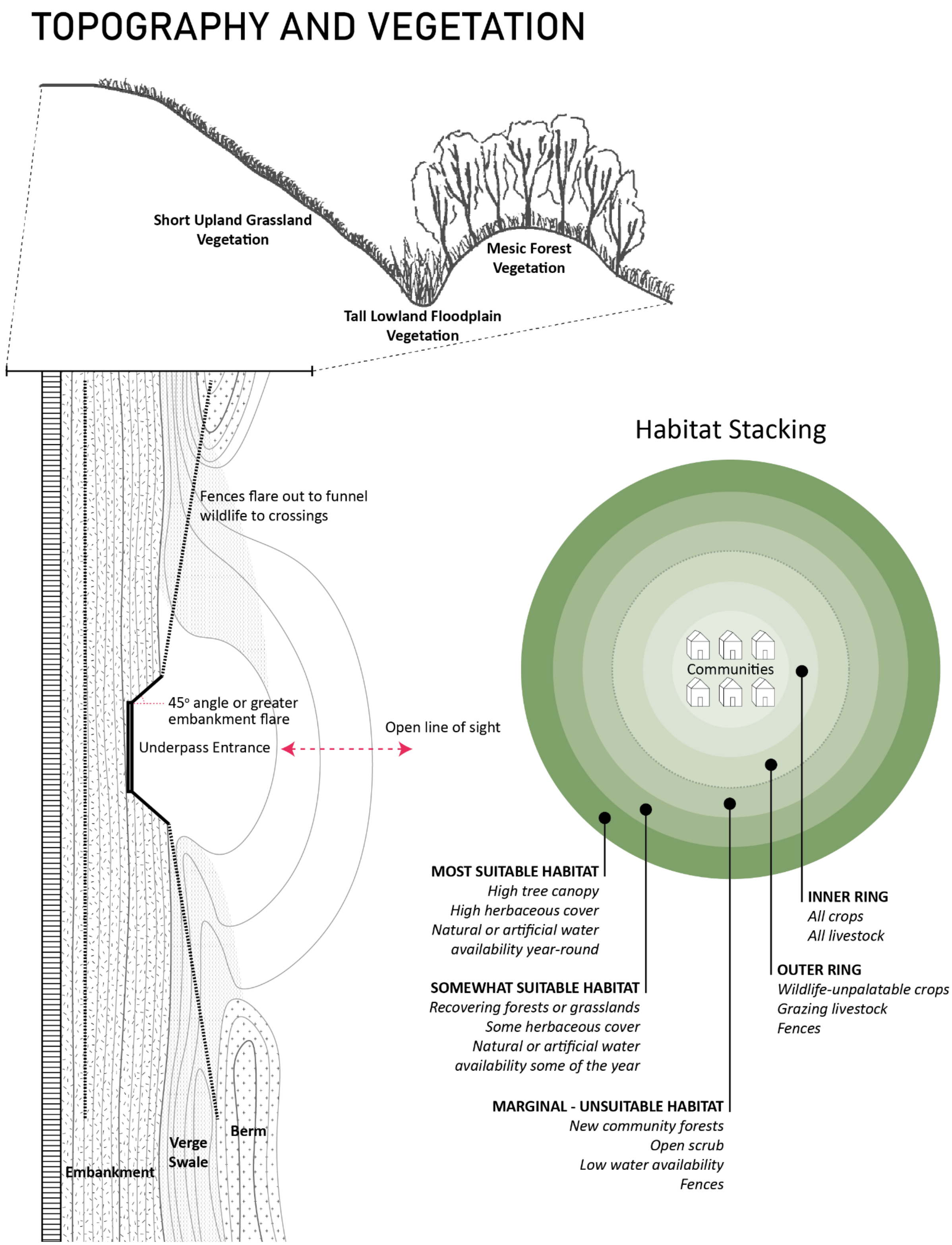


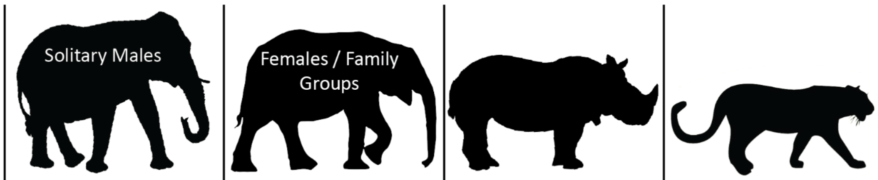
Figure 20: Regional strategies to maintain connectivity and mitigate conflict and habitat degradation. Based on information from Lucas et al., 2017; Carvalho et al., 2017; A. McCay, personal communication, April 28, 2021; Asian Development Bank, 2019.

Rail Verge Planting and Topography

Mitigating noise and vibration begins with the design of the tracks themselves, but interventions in the verges are also effective. Soil berms and dense vegetation in the verges of the railway will both dampen noise and vibration (Lucas et al., 2017, p. 90). However, this could also reduce visibility for train drivers and wildlife alike and even attract wildlife to verges, potentially increasing instances of train-wildlife collisions (Carvalho et al., 2017, p. 36) if crossings, fences, or other mortality-mitigating tools are not used. The embankments of the elevated rail line in Nepal can be planted with native upland grasses, as these will reduce erosion while still providing some visibility. Regular maintenance will be necessary in order to prevent denser woody vegetation from taking over. Treating the embankment soil with gypsum, applying compost or mulch during and following construction, lattice plots, interception, and drainage can all further mitigate erosion (Lucas et al., 2017, pp. 92-93). In the verges, lowland floodplain vegetation will be more appropriate, particularly in those areas where the rail embankment and surrounding berms form swales along the rail corridor. It is important to note, however, that erosion from the embankment could pollute the soil in these swales, limiting which plant species are viable (Lucas et al., 2017, p. 85). Using ethylenediaminetetraacetate (EDTA) with water or thermosetting plastic resin to clean the ballast can be used to reduce soil pollution generated by trains (Lucas et al., 2017). Woody vegetation representing the mixed deciduous and sal forests of the Terai are appropriate for the berms, dampening noise and vibration from the passing trains while still being far enough from the tracks to maintain visibility and avoid creating an ecological trap.

Water and Habitat Management

Food and water availability are powerful motivators for animal movement. Carvalho et al. (2017) suggest supplemental feeding stations as a possible method for attracting wildlife away from railways (p. 36). Likewise, Joshi & Puri (2019) recommend the construction of artificial reservoirs so that elephants in Rajaji National Park in India no longer have to cross a railroad to reach water (p. 377). Water can be a driver of human-wildlife conflict as well. In southern India, ponds and irrigation reservoirs can attract elephants into villages and agricultural areas, resulting in crop destruction and potentially dangerous confrontations with people (Sukumar, 1992, p. 131). Supplemental food and water stations could be used to attract wildlife away from villages and agriculture. This is especially important in the context of decreasing river water levels due to mining at their headwaters and climate change, as decreasing availability of water in the dry season of the Terai appears to be one factor in the recent increase in tiger attacks near Bardiya National Park (Rauniyar, 2021). In a larger regional context, different land cover types of varying suitability for the target species can be managed to better control the movement of wildlife through the region. A method called habitat stacking, developed by landscape designer Alex McCay, sorts habitats and land cover types by their suitability for a given wildlife species. Then, these are arranged in bands beginning with the most suitable habitat in the center and continuing with decreasingly suitable habitat out from that center. The effect is a wildlife corridor that helps to control the movement of wildlife near populated areas and often allows for greater visibility of potentially dangerous wildlife before they get too close to settlements or agricultural fields (A. McCay, personal communication, April 28, 2021). Figure 21 offers a simplified matrix of the value of different habitats, crossing types, and topographic conditions for the three target species. This type of information can be used as a broad basis for management decisions. Habitat stacking near populated areas, combined with managed permanent water sources, crossings, and fences, can reduce the risk of large animals coming into frequent contact with people.



	Solitary Males	Females / Family Groups		
Habitat				
Sal Forest	●●○	●○○	●○○	●●○
Mixed Hardwood Forest	●●○	●●○	●●○	●●○
Riverine Forest	●○○	●○○	●●●	●●●
Grassland	●●○	●●●	●○○	●●○
Floodplain Grassland	●●●	●●●	●●●	●●●
Wetland	○○○	○○○	●○○	●●●
Water	○○○	●○○	●●○	●●●
Open Scrub	○○○	○○○	○○○	○○○
Crossing Types				
Corrugated Metal Pipe Culvert	○○○	○○○	○○○	○○○
Concrete Box Culvert	●○○	●○○	○○○	●●○
Prefabricated Arch Underpass	●●○	●●○	○○○	●●●
Single Span Girder Bridge	●●●	●●●	○○○	●●●
River Bridge / Viaduct	●●●	●●●	●●●	●●●
Slope				
Gentle	●●●	●●●	●●●	●●●
Medium	●○○	●●○	○○○	●●○
Steep	○○○	○○○	○○○	●○○

Figure 21: Matrix of habitat types, crossing types, and slope conditions. The dots indicate the relative value of the feature to the species, with three blank dots being the lowest value and three black dots being the highest. Information from Thapa & Tuladhar, 2021; Asian Development Bank, 2019; Steinheim et al., 2005; de Negt et al., 2011; Smith, 1993; Sunquist, 2010; Wikramanayake et al., 2010; Thapa, 2005; Dinerstein, 2003; Von Houwald, 2015; Sukumar, 1992.

Bengal Tiger (*Panthera tigris tigris*)

Tigers are the mammal around which the Terai Arc Landscape conservation plan was designed (Thapa & Tuladhar, 2021; Dinerstein, 2003; Wikramanayake et al., 2010). Tigers generally have a low tolerance for one another, with breeding females defending home ranges of at least 15-20 km^2 up to 39 km^2 and males occupying much larger 30-105 km^2 territories that overlap with those of several breeding females (Larson, 2006; Sunquist, 2010). They are habitat generalists that will disperse across secondary habitat (Smith, 1993) but will not cross intensive agriculture, even at night (Dinerstein, 2003). Given the large area and opportunities for dispersal needed to sustain a healthy tiger population, it seems intuitive that they would serve as an effective umbrella species. Large mammal presence in the corridors restored for the Terai Arc Landscape conservation plan lends support to this assumption. Among the mammals that seem to have benefited from corridors restored for tigers are rhinos and elephants (Wikramanayake et al., 2010, pp. 171-172). The plan has benefited tigers as intended as well. The Khata Corridor has been particularly successful for tiger conservation, to the point that it may actually support resident tigers (Wikramanayake et al., 2010). At the same time, human-tiger conflict is a concern in this landscape. Tigers rely on large prey animals (Sunquist, 2010), which could lead them to kill cattle. They may also pose a direct danger to communities in the Terai. Although no human fatalities were linked to tigers in Bardiya National Park between 2010 and 2019, 10 occurred between August 2020 and April 2021 alone (Rauniyar, 2021).

Crossing Structure Design

Just as tigers were the focal point of the Terai Arc Landscape conservation plan, they are a sensible focus for the East-West rail alignment mitigation plan. Adapted drainage culverts under the railway can easily serve as underpasses. Expanding culverts to accommodate larger wildlife has the added benefit of increasing their capacity in the face of climate uncertainty. Tigers are purposeful in their movements and will follow specific routes between hunting areas within their home ranges, often using trails and infrastructure for easier and quieter passage (Sunquist, 2010, p. 22). So, care should be taken to preserve existing tiger trails with underpasses where they would not already be preserved with adapted drainage culverts. The minimum openness index value for tigers is about 2.0, meaning that a 20-meter-long underpass must be at least 10 meters wide and 4 meters high. Anything longer must be at least 15 meters wide and 4.5 meters high (Asian Development Bank, 2019, p. 40). Dry ledges, either in the form of stacked flat-topped rocks or shelves attached to the walls of the underpass give the option for an individual to cross above the water level. In any case, dry ledges must be sturdy enough to hold tigers. Females are, on average, 100-160 kg and 2.5 m long, while males are 190-260 kg and over 3 m long (Larson, 2006).

At crossing entrances, grass and shrub cover must be available. Tigers are ambush predators that rely on dense to moderate cover for hunting (Sunquist, 2010, p. 23) and are reluctant to cross open areas. Though it is not necessary (and, in fact, somewhat counterproductive) to provide suitable hunting habitat in and around crossings, it is necessary to provide enough cover to prevent feelings of exposure. One study in the Coyote Valley of North America found that cougars, large felids similar in behavior to tigers, were much less likely to use a crossing without cover vegetation at its entrances (Suraci & Wilmers, n.d.). Tall grasses from the alluvial grassland/moist deciduous forest mosaic that characterizes much of the Terai offer appropriate cover. Discouraging human and livestock use of tiger underpasses is important. Not only could use of the same structures increase the risk of human-tiger conflict, but also grazing could destroy tall grasses and shrubs, creating entrance habitat that is too open for tigers.

Even if crossings prevent fragmentation, tigers will not be able to sustain a breeding population without an abundance of large prey (Sunquist, 2010). Connectivity must be maintained for gaur (*Bos gaurus*), water buffalo (*Bubalus arnee*), wild boar, and deer as well. The minimum openness index value is the same for bovids and large ungulates as it is for tigers (Asian Development Bank, 2019, p. 40), so crossings sized for tigers are also capable of accommodating their prey. However, some of these animals may follow different trails than tigers or be more averse to crossing through drainages. Not only that, but the presence of tigers may also decrease prey animals' likelihood of using crossings, particularly more confined underpasses. Additional crossings intended for prey animal use may be necessary. Otherwise, tiger underpasses should provide dry ledges that are traversable by bovids and ungulates as well as striking a balance between cover for the tigers and open sightlines through the crossing for the prey.

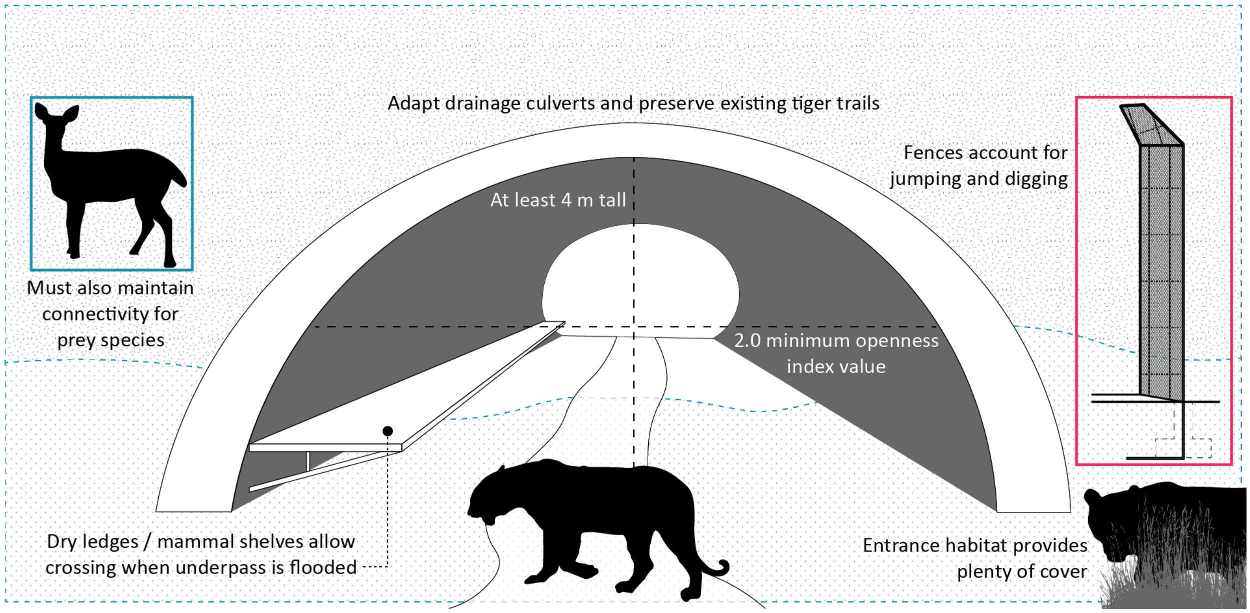


Figure 22: Adapting drainage culverts for use by tigers. Figure 23 shows more detailed tiger fencing standards. Information from Asian Development Bank, 2019; Sunquist, 2010; Suraci & Wilmers, n.d.; Bissonette & Adair, 2008; Carvalho et al., 2017.

Rail Alignment Scale

Tigers use both the Khata and Kamdi Corridors. However, according to our predicted occupancy results in the Wildlife Occupancy section, Khata is much more heavily utilized and should be the priority for crossing installations if resources are limited. Our species model covariates indicated that tigers are associated with areas that have a gentle slope and are near to villages. This presents a further opportunity to convert necessary drainage culverts into tiger underpasses. Yet it also presents a safety challenge by potentially funneling tigers through areas close to where people live and work.

Though tigers are associated with lower elevation alluvial grasslands and moist deciduous forests, they may also be found in upland climax sal forests (Sunquist, 2010; Wikramanayake et al., 2010). This indicates that, even though they may prefer flat lowland areas, they are capable of traversing steeper terrain. The railway could serve as a pathway between suitable habitats, carrying a heightened potential of tiger-train collisions. Fencing to control tiger movement must take their strength and ability to both jump and dig into account. According to the AZA Tiger Species Survival Plan, the strongest and least maintenance fencing material is metal bars. Welded 6-gauge wire mesh may also be appropriate, but not lightweight wire mesh. Figure 23 shows tiger fencing design standards. As already discussed, fencing the entire railway is not appropriate. Warning signals for train operators can be focused between mid-October and mid-February, as tigers use the Khata Corridor more in the winter than in the summer (Wikramanayake et al., 2010). Warning signals aimed at animals, as in Figure 19, are also an option. As with most mammals, tigers will see low wavelength blue light signals easily. A tiger's snarl could be a potentially effective audio signal to draw tigers away from the tracks. This sound effect could have the added benefit of scaring many prey species away from the tracks as well.

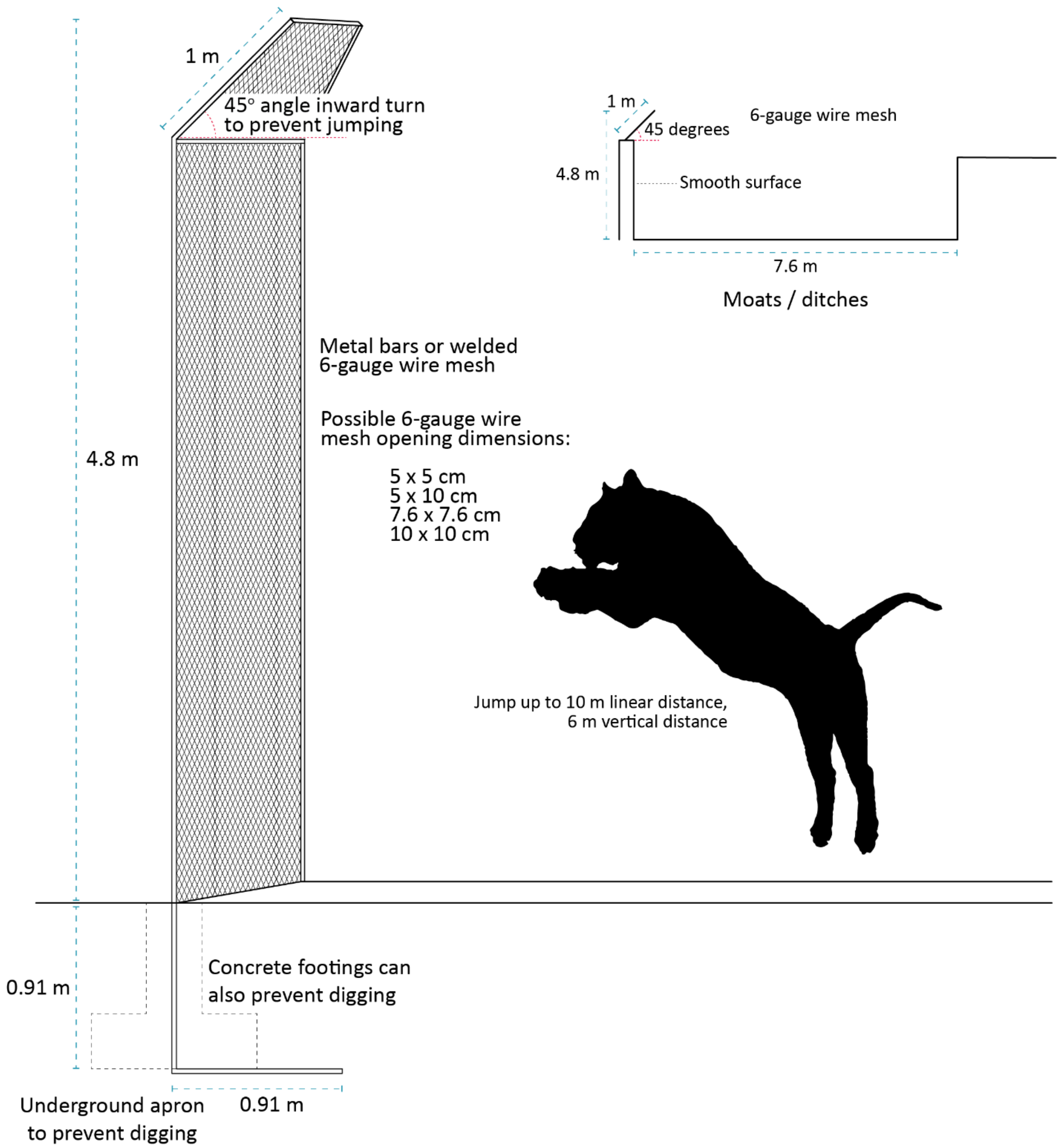


Figure 23: Design standards for tiger fences and ditches. Information from AZA Tiger Species Survival Plan (2016).

Regional Scale

Safety for communities in the Terai must be the regional priority. Fences, as shown in Figure 23, are one method to keep tigers separate from people. For habitat stacking, forests and grasslands with high ground vegetation cover, particularly tall grasses, can be used as core tiger habitat. Agriculture and open habitats with little to no tall ground vegetative cover can be used closer to villages. Tigers may come into closer quarters with people in the dry season, when water availability is low and more areas become accessible to both people and wildlife. Tiger monitoring and safety training can be organized around this time of year. Additionally, artificial water sources can be created in core tiger habitat to ensure that tigers have access to water even in the dry season, potentially reducing the likelihood that they will venture close to villages as they search for water. Tigers can swim in pools about 1 meter in depth with gently sloping sides (AZA Tiger Species Survival Plan, 2016), though smaller permanent sources of water may be enough to sustain tigers in the dry season.

Greater One-Horned Rhinoceros (*Rhinoceros unicornis*)

The Greater One-Horned Rhinoceros is unique in this landscape given the relatively small home ranges it inhabits in high quality habitat. In Chitwan National Park, these may be as small as 3 km^2 (Steinheim et al., 2005, p. 384). Perhaps due in part to their small range, Nepal has had considerable success in its conservation of this species, increasing its population from less than 100 individuals in the 1970s to around 600 in the 1990s (Thapa, 2005, p. 4). Populations recover quickly when protected from poaching and provided with suitable habitat. Individuals may move a linear distance of over 60 km in a year (Dinerstein, 2003, pp. 84-85, 98). This gives them a high movement potential and increases their chances of colonizing available suitable habitat. Yet they will not travel far if their resource needs are met in a small area (Thapa, 2005, p. 56), so the East-West rail alignment may impact them less in some areas than farther-ranging species. In fact, this species faces a much greater threat from poaching than from fragmentation and habitat degradation (Steinheim et al., 2005, p. 377). That said, safe passage across the railway is still important to maintain dispersal between populations and to provide avenues for rhinos to colonize available suitable habitat. This is especially important in regions where the habitat mosaic is less broadly suitable; though mean annual home ranges are about 4.3 km^2 for males and 3.5 km^2 for females in Chitwan, they are larger in less suitable Bardiya (Dinerstein, 2003, p. 111). Home range sizes relate to the fact that rhinos are highly specialized feeders that depend on specific habitats. To maintain and improve upon prior conservation success for this species as the railway is constructed, a focus on maintaining waterways and early successional riverine habitats is necessary.

Crossing Structure Design

Few studies or precedents exist for rhino crossing structures. As large ungulates, they likely have a minimum openness index value of about 2.0. As with tigers, this would require a 20-meter-long underpass to be at least 10 meters wide and 4 meters high. Anything longer would need to be at least 15 meters wide and 4.5 meters high (Asian Development Bank, 2019, p. 40). Material-wise, softer substrates like soil, sand or wood chips are more appropriate than abrasive brushed concrete, which can damage rhinos' feet (Von Houwald, 2015). Rhinos are known for rubbing their horns against flat surfaces, potentially causing damage to concrete walls not covered by wooden barrier material (Von Houwald, 2015, p. 23). This has implications for the maintenance of wildlife underpasses if rhinos are using them.

That said, rhinos have poor eyesight which could make them more suspicious of confined spaces. It is not clear whether they would be willing to use an underpass at all. Since overpasses are open to the air, they may be a more appealing crossing type for skittish species. However, the massive footprint that would be necessary in order to build an overpass over this raised railway would be expensive and destroy a large tract of existing habitat during construction. The best crossing option for rhinos in the Terai is likely to be bridges, particularly due to their habitat preferences. They are strong swimmers that live close to rivers (Dinerstein, 2003). They spend 85% of their time in the tallgrass floodplain, khair-sissoo forest, and riverine forest habitat types (Steinheim et al., 2005, p. 383), all of which are associated with rivers. The tallgrass floodplain is the most important habitat type of the three. Bridges will already be necessary wherever the railroad crosses a waterway. Extending these bridges far beyond the riverbanks so that they leave riparian habitats intact may be the most effective crossing strategy for rhinos. It also may benefit the other two target species, both of which spend time along rivers and associated ecologies as well.

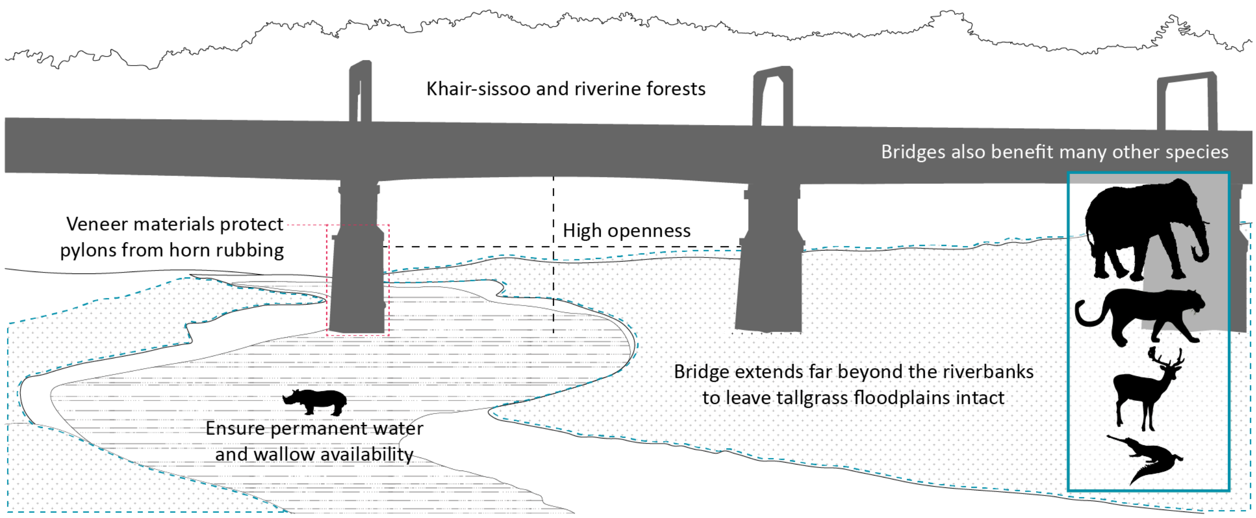


Figure 24: Extending the rail bridge across the Girwa River so that it leaves floodplain ecological communities intact helps to maintain connectivity for the greater one-horned rhinoceros. Information from Von Houwald, 2015; Dinerstein, 2003; Steinheim et al., 2005.

Rail Alignment Scale

Rhinos traverse the Khata Corridor, but not the Kamdi Corridor. As discussed, bridges over waterways are a reasonable focus for rhinos. The high significance of water in our step-selection covariates and the fact that our least cost paths are primarily associated with the Girwa River in Section 3 further strengthen the argument for wider bridges. For the benefit of rhinos as well as tigers, elephants, and a variety of other aquatic and riparian species, bridges should be designed to leave as much of the Girwa River system intact as possible. This includes its tributaries and associated forests and floodplain grasslands.

Rhinos may spend the majority of their time in lowland riverine ecologies, but they are capable of traversing steeper terrain. They inhabit otherwise unsuitable upland Sal forest during the monsoon season in order to escape flooding (Dinerstein, 2003). The rail embankment could provide a similar refuge from floodwaters, potentially leading to rhino-train collisions in this season. Additionally, home ranges expand and contract throughout the year, at their maximum in the hot dry season and minimum in the monsoon season (Dinerstein, 2003, p. 111). Rhinos spend more time browsing and foraging in the cool months and more time thermoregulating in the hot months (Thapa, 2005). What this means for the railway is unclear. Wallowing and staying in the shade are the main methods of thermoregulation, and the embankment would provide for neither. Yet searching for scarce food in the hot dry season could encourage rhinos to cross the rails. Conversely, browsing and foraging in the cool months could also encourage them to cross the rails in search of suitable habitats. More research is necessary before seasonal warnings are used for rhinos. However, rhinos are most active in the late afternoon and night time regardless of the season (Von Houwald, 2015), so overnight speed reductions, closures, and warnings could be effective measures.

Fences for rhinos must be strong. Solid walls, stacked stones, wooden panels, and steel fences 1.4 m tall or higher all may be used to control their movement, though flat walls are not recommended due to the tendency to rub horns on flat surfaces. Wood panels may be used to prevent damage to the fence itself, but will increase the level of necessary maintenance. Edges that provide traction should be avoided as they can be used by rhino calves to climb. Ditches are not recommended because the animals may fall in and get trapped or injured. Finally, electric fences are not a viable option. Apart from being expensive, maintenance-intensive, and potentially dangerous to both people and wildlife, they will not stop a rhino that is scared or excited (Von Houwald, 2015).

Regional Scale

As the rail verge aids in their dispersal, invasive species such as *Micania micrantha* can make habitat inaccessible to large mammals (Von Houwald, 2015) or outcompete important species that they eat. Invasive species removal may be necessary. Additionally, interactions between species must be monitored. One major reason that rhinos spend so much of their time in limited habitat types is their highly specialized diet. The tall grass *Saccharum spontaneum* is particularly vital (Thapa, 2005). This and other floodplain grasses make up the bulk of their diet. While elephants inhabit a wider variety of habitats and eat a more diverse diet consisting largely of browse, they also eat floodplain grasses – *Saccharum spontaneum* in particular (Steinheim et al., 2005). If *Saccharum spontaneum* is overexploited, elephants can shift their diets, but rhinos cannot. The rail embankment could potentially concentrate wildlife in the alluvial grasslands, leading to overexploitation of grasses. Additionally, habitat shifts caused by the rail embankment and climate change could affect grasses. Continued monitoring of rhinos, elephants, and riverine ecological communities will be necessary.

Though rhinos will raid rice, corn, wheat, and hot chili, they do not often wander farther than 1 km from the boundaries of protected areas to do so. They will, however, walk through flood plains near to human settlements or through agricultural fields at night on their way between habitat patches (Dinerstein, 2003, pp. 49, 98). Rhinos will feed on invasive weeds in open scrub (Dinerstein, 2003, p. 49). As livestock grazing can convert forests into open scrub, this could bring rhinos closer to settlements. Areas with up to about 20% forest cover are a suitable habitat mosaic for rhinos. Any more, and the area becomes unsuitable (Thapa, 2005, p. 53). With that in mind, strips of dense community forest around agriculture could lessen the likelihood that rhinos will enter settlements. Early successional, high-disturbance habitats near to water can form the suitable habitat core (Dinerstein, 2003, p. 15) of a rhino habitat stacking strategy. Similar to tigers, artificial sources of water may help to draw rhinos away from settlements and the railways. Particularly in the hot, humid monsoon season, they depend on wallows for thermoregulation (Thapa, 2005). The availability of wallows and oxbow lakes in Bardiya and its surroundings is low (Dinerstein, 2003, p. 133), so creating more artificial ones could have a major impact on rhino movement.

Indian Elephant (*Elephas maximus indicus*)

A greater body of research on the impacts of railroads on elephants as well as human-elephant coexistence exists than for the other two target species. Adult males are typically solitary, while females live in family groups consisting of a matriarch, her close female relatives, and their calves (Sukumar, 1992, p. 50). The speed and volume of trains may cause panic and confusion, which can result in groups being separated on either side of the track. Elephants are then killed as they return to the tracks to find family members or as matriarchs attack the train in an effort to protect the group (Joshi & Puri, 2019, p. 376). In northern West Bengal, India, adult males and calves are hit by trains more frequently than expected based on their representation in the population (Roy & Sukumar, 2017, p. 163). This may relate to the wider ranges and behavioral traits of adult males. Linear infrastructure poses a particular fragmentation threat to elephants given their large home ranges. At minimum, family groups can occupy home ranges of over 100 km^2 while solitary bulls can occupy home ranges between 170 km^2 and 320 km^2 (Sukumar, 1992, pp. 63-64). Based on the principles of island biogeography, Sukumar (1992) recommends a minimum reserve size of 4400 km^2 representing a diverse range of habitat types for Asian elephants in order to maintain a viable population (pp. 205-206). Coexistence can be a challenge in the Terai and may become more difficult after railway construction is completed. Human-elephant conflict arises when elephants raid crops or when people encounter elephants in the forest. Injuries and other negative experiences may even cause a particularly aggressive bull elephant to go “rogue,” a significant hazard for the people who live and work in and around forests (Sukumar, 1992, pp. 135-142).

Crossing Structure Design

Elephants require the largest crossing structures of any animal in this landscape. Bridges above riverine habitats could be used by elephants as well as rhinos, but since they are not as closely associated with rivers, they likely will not be enough on their own. Overpasses must be at least 5 meters wide and have a soil substrate, although bulls will use narrower ones (Sukumar, 1992, p. 207). Again, overpasses in this case may do more harm than good due to the massive footprint that would be necessary for their construction. In the Terai, they may be more feasible for lower-lying infrastructure like canals or ground-level roads. African elephants will use underpasses with an openness index of 2.25 – but this should be considered a minimum. The Asian Development Bank (2019) recommends that an underpass up to 20 meters long should be 12 meters wide and 5.5 meters tall, while longer underpasses should be 15 meters wide and 6.5 meters tall (pp. 38, 40). It is worth noting that some elephants can reach anything as far up as 7.3 meters (Association of Zoos and Aquariums, 2012, p. 2), so no exposed pipes, wires, or lighting fixtures should be present on the walls and ceilings of these underpasses in order to prevent elephants from pulling them down. As with rhinos, concrete may be abrasive to an elephant's feet, so sand or soil substrate should cover the crossing floor. Also, crossings should be clear of large debris and rip rap which might otherwise make them difficult for elephants to traverse.

Rail Alignment Scale

Adult female elephants pass information, such as migration routes, down through generations. As a result, movement patterns remain essentially unchanged for centuries (Sukumar, 1992, p. 66). It is particularly important to construct crossings wherever elephant trails would be obstructed by the rail embankment. As with tigers, elephants are found in both the Khata and Kamdi Corridors - but if resources are limited, then Khata is the more important corridor to focus on due to our elephant occupancy findings in our Wildlife Occupancy section. If existing elephant trails cannot be easily identified, our findings and those of other researchers suggest that forested areas with a gentle slope and water nearby should be preserved as potential habitat.

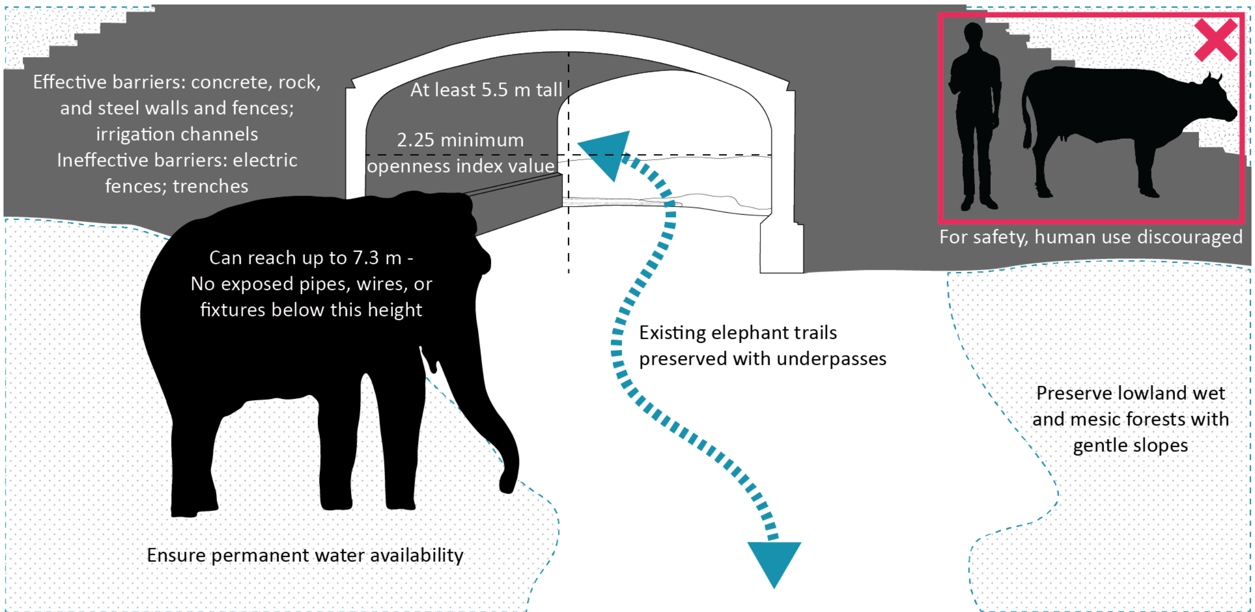


Figure 25: Standards for underpasses built to preserve existing elephant trails. Information from Sukumar, 1992; Asian Development Bank, 2019; Association of Zoos and Aquariums, 2012.

Elephants struggle to traverse steep terrain, but may still venture into upland forests, particularly if lowland ecologies become degraded. Additionally, deforestation and fences may encourage elephants to use the rail line as an uninterrupted corridor through the landscape (Chamling & Bera, 2020). Operators should expect to occasionally encounter elephants on the East-West railway tracks. Elephant activity peaks at night. Additionally, elephants struggle to approximate object distance at night and become disoriented by high beam lights (Joshi & Puri, 2019, pp. 373, 375). In northern West Bengal, train-elephant collisions peak at 10-11 PM and 1-2 AM (Roy & Sukumar, 2017, p. 164). Limiting traffic and slowing the trains that do run to 30-35 kph overnight (Joshi & Puri, 2019, p. 374), along with training and radio warnings of elephant movements near the tracks (Joshi & Puri, 2019; Roy & Sukumar, 2017), give operators a much greater chance of stopping a train before hitting an elephant. Joshi & Puri (2019) also stress that topography and vegetation can both play a role. The topography along the verges should be as flat as possible in order to avoid creating a trap where the rails are the only traversable terrain and elephants are not able to get out of the way of an approaching train. Additionally, forests should not be grown on the embankment, as this both decreases visibility for operators and increases the likelihood that elephants will venture onto the rails regularly. It may be enough to focus vegetation management on those areas that are already known as elephant trails, or at least where dense tracts of forest are bisected by the rails. This can also be paired with warning signage for operators and audio warnings for elephants using their own warning calls. As with other species in the Terai, movement varies with the seasons. Family groups conglomerate into much larger clans in the hot dry season (Sukumar, 1992) and may cross the rails in search of water or food. In northern West Bengal, collisions peak during the paddy and maize cultivation seasons as elephants cross the rails to raid crops (Roy & Sukumar, 2017, pp. 164-165). In the Terai, this may be particularly important to consider wherever the East-West alignment forms the border between forests and agriculture.

Elephant fences should be at least 2.4 meters tall and can consist of concrete, rock, horizontal steel rails, pipes, or cables (Association of Zoos and Aquariums, 2012, p. 5). Each of these options is expensive and should only be used sparingly. Necessary infrastructure such as irrigation canals can take the place of fences. According to Sukumar (1992), irrigation canals can be effective barriers to elephant movement, while dry trenches are not. This is due to the fact that bull elephants will dig through the soil and fill trenches with it (pp. 211-213). As with rhinos, electric fences are not recommended (Association of Zoos and Aquariums, 2012, p. 5) – at least not in the long term. They require proper design and frequent maintenance in order to remain effective, and have caused elephant mortality in some cases. Elephants can also learn the weaknesses of an electric fence and use their feet or tusks to break through it (Sukumar, 1992, p. 213).

Regional Scale

Elephants inhabit a wide variety of habitats, moving between grasslands and forests in search of grasses and browse throughout the year. Generally, though, they are a forest species, with flat lowland forests serving as prime habitat (Sukumar, 1992). Restoring habitat through community forestry has already helped to reestablish connectivity for elephants in the Terai (Thapa & Tuladhar, 2021). Crop raiding is common after dark and can result in dangerous encounters between people and elephants. For habitat stacking, forests form the suitable habitat core. Visibility in forests is low, which can lead to dangerous encounters between people and elephants. Human use of forested elephant trails and crossing structures should be discouraged. Open scrub and grasslands buffer forests from agriculture and the rail line. Elephants may still enter these habitats, but will at least be more visible. Unpalatable crops like Mentha and Chamomile (Thapa & Tuladhar, 2021, p. 52) can buffer more sensitive agriculture from elephant corridors. Livestock grazing degrades forests and short rotation slash and burn cultivation severely reduces forest cover, both of which reduce elephant habitat suitability and could encourage them to stray onto the rails or raid crops. Conversely, limited timber extraction and long rotation burning can slightly improve habitat quality (Sukumar, 1992). Water also influences elephant movement, particularly in the hot dry season. Even when a riverbed dries out, elephants still seek it out and dig for subsurface water. They are also attracted to artificial water sources like village ponds, reservoirs, and irrigation systems (Sukumar, 1992). Permanent artificial water sources can reduce the need for elephants to cross the rails or venture into villages (Joshi & Puri, 2019). Pools large enough for swimming must have rounded corners and a gentle slope no more than 30 degrees along the edges (Association of Zoos and Aquariums, 2012, pp. 8-9).

Conclusions and Recommendations

Nepal's responsibility to minimize harm to people necessitates careful attention to the railway's impacts, including the ways in which it will affect wildlife behavior. Our wildlife occupancy study shows high mammalian richness in the Khata and Kamdi corridors, suggests that many of the species of the Terai are associated with smooth, lowland terrain, and reveals that tigers and elephants are in fact crossing the expected railway alignment. In line with these results, our wildlife movement study suggests that rhinos depend on smooth, lowland terrain near to water and generates least-cost paths that cross the expected alignment near to the river. The tall, steep rail embankment could create a significant barrier for wildlife, or become a deadly ecological trap for those species that do try to cross it. With all of this in mind, maintaining wildlife connectivity and mitigating human-wildlife conflict in the Terai as the new East-West railway is constructed will require a system of various interconnected strategies along the alignment. In this system, crossings preserve existing wildlife trails and vital habitats: large, open drainage culverts with plenty of vegetative cover for tigers, bridges above floodplain habitat for rhinos, and elephant trail underpasses for elephants. Crossings have natural substrate, dry ledges, open sightlines, and similar conditions to the surrounding habitat. Limited fencing directs wildlife towards crossings and away from villages. Rail traffic is limited and slowed at night. Visual and audio warnings for both operators and wildlife aim to prevent collisions on the rails. Finally, habitat stacking maintains wildlife corridors while reducing the chance of direct encounters between wildlife and people. The final design of each of these interventions should be informed by the input of local communities in order to minimize harm and incorporate local knowledge, and free, prior, and informed consent should be obtained prior to construction. Additionally, continued monitoring during and after construction will determine the need for further mitigation efforts. In the meantime, the recommendations outlined in this report can inform the next steps in Nepal's successful conservation plan in the Terai Arc Landscape.

Limitations / Future Research Needs

Among the limitations of this project is the fact that the actual route of the railway is not publicly available. We know the alignment in a general sense, but do not have access to official construction plans. However, the important corridors identified in this study are relevant regardless of the official alignment. While the impacts of infrastructure and effectiveness of crossings have been well studied for elephants, less is known about tigers and rhinos. We combined wild animal habitat and behavior information, captive care information, and general information on crossings and similar species to make informed recommendations. Continued monitoring of each of the target species will be necessary, and further mitigation may be needed in the future. The railway will be up on a 7-15 m tall embankment which could exacerbate flooding, alter waterways, and generate polluted runoff. A hydrological study would help to fully understand these impacts. Finally, while tigers, rhinos, and elephants may act as umbrella species, much of the regional wildlife is not fully accounted for in this project. Flying and arboreal species may be hit by trains or become entangled in wires above the tracks. Reptiles, amphibians, and small mammals may require many more crossings spaced much closer together than those for large mammals. And without a hydrology study and subsequent mitigation, aquatic species could experience habitat degradation and fragmentation. Meeting the needs of these animals is also critical and should be the focus of further research.

Conclusions

To conclude, we discovered a diversity of IPLCs in Banke-Bardiya Complex who will be impacted by the electrified railway as construction continues west across Nepal. At least 139 villages within one kilometer of the railway could face potential health and safety impacts, and at least 16 villages will be fragmented. Village fragmentation can create issues in accessing community resources, devalue lands, and have health and safety impacts (FPIC & Rights Forum, 2020). Additionally, land will be lost due to pooling with potential for displacement. Displacement due to development can result in economic, cultural, and social losses (Neef & Singer, 2015), in addition to the loss of one's home and biocultural connections to land (McLean, 1999). We found there are already land compensation issues, too, where construction is occurring east of BB Complex in Chandrapur and Gujara municipalities. Through analyzing Indigenous rights to advocate for communities, we found that Nepal has committed to internationally recognized rights of Indigenous peoples through ILO 169 and UNDRIP, as well as through national rights implementations. We concluded that a rights advocacy approach can be used to mitigate further harm to people by the railway. Specifically, obtaining FPIC prior to construction in BB Complex and in the process establishing clear compensation and other expectations would prove worthwhile to achieving equitable sustainability and development goals.

We used camera trap data to model the occupancy of mammal species throughout the Banke-Bardiya Complex, focusing on the Khata and Kamdi Wildlife Corridors. We found that these corridors, particularly the Khata Corridor, support a high level of mammalian diversity. Tigers were found to occupy the Khata and Kamdi Corridors while elephants and rhinos were found to occupy the Khata Corridor. Additionally, our analysis of tiger and elephant individuals reveals these animals are using the Khata Corridor and crossing the planned railway alignment. Though we found occupancy was associated with various natural and anthropogenic factors, increasing occupancy closer to human settlements was an interesting result. This finding suggests that these corridors are potential hotspots for human-wildlife conflict, and mitigation mechanisms should be employed. Additionally, higher mammal occupancy in flatter slope areas suggests that terrain alterations from the railway could negatively impact wildlife in the area and prevent crossings. Overall, our results suggest that landscape design, crossing structures, and railway/train alterations are needed to minimize the impact of the railway on wildlife and facilitate safe crossings.

Using the wildlife movement data and modeling, we found that movement can change across different seasons. Understanding seasonal dynamics of vegetation around crossing areas will be important when choosing a wildlife crossing location. As for location, the rhinos and modeling showed the importance of prioritizing a crossing structure in a small forest patch along the Girwa River. The river was an important “highway” for rhinos and will be an important place to focus on allowing for wildlife movement. There is also an important forest patch running through the middle of the Khata Corridor, which is a second place that will be critical to add a wildlife crossing structure. Through identifying best paths for wildlife to take, it is possible to confirm important areas to prioritize placing a wildlife crossing structure within the Khata Corridor.

Although the new railway could fragment important corridors and amplify human-wildlife conflict, the literature provides a range of techniques and standards that can mitigate these effects. We outlined a conservation plan for the Terai at three scales: the crossing structure scale (where crossings and fences are designed), the rail alignment scale (where decisions on the placement of crossings, fences, and other deterrents and warnings are made), and the regional scale (where habitat and water management help to reduce encounters between people and wild animals). Wide underpasses with dry ledges, overnight speed reductions, and artificial water sources in the dry season are some of the important elements of this plan for mammals in general. For tigers, converting culverts into wider underpasses helps both to maintain connectivity and better prepare drainage infrastructure for climate change. Further crossings may be necessary to ensure that prey species are also successfully crossing the rail alignment. For rhinos, the rail bridge over the Girwa River should be expanded so that alluvial grasslands and riparian forests are left intact. For elephants, the trails already followed by family groups can be preserved with large underpasses. Following construction, further research will reveal the need to reassess this system. Until then, we have provided a framework to continue Nepal’s legacy of successful conservation work even as linear infrastructure develops in the Terai.

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Appendices

Appendix A: Villages in 1 km buffer zone of proposed railway

Village names in a 1 km buffer zone of the proposed railway in Banke-Bardiya Complex. At least 139 villages are within the buffer zone.

Laksmipur (Bhagaraiya)	Damauli	Kothiya	Patharbojhi
Akalgharwa	Daphaiya	Kothiyaghat	Pattharbojhi
Aurahawa	Devipur	Krisna Nagar	Phattepur
Badki Deuda	Dhanaura	Kuniyan	Piparhawa
Baida	Dhobinipur	Lalahi	Prempurwa
Baisa	Dhodpurwa	Madanapur	Ram Nagar
Baji Saduwa	Dhundirajpur	Madhuban	Ramanpur
Banbagiya	Dhundirajpur(Gidarpur)	Mahabalipur	Rameshwarpurwa
Bandalipur	Echgaun	Mahadeuli	Ranipur
Banjaridanda	Gabur	Mahendrapur	Rihar
Barbatta	Galarabans	Mahuwa (Manpur)	Saipurwa
Bardiya	Ghorpitta (Tinsimari)	Mataiya	Sano Khairahani
Bargadhi	Gularpurwa	Meraiya	Sanokhata
Barha Bardiya	Gurudayalpur	Motidanda	Shamsherganj
Basant	Guruwagaun	Motipur	Shangkarpur
Basanta	Haraiya	Murahiya	Siktirihar
Belaspur	Hasnapur	Muraiya	Simruwa
Bhagatpur	Hawaldarpur	Nangapur	Sinabans
Bhagawanpur	Husenapur	Naranpur	Sisawa
Bhagawatipur	Idaipur	Natanpurwa	Sorha Bigha
Bhagranpur	Jabdahawa	Nawalpur	Sukhrampurwa
Bhajanpurwa	Jagatiya	Nayanbasti	Sukumbasi Tol
Bhangaha	Jamunabojhi	Nehalpur	Tapara
Bhawaniyapur	Jangapur	Newarpur	Tara Nagar
Bhikharipur	Jhakkipur	Ostajpur	Tarkapur
Bhogpur	Jhanjhatpurwa	Pachkawa	Thanda
Bijay Nagar	Jhaptipur	Padnaha	Thapuwa
Bipatpur	Kajenipur	Pahadipur	Thapwa
Butaha	Kalabanjar	Pahadiyapur	Tharu Sanduwa
Chaudhariya	Khairahani	Pakhaipur	Tighra
Chhagaurepur	Khairi	Pandepur (Gholwa)	Tikulipur
Chhotki Deuda	Khajura	Paragpur	Titihiriya
Chikengaudi	Khalla Hariharpur	Parsenipur	Toraiya
Chitawan Tol-3	Khata	Parsharampur	Uttar Khairi
Dalai Jharan	Khuti	Parvatipur	

Appendix B: Species detection and presence data

Species names, body size, number of detections, and detection rate per 100 camera trap days for the 27 mammal species detected. Mammal species weighing under 0.5 kg were not included in this study. DD = Data Deficient, CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern

Common name	Scientific name	Body size	National Status (Amin et al., 2018)	Global Status (IUCN, 2021)	Detections	Detection rate (SD)
Crab-eating mongoose	*Herpestes urva*	Small	VU	LC	2	0.15 (1.36)
Himalayan crested porcupine	*Hystrix indica*	Small	DD	LC	19	1.46 (3.62)
Honey badger	*Mellivora capensis*	Small	EN	LC	1	0.08 (0.22)
Indian grey mongoose	*Herpestes edwardsi*	Small	LC	LC	4	0.31 (1.10)
Indian hare	*Lepus nigricollis*	Small	LC	LC	75	5.67 (18.42)
Jungle cat	*Felis chaus*	Small	LC	LC	12	0.54 (1.26)
Large Indian civet	*Viverra zibetha*	Small	NT	LC	2	0.15 (2.00)
Leopard cat	*Prionailurus bengalensis*	Small	VU	LC	18	1.23 (4.96)
Masked palm civet	*Paguma larvata*	Small	LC	LC	44	3.37 (3.91)
Rhesus macaque	*Macaca mulatta*	Small	LC	LC	31	2.30 (5.44)
Small Indian civet	*Viverricula indica*	Small	LC	LC	62	4.75 (6.79)
Smooth-coated otter	*Lutrogale perspicillata*	Small	EN	VU	1	0.08 (0.89)
Terai grey langur	*Semnopithecus hector*	Small	LC	NT	2	0.15 (0.46)
Yellow throated marten	*Martes flavigula*	Small	LC	LC	2	0.15 (1.88)
Barking deer	*Muntiacus muntjak*	Medium	VU	LC	54	4.14 (7.17)
Chital	*Axis axis*	Medium	VU	LC	178	13.64 (15.83)

Four-horned antelope	*Tetracerus quadricornis*	Medium	DD	VU	1	0.08 (1.00)
Golden jackal	*Canis aureus*	Medium	LC	LC	11	0.84 (4.77)
Hog deer	*Axis porcinus*	Medium	EN	EN	52	3.99 (4.35)
Leopard	*Panthera pardus*	Medium	VU	VU	16	1.07 (3.84)
Striped hyena	*Hyaena hyaena*	Medium	EN	NT	12	0.92 (4.93)
Asian elephant	*Elephas maximus*	Large	EN	EN	17	1.30 (1.88)
Greater one-horned rhinoceros	*Rhinoceros unicornis*	Large	EN	VU	12	0.92 (1.43)
Nilgai	*Boselaphus tragocamelus*	Large	VU	LC	11	0.84 (5.22)
Sambar	*Rusa unicolor*	Large	VU	VU	14	1.07 (1.59)
Tiger	*Panthera tigris*	Large	EN	EN	72	5.52 (5.48)
Wild boar	*Sus scrofa*	Large	LC	LC	73	5.60 (6.10)

Appendix C: Individual detection data

Tiger and Asian elephant individuals detected by camera traps in the Banke-Bardiya complex between March 28, 2015 and March 20, 2020. An individual was considered to have crossed the railway alignment if they were detected by at least one camera trap both north and south of the planned railway.

Individual ID	Species	Sex	No. Camera Traps that Detected the Individual	Crossed Railway Alignment?
TIG01	Tiger (*Panthera tigris*)	Male	3	Yes
TIG02	Tiger (*Panthera tigris*)	Female	1	No
TIG03	Tiger (*Panthera tigris*)	Unknown	1	No
TIG04[1]	Tiger (*Panthera tigris*)	Female	4	Yes
TIG05[1]	Tiger (*Panthera tigris*)	Male	1	No
TIG06	Tiger (*Panthera tigris*)	Male	6	Yes
TIG07	Tiger (*Panthera tigris*)	Male	2	Yes
TIG08[2]	Tiger (*Panthera tigris*)	Female	1	No
TIG09[2]	Tiger (*Panthera tigris*)	Male	1	No
TIG10	Tiger (*Panthera tigris*)	Male	1	No
TIG11	Tiger (*Panthera tigris*)	Unknown	1	No
TIG12	Tiger (*Panthera tigris*)	Unknown	1	No
ELE01	Asian elephant (*Elephas maximus*)	Male	1	No
ELE02	Asian elephant (*Elephas maximus*)	Male	1	No
ELE03	Asian elephant (*Elephas maximus*)	Male	1	No
ELE04	Asian elephant (*Elephas maximus*)	Male	1	No
ELE05	Asian elephant (*Elephas maximus*)	Female	1	No
ELE06	Asian elephant (*Elephas maximus*)	Male	1	No
ELE07	Asian elephant (*Elephas maximus*)	Male	2	Yes
ELE08	Asian elephant (*Elephas maximus*)	Unknown	1	No
ELE09	Asian elephant (*Elephas maximus*)	Male	1	No

[1] TIG04 (female) and TIG05 (male) were observed by the same camera trap within 5 minutes of each other, indicating the possibility they are a breeding pair.

[2] TIG08 (female) and TIG09 (male) were observed by the same camera trap within 5 minutes of each other, indicating the possibility they are a breeding pair.