Addressing ecological connectivity in the development of roads, railways and canals

Robert Ament, Anthony Clevenger, and Rodney van der Ree, Editors

IUCN WCPA Technical Report Series No. 5

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IUCN PROTECTED AREA DEFINITION, MANAGEMENT CATEGORIES AND GOVERNANCE TYPES

IUCN defines a protected area as:
A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

The definition is expanded by six management categories (one with a sub-division), summarized below.
Ia Strict nature reserve: Strictly protected for biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.
Ib Wilderness area: Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.
II National park: Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
III Natural monument or feature: Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
IV Habitat/species management area: Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.
V Protected landscape or seascape: Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI Protected areas with sustainable use of natural resources: Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

The category should be based around the primary management objective(s), which should apply to at least three-quarters of the protected area – the 75 per cent rule.

The management categories are applied with a typology of governance types – a description of who holds authority and responsibility for the protected area. IUCN defines four governance types.
Type A. Governance by government: Federal or national ministry/agency in charge; sub-national ministry or agency in charge (e.g. at regional, provincial, municipal level); government-delegated management (e.g. to NGO).
Type B. Shared governance: Trans-boundary governance (formal and informal arrangements between two or more countries); collaborative governance (through various ways in which diverse actors and institutions work together); joint governance (pluralist board or other multi-party governing body).
Type C. Private governance: Conserved areas established and run by individual landowners; non-profit organisations (e.g. NGOs, universities) and for-profit organisations (e.g. corporate landowners).
Type D. Governance by Indigenous peoples and local communities: Indigenous peoples' conserved areas and territories - established and run by Indigenous peoples; community conserved areas – established and run by local communities.

For more information on the IUCN definition, categories and governance types see Dudley (2008). *Guidelines for applying protected area management categories*, which can be downloaded at: www.iucn.org/pa_categories

For more on governance types, see Borrini-Feyerabend, et al., (2013). *Governance of Protected Areas: From understanding to action*, which can be downloaded at https://portals.iucn.org/library/node/29138

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International Union for Conservation of Nature (IUCN)

IUCN helps the world find pragmatic solutions to our most pressing environment and development challenges. IUCN works on biodiversity, climate change, energy, human livelihoods and greening the world economy by supporting scientific research, managing field projects all over the world, and bringing governments, non-governmental organisations, the United Nations and companies together to develop policy, laws and best practice. IUCN is the world's oldest and largest global environmental organisation, with more than 1,400 members from government and non-governmental organisations and more than 15,000 volunteer experts volunteer experts. IUCN's work is supported by around 950 staff in more than 50 countries and hundreds of partners in public, non-governmental organisations and private sectors around the world.

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IUCN World Commission on Protected Areas (WCPA)

IUCN's World Commission on Protected Areas (WCPA) is the world's premier network of protected and conserved areas expertise. The Commission has over 2,500 members spanning 140 countries who provide strategic advice to policymakers and work to strengthen capacity and investment for protected areas establishment and management. The Technical Reports series is one of the Commission's flagship products, providing timely guidance on aspects of protected area planning, management and assessment

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Opened for signature at the Earth Summit in Rio de Janeiro in 1992, and entered into force in December 1993, the Convention on Biological Diversity is an international treaty for the conservation of biodiversity, the sustainable use of the components of biodiversity and the equitable sharing of the benefits derived from the use of genetic resources. With 196 Parties so far, the Convention has near universal participation among countries.

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WCPA Connectivity Conservation Specialist Group (CCSG)

CCSG was established in 2016 under the IUCN World Commission on Protected Areas (WCPA) to support information sharing, active participation, global awareness, and action to maintain, enhance, and restore ecological connectivity conservation around the world. Its objective is to advance the science, policy, and practice at international, national, and subnational levels to meet the growing demand for solutions that advance the identification, recognition, and implementation of consistent connectivity conservation measures.

www.iucn.org/wcpa-connectivity
www.conservationcorridor.org/ccsg

Center for Large Landscape Conservation (CLLC)

CLLC develops solutions, implements projects and contributes to global efforts that connect and protect crucial habitat across terrestrial, marine and freshwater ecosystems. It provides expertise through four key focus areas: science, policy, mentorship and networking, and on-the-ground project implementation. By bringing knowledge and experience to bear on connectivity conservation issues worldwide, the Center works with communities, governments and other stakeholders to stop fragmentation and safeguard the legacy of protected and conserved areas by making them part of larger ecological networks for conservation.

www.largelandscapes.org

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Cover photo: Asian elephant (*Elephas maximus*) in Sabah, Malaysia © Gary Tabor

Back cover photo: A white-faced capuchin (*Cebus imitator*) crosses above Route 257 using a canopy bridge in Costa Rica. © Panthera

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Foreword

The planet is experiencing unprecedented levels of land conversion and habitat loss, often in the most biologically rich ecosystems. The process of degradation often begins with a single road that triggers a cascading array of associated development and impacts. We recognize the societal and economic benefits of infrastructure, but at the same time we must temper indiscriminate development with safeguards for biodiversity, vital ecological services, and Indigenous Peoples and local communities. There are few trade-offs with habitat loss and fragmentation. With every hectare lost, we lose opportunities to conserve biodiversity and improve human health and wellbeing.

It is often a challenge to understand the cumulative impacts of infrastructure on nature. This Technical Report explores linear transport infrastructure (LTI) – roads, railways and canals - and solutions to its profound impacts on ecological connectivity, biodiversity, crucial habitats, and protected and conserved areas. These impacts extend well beyond the visible, direct footprint of every LTI project. But creative solutions abound: for the elephant populations reconnected by an overpass on the flanks of Mount Kenya; for a tiger who traversed its habitat in and out of India's Pench National Park thanks to passages constructed on National Highway 7; and for a grizzly bear, granted passage over the TransCanada Highway and Canadian Pacific Rail, whose barrage of noise, lights and vibrations run through the heart of Banff National Park. As a global community, we have underestimated these impacts for too long. From the ecology to the engineering to the economics of infrastructure development, numerous disciplines must come together to craft solutions that balance the needs of people and nature.

For certain, LTI provides access to markets, transports people and their goods and services, and creates jobs. However, LTI can also sever human communities, fragment habitat, isolate wildlife populations, and disrupt fundamental ecological processes on which we all depend. So, while LTI is often portrayed as an investment in the future, that same future must also account for the twin challenges of our time: biodiversity loss and climate change. Smart LTI development means addressing today's needs so that future generations will be proud of the decisions we make. As this Technical Report makes clear, a proactive approach means avoiding the harmful impacts of development from the very beginning and not trying to devise 11th hour solutions.

As we maintain and grow our protected areas and implement other landscape-based conservation solutions, we seek to maximise their effectiveness over the long term. If we are to have well-connected protected area networks, we must think ahead about how proposed LTI is planned and constructed. We must also find opportunities to proactively retrofit existing LTI. As connectivity conservation is the countermeasure of fragmentation, this report stresses the need to avoid processes of fragmentation in the first place, and mitigate all adverse impacts using the best science available. Protected and conserved areas, ecological corridors, and other areas important for biodiversity are not the place for new roads, railways and canals. Rather, they can serve as a starting point for planning that sites, builds, and maintains infrastructure with appropriate safeguards to protect nature and benefit all people.

This is the first time that an IUCN publication systematically addresses the array of LTI impacts on protected and conserved areas and provides clear and practical solutions. We are proud of this effort and hope that you will use this Report as a 'road map' to success in your home landscapes.

Dr. Madhu Rao
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IUCN WCPA Connectivity Conservation Specialist Group

Executive summary & key messages

The unprecedented rate of linear transport infrastructure (LTI) development such as roads, railways and canals is a key driver of global biodiversity decline. Direct impacts have been documented around the world: primarily habitat degradation, fragmentation and loss, direct species mortality, and the creation of physical barriers and filters to wildlife movement and ecological flows. In addition, other impacts can occur, such as pollution due to noise, light, vibration and chemicals, air and water quality degradation, the spread of invasive alien species and changes in hydrology and microclimate. Protected areas and other effective area-based conservation measures (OECMs) (hereafter referred to as "conserved areas" and "protected and conserved areas (PCAs)) can face severe impacts to their ecosystems, species and habitats with the expansion within or nearby of linear transport infrastructure. As more intact areas with high environmental, biodiversity and ecological connectivity values become more accessible, an assortment of indirect problems can arise, including increased rates of hunting and poaching of wildlife; illegal mining, logging and other extractive industries; increased frequency and intensity of wildfires; land speculation and illegal settlement. Addressing these direct and indirect impacts will require much more attention, increased technical skills and a better trained workforce as the demand for LTI grows precipitously around the world, especially in developing countries of Africa, Asia and South America.

Ambitious economic and social development programs can generate large LTI investments to give communities better access to services, markets and resources. These projects either expand the size and volume of existing linear infrastructure or are constructed in previously undeveloped, intact landscapes, often of high conservation value. Without proper safeguards for biodiversity and ecological connectivity, given the present speed and scale of expansion, there lies a high potential to unravel the progress made over the past five decades to designate, design and manage PCAs embedded in ecological networks. Thus, the future will require planners and decision-makers to strike a balance between the anticipated socio-economic benefits of LTI with the challenges of safeguarding healthy ecosystems, ecological connectivity and biodiversity.

The purpose of this WCPA Technical Report *Addressing ecological connectivity in the development of roads, railways and canals* is to provide an overview of practical, feasible science-based strategies for PCA managers, transport practitioners, industry, conservationists and other interested stakeholders. It introduces and describes the numerous solutions that are available to support biodiversity and ecological connectivity conservation in, and adjacent to, PCAs. It promotes best practices and provides details for the various phases of infrastructure development: planning, design, construction, operations and monitoring. This is the first IUCN publication to examine this topic in this context, and is intended to increase awareness and inspire commitment, the allocation of resources, good governance and effective policies. Combined, these actions will contribute to more successful conservation, sustainable livelihoods and resilient landscapes. Overall, this report identifies effective solutions that can be used in a variety of contexts around the world to better address ecological connectivity when developing LTI in and adjacent to PCAs.

Key messages

- The direct and indirect impacts of LTI on ecological connectivity, biodiversity, crucial habitats and PCAs are increasing around the world. They need to be better accounted for and addressed with adequate, effective safeguards.
- It is important to have policies and plans that promote and adequately fund effective safeguards for biodiversity and ecological connectivity. This will help more projects achieve no net loss or net gains of biodiversity.
- Full, effective and genuine participation of local communities and Indigenous peoples is necessary and increases the potential for LTI projects to benefit all stakeholders.
- Investment mechanisms and decisions for funding projects require environmental and social due diligence throughout the process, in project identification, feasibility, assessment, design and implementation. These mechanisms will ensure that LTI projects achieve their social and environmental safeguard objectives.
- Incorporating climate risk and applying the mitigation hierarchy – avoid, minimise, mitigate/restore and offset/compensate - should always be applied in the proper order to achieve the best possible safeguards for biodiversity and ecological connectivity.
- The impacts to PCAs, their ecological connectivity and biodiversity should be considered at the beginning of the planning phase of LTI projects. Only when all avoidance and minimization options have been exhausted should appropriate mitigation and compensation measures be applied through careful planning, assessment and design.
- There are many practical and proven science-based mitigation strategies and techniques that effectively protect the ecological connectivity of PCAs and reduce the direct mortality of wildlife caused by roads, railways and canals.

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Acronyms

ADB	Asian Development Bank
AIIB	Asian Infrastructure Investment Bank
BACI	Before-After-Control-Impact
BBA	Baseline biodiversity assessment
BNG	Biodiversity net gain
BRI	Belt and Road Initiative
CBD	Convention on Biological Diversity
CCSG	Connectivity Conservation Specialist Group of WCPA
CDB	China Development Bank
CMS	Convention on Migratory Species of Wild Animals
EIA	Environmental impact assessment
EMP	Environmental management plan
ESF	Environmental and Social Framework
ESG	Environmental, social and governance
ESIA	Environmental and social impact assessment
ESS	Environmental and Social Standards
IUCN	International Union for Conservation of Nature
FPIC	Free, Prior and Informed Consent
G20	Group of Twenty
G7	Group of Seven
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
IFC	International Finance Corporation
IFI	International finance institution
LTI	Linear transport infrastructure
MDB	Multilateral development bank
NDB	New Development Bank
NGO	Nongovernmental organisation
NNL	No net loss
ODA	Official development assistance
OECM	Other effective area-based conservation measure
PA	Protected area
PCA	Protected and conserved area
PPP	Public-private partnership
PPPs	Plans, policies and programmes
SDGs	Sustainable Development Goals
SEA	Strategic environmental assessment
TWG	Transport Working Group of the CCSG of WCPA
UN	United Nations
UNEP	United Nations Environment Programme
WCPA	IUCN World Commission on Protected Areas
USAID	United States Agency for International Development

Glossary

Arboreal crossing structure: Wildlife crossing structure for arboreal species (e.g. glider pole, canopy rope ladder).

Avoidance: The first step of the mitigation hierarchy. Any action that prevents an impact from occurring, often involving the relocation of an activity or infrastructure away from important habitat.

Before-After-Control-Impact (BACI): A study design in which data are collected before and after an intervention (or impact) at sites with and without an intervention; the latter known as control sites.

Barrier effect: The extent to which roads or other linear features prevent animal movement. The barrier effect can be quantified by species, populations, etc. May also be termed the 'filter effect' when the barrier is partial.

Biodiversity: The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (CBD Article 2, 1992).

Compensation: Sometimes referred to as offsetting, the fifth step in the mitigation hierarchy. Involves replacing or substituting resources or environments that are typically outside of the footprint of an infrastructure project that cannot be avoided, minimised, mitigated or restored on site. Compensation usually involves payments as offsets, such as to fund and implement management plans for PCAs, support research that enhances biodiversity protection, or enhance enforcement activities and infrastructure.

Connectivity

- **Ecological connectivity**: The unimpeded movement of species and the flow of natural processes that sustain life on Earth (CMS, 2020a).

  There are various sub-definitions of *ecological connectivity* that are useful in the context of this Technical Report:

  - **Ecological connectivity for species (scientific-detailed definition):** The movement of populations, individuals, genes, gametes and propagules between populations, communities and ecosystems, as well as that of non-living material from one location to another.
  - **Functional connectivity for species:** A description of how well genes, gametes, propagules or individuals move through land, fresh water and seascapes (Rudnick et al., 2012; Weeks, 2017).
  - **Structural connectivity for species:** A measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances and other land, freshwater or seascape elements presumed to be important for organisms to move through their environment. Structural connectivity is used in efforts to restore or estimate functional connectivity where measures of it are lacking (Hilty et al., 2019).

Conservation: The protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term persistence.

Dispersal: The movement of individuals or seeds from one site to another breeding or growing site.

Ecological corridor: A clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity (Hilty et al., 2020).

Ecological network (for conservation): A system of core habitats (protected areas, OECMs and other intact natural areas), connected by ecological corridors, which is established, restored as needed and maintained to conserve biological diversity in systems that have been fragmented (Hilty et al., 2020).

Ecosystem: A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. It is the sum total of all the abiotic and biotic processes going on in an ecosystem that transfer energy and matter within and between ecosystems (e.g. biogeochemical cycles, primary production, etc.) (CBD Article 2, 1992).

- **Ecosystem functioning:** The collective life activities of plants, animals and microbes and the effects these activities – feeding, growing, moving, excreting waste, etc. – have on the physical and chemical conditions of the environment (Naeem et al., 1999).
- **Ecosystem services:** The benefits people obtain from ecosystems. These include provisioning services such as food and water production; regulating services such as flood and disease control; cultural services such as spiritual, recreational and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth (Millennium Ecosystem Assessment, 2005).
- **Ecosystem structure:** The biophysical architecture of an ecosystem; the composition and arrangement of all the living and non-living physical matter at a location (Russi et al., 2013).

Environmental impact assessment (EIA): The process of identifying, predicting, evaluating and mitigating the bio-physical, social and other relevant effects of development proposals prior to major decisions being taken and commitments made (IAIA, 2009).

Fragmentation: The breaking up of a habitat, ecosystem or land-use type into smaller and, often, more isolated parcels, thereby reducing the number of species that can be supported.

Free, Prior and Informed Consent (FPIC): A legal principle (UNDRIP, 2007), framework and process that should be applied to all development projects that may affect livelihoods, resources or lands of Indigenous, marginalized, local or rural communities.

Gene flow: The transfer of alleles or genes from one individual or population to another.

Habitat: The place or type of site where an organism or population naturally occurs (CBD Article 2, 1992).

Indigenous Peoples: Tribal peoples whose social, cultural and economic conditions distinguish them from other sections of the national community, and whose status is regulated wholly or partially by their own customs or traditions or by special laws or regulations. The term also includes peoples in independent countries who are regarded as indigenous on account of their descent from the populations that inhabited the country, or a geographical region to which the country belongs, at the time of conquest or colonisation or the establishment of present state boundaries and who, irrespective of their legal status, retain some or all of their own social, economic, cultural and political institutions (Borrini-Feyerabend et al., 2004; following IUCN's use of the International Labour Organization's ILO Convention 169 on Indigenous and Tribal Peoples). Preferred terminology varies around the world, and terms such as 'Aboriginal' or 'Traditional Peoples' are sometimes used instead.

Landscape: A heterogeneous space comprising a cluster of interacting ecosystems, geological features and ecological processes, and often including human influences. Landscapes are generally large but can be defined at a range of spatial scales.

Linear transport infrastructure (LTI): Roads, railways and canals, for the purpose of this publication. Other forms of LTI exist, including power transmission lines and pipelines.

Migration: The regular annual or seasonal movement of individual animals or populations of animals between distinct habitats, each of which is occupied during different parts of the year.

Migratory species: The entire population or any geographically separate part of the population of any species or lower taxon of wild animals, a significant proportion of whose members cyclically and predictably cross one or more national jurisdiction boundaries (CMS Article 1, 1979).

Minimisation: The second step of the mitigation hierarchy that occurs after all possible avoidance has occurred. Describes any actions to reduce the severity of the impact of an activity or development.

Mitigation: The third step of the mitigation hierarchy. Mitigation occurs after all possible avoidance and minimisation alternatives have been implemented. Mitigation measures are implemented to moderate, reduce or eliminate unavoidable impacts over time.

Mitigation hierarchy (also called effects management hierarchy): A simple framework that allows proponents to assess and address the impacts of infrastructure with an initial focus on avoidance, and if not possible, followed by minimisation, mitigation, restoration and finally, compensation (or offsetting) of residual impacts.

Monitoring: The collecting of information on indicators and/or targets repeatedly over time to evaluate trends in the status of conservation targets, often related to evaluating the effectiveness of management and/or governance activities.

Other effective area-based conservation measure (OECM): A geographically defined area other than a protected area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic and other locally relevant values are also conserved (IUCN WCPA, 2019).

Overpass: A wildlife crossing structure that facilitates movements of wildlife over/above LTI.

Population: All the organisms of the same species that live in a specific geographic area at the same time and have the capability of interbreeding.

Protected area: A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008; Stolton et al., 2013).

Restoration: The fourth step in the mitigation hierarchy. Restoration or rehabilitation occurs after all possible avoidance, minimisation and mitigation actions have been implemented. Restoration involves measures to repair and rehabilitate ecosystem structure such as reforestation, or ecosystem function such as functional ecological connectivity. Restoration is aimed at reversing habitat degradation and typically occurs at or nearby to the site of an infrastructure project.

Rightsholders, stakeholders: In the context of protected areas and conservation, the term 'rightsholders' refers to people (such as but not limited to landowners) socially endowed with legal or customary rights with respect to land, water and natural resources. By contrast, 'stakeholders' possess direct or indirect interests and concerns about these resources but do not necessarily enjoy a legally or socially recognised entitlement to them (Borrini-Feyerabend et al., 2013).

Safeguards: Policies, practices and other direct and indirect measures that aim to avoid or minimize environmental and social harm during the planning, design, construction and operation of LTI.

Strategic environmental assessment (SEA): The proactive assessment of numerous alternatives to proposed or existing plans, policies and programmes in the context of a broader vision, set of goals, or objectives to assess the likely outcomes of various means to select the best alternative(s) to reach desired ends (Noble, 2000).

Underpass: A wildlife crossing structure that facilitates the movements of wildlife under LTI.

Verge: Also referred to as 'right-of-way'. The area of land between the LTI and fence or other boundary demarcating the land reserved for the infrastructure. Verges can be cleared or continue to support natural vegetation and habitats.

Wildlife crossing structure: Any structure designed as purpose built or retrofitted to facilitate the safe movement of wildlife across LTI.

Wildlife-vehicle collision (WVC): The act of animals being hit by vehicles, trains or ships.

Part 1

Introduction: Linear transport infrastructure, protected and conserved areas and ecological connectivity

Deforestation and land grading in Malaysia. New roads increase logging and fragmentation of forests, and entire landscapes. © Adobe Stock

The unique role of linear transport infrastructure in balancing sustainable development and biodiversity conservation

The global decline of biodiversity has reached an unprecedented rate, and infrastructure development to support a growing human population is a key driver (Rockström et al., 2009; Butchart et al., 2010; EEA-FOEN, 2011; McCallum, 2015). The variety of impacts that LTI has on biodiversity and ecosystems are well-described and include habitat loss, wildlife-vehicle collisions (WVCs) which kill and injure wildlife and motorists, creation of physical barriers, noise and light disturbance, the spread of pollution and invasive alien species, and changes in hydrology and microclimate (Forman et al., 2003; Benítez-López et al., 2010; van der Ree et al., 2015a). The increasing scale of impacts is exemplified by the prevalence of roads now fragmenting Earth's terrestrial surface into more than 600,000 patches, the majority less than one square kilometre in area (Ibisch et al., 2016). Railways and canals have similar ecological impacts to roads, albeit at different spatial scales and intensities. Furthermore, while the number and extent of protected and conserved areas (PCAs) continues to increase around the world (UNEP-WCMC, 2021), ongoing urbanisation and intensification of land use, coupled with rapidly developing transport infrastructure, is jeopardizing ecological connectivity.

Linear infrastructure can be a barrier or filter to wildlife movement and ecological flows, as well as a threat to the integrity of PCAs when routes are constructed within or near their borders (Ament et al., 2008; Laurance et al., 2009; EEA, 2012). There are many direct impacts on ecological connectivity including fragmentation of intact habitats and PCAs (reducing structural connectivity), degradation, alteration and loss of habitat (reducing structural and functional connectivity), and species and process alteration (removing functional connectivity). Once areas become more accessible, indirect impacts include human encroachment and subsequent intensification of hunting, logging, land use, and permanent settlement in and around areas with high environmental and ecological connectivity values. As a result, there has been an increase in global attention to protect the various interconnections of nature, including plant and animal dispersal, wildlife migration, fluvial processes and the connectivity that is inherently present in large wild areas.

Importantly, this awareness has been increasingly incorporated into international policies in recent years, including:

- The Convention on Biological Diversity's 15th Conference of the Parties (CoP-15) adopting the Kunming-Montreal Global Biodiversity Framework' emphasizing the fundamental contribution of ecological connectivity to healthy ecosystems for achieving objectives as part of

An Asian elephant (*Elephas maximus*) walks along a road within Banke National Park in Nepal. © Pramod Neupane its strategic plan for the period 2022–2030, in particular under Goal A, Targets 1, 2, 3, and 12 (CBD, 2022).

- The UN Ocean Conference adopting the political declaration Our ocean, our future, our responsibility', including Objective 13 stressing use of "cooperative, ecologically representative, and well-connected" marine protected areas as essential for science-based ocean conservation (UNOC, 2022).

- The 15th Conference of the Parties to the UN Convention to Combat Desertification (UNCCD) adopting the Land, Life and Legacy Declaration' encouraging Parties take into account the "connectivity of ecosystems" to accelerate commitments to achieve land degradation neutrality by 2030 (UNCCD, 2022).

- The 5th session of the UN Environment Assembly in 2022 issuing its ministerial declaration reaffirming commitment to the UN Decade of Ecosystem Restoration and work towards halting the fragmentation of ecosystems, including by "promoting ecological connectivity" (UNEP, 2022a), and adopted a policy resolution on "Sustainable and Resilient Infrastructure" (UNEP, 2022e).

- The 2021 G7 Leaders' Summit (Canada, France, Germany, Italy, Japan, United Kingdom, United States) agreeing to the 2030 Nature Compact' advocating for "…improved quality, effectiveness and connectivity of protected areas and other effective area-based conservation measures (OECMs)…" (G7, 2021).

- The UN General Assembly in 2021 adopting Resolution 75/271 Nature knows no borders: transboundary cooperation – a key factor for biodiversity conservation' encouraging "…member States to maintain and enhance connectivity of habitats, including but not limited to those of protected species and those relevant for the provision of ecosystem services, including through increasing the establishment of transboundary protected areas, as appropriate, and ecological corridors based on the best available scientific data…" (UNGA, 2021).

- The UN Decade on Ecosystem Restoration Strategy' (2021–2030) identifying activities necessary for catalysing large-scale restoration, including "the importance of ecological connectivity in restoring ecosystem functioning and how to incorporate this concept into natural resource planning and management" (UNDER, 2021).

- The IUCN World Conservation Congress in 2020/2021 adopting Resolution 073 Ecological connectivity conservation in the post-2020 global biodiversity framework: from local to international levels' (IUCN, 2020a) emphasizing the importance of ecological networks and corridors to sustaining biodiversity and nature's contributions to people, and recommending that all IUCN Members work to conserve connectivity by:
  - Documenting it across ecosystems;
  - Informing policies, laws, and plans; and
  - Identifying key drivers and building synergies across institutions and borders to implement solutions.

- The 13th Conference of the Parties to the Convention on Migratory Species (CMS) adopting Resolution 12.26 (REV.COP13) Improving Ways of Addressing Connectivity in the Conservation of Migratory Species' including the first-ever definition by a multilateral environmental agreement of "ecological connectivity" as "the unimpeded movement of species and the flow of natural processes that sustain life on Earth" (CMS, 2020a).

These developments also build on a wide-ranging mandate to advance more sustainable infrastructure in international and regional policy, including:

- The Convention on Biological Diversity's 15th Conference of the Parties (CoP-15) adopting the Kunming-Montreal Global Biodiversity Framework' Target 14 for ensuring "the full integration of biodiversity and its multiple values into policies, regulations, planning and development processes, poverty eradication strategies, strategic environmental assessments, environmental impact assessments and, as appropriate, national accounting within and across all levels of government and across all sectors…" (CBD, 2022).

- The 1st IUCN Africa Protected Areas Congress adopting the Kigali Call to Action for People and Nature', including calling for "restoring fragmented and degraded ecosystems and avoiding or mitigating the impacts of climate change, new infrastructure and environmentally destructive activities, thereby maintaining ecological connectivity through networks of protected and conserved areas, including OECMs and transboundary areas" (APAC, 2022).

- The 3rd Asian Elephant Range States Meeting adopting the Kathmandu Declaration for Asian Elephant Conservation' (AsERS, 2022) containing two priority commitments to be achieved by 2025:
  - "Promote the maintenance and connectivity of large Asian Elephant conservation landscapes where new permitted developmental activities such as linear infrastructures are elephant- and biodiversity-appropriate"; and
  - "Promote the development of national guidelines on wildlife-friendly linear infrastructure, including elephant, based on those developed by the Asian Elephant Specialist Group of the IUCN SSC and Connectivity [Conservation] Specialist Group [of the IUCN WCPA] after Range States consultations".

- The 2nd Asia Parks Congress concluding the Kota Kinabalu Declaration' (APC, 2022) calling for:
  - "Maintaining and restoring fragmented ecosystems and avoiding or mitigating the impacts of new infrastructure and environmentally destructive activities";

  - "Establishing and restoring ecological connectivity through networks of protected and conserved areas"; and
  - "Securing natural habitat and improving connectivity of protected areas to maintain viable population of critically endangered species such as Asian rhinos".

- The Group of 20 (G20) setting forth an agenda to promote infrastructure that is "sustainable, resilient, modern, connected and inclusive" and developing national buy-in through virtual workshops in 2021 hosted by the G20 Infrastructure Working Group (G20, 2021).

- The IUCN World Conservation Congress in 2020/2021 adopting Resolution 071 Wildlife-friendly linear infrastructure' (IUCN, 2020b):
  - Recognizing preparation of this present publication;
  - Requesting multiple constituencies and stakeholders to increase collaboration "…for more effective new and existing linear infrastructure avoidance and mitigation, based on specific targets and indicators";
  - Outlining development and implementation of a suite of more advanced methods, tools, and measures toward providing all necessary protection for biodiversity; and
  - Inviting all relevant actors to work together in a diverse coalition to mainstream wildlife-friendly linear infrastructure in science, policy, and practice.

- The 13th Conference of the Parties to CMS further adopting Decisions 13.130 to 13.134 regarding Infrastructure Development and Migratory Species' directed respectively to Parties, the Scientific Council, the Secretariat, and other stakeholders, including a request to establish a "multi-stakeholder Working Group on linear infrastructure" (CMS, 2020b).

- The 13th Conference of the Parties to CMS adopting Resolution 11.24 (Rev.COP13) in 2020 on the Central Asian Mammals Initiative' recognizing the particularly detrimental impacts that linear infrastructure can have on migratory mammals, direct mortality, fragmentation of habitats, disruption of movement, and "…the urgent need to mitigate the direct and indirect impacts on migratory mammals, including the increased human habitation and associated poaching along infrastructure routes" (CMS, 2020c).

- The 14th Conference of the Parties to the CBD adopting Decision 14/3 in 2018 titled Mainstreaming of biodiversity in the energy and mining, infrastructure, manufacturing and processing sectors' providing a comprehensive listing of actions that can be taken across sectors to increase and improve the application of best practices and emphasizing a long-term strategic approach (CBD, 2018a).

Nine-banded armadillo (*Dasypus novemcinctus*) roadkill in Costa Rica. © Daniela Araya-Gamboa

- The United Nations and its Member States adopting in 2015 the 2030 Agenda for Sustainable Development' and its 17 Sustainable Development Goals (SDGs) – in particular, Goal 9 "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" and Goal 15 "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (UNDESA, 2021).

The importance of ecological connectivity to global environmental integrity

Identifying and prioritizing where to conserve ecological connectivity can reduce threats to biodiversity and increase opportunities for climate change adaptation (see for example Figure 1). However, even as PCAs and larger ecological networks are increasingly being recognised as critical for conserving biodiversity and providing ecosystem services, they are simultaneously being impacted by the increasing demand for transportation services. This growth is especially rapid in tropical and subtropical countries where infrastructure is often built through PCAs and unprotected wilderness because such lands are typically owned by governments and can avoid issues associated with private property such as eminent domain, just compensation and resettlement. Importantly, these impacts are in addition to those caused by the vast network of existing infrastructure within and near to areas of high conservation value.

The anticipated benefits of improved transportation include the improvement of trade routes and access to natural resources, including supporting mining, logging, and hydroelectric operations (Caro et al., 2014). Yet, for all the expected economic and social benefits, the environmental impacts are mounting. For example, in Brazil, if originally planned reconstruction of the BR-319 (Manaus-Porto Velho) Highway – from dirt passable in the dry season to a new paved road – were to commence, it is considered to be the "beginning of the end" of large, still intact areas of the Amazon Rainforest by linking the current "arc of deforestation" to central Amazonia (Fearnside & de Alencastro Graça, 2006). In another example in Africa's Congo Basin, the movements of forest elephants are increasingly restricted due to the

Figure 1: Jaguar (*Panthera onca*) populations and corridors mapped across its range. Populations and ecological corridors were prioritised according to ecological importance, network integrity, and vulnerability. © Panthera

construction of new roads to connect human settlements and facilitate extractive industries, such as logging and mining (Blake et al., 2008). Railways have similar barrier effects on wildlife, especially smaller species such as the Eastern box turtle in the USA (Kornilev et al., 2006). Large canals on the other hand are almost total barriers to the movement of all non-flying terrestrial vertebrates (Gregory et al., 2021).

The current challenges to the ecological connectivity of PCAs and remaining intact natural areas are predicted to escalate. The world's road systems are projected to increase by over 25 million lane-kilometres and its rail systems by 300,000 track-kilometres by mid-century with most of this burgeoning expansion slated for developing countries (Dulac, 2013). New canals continue to be built around the world, but global forecasts in growth are not available. While much attention is paid to the ecological consequences of China's Belt and Road Initiative (BRI) – one of the largest infrastructure and development plans in history (Hughes et al., 2020; Narain et al., 2020; Ng et al., 2020) – there are many other investments being made by governments and financial institutions around the world that may have similar impacts (Jones et al., 2019; Joniak-Lüthi et al., 2022). The cumulative impacts of an innumerable number of smaller projects, such as sealing unpaved roads or widening existing networks, must also be recognised as significant contributors. While many projects have the potential to contribute to economic and social development through increased access to markets and resources, there are also environmental and social costs that must be better accounted for, and balanced with, the development of LTI (Vilela et al., 2020).

Avoiding and limiting habitat fragmentation, especially due to the development of linear infrastructure, is a central component of conserving ecological connectivity and an increasingly important facet of PCA management. The overriding fact is that LTI can result in a direct loss of habitat, degradation of habitat quality and habitat fragmentation. It also can form a barrier to the movement of wildlife, impede ecological flows, reduce beneficial natural processes and ecosystem services and threaten human and wildlife safety through WVC on roads, wildlife strikes by trains, and drownings in canals.

Linear infrastructure that transports people, goods and services — here with a focus on roads, railways and canals — often poses an even greater risk to biodiversity than other forms of linear infrastructure such as power transmission lines, gas and oil pipelines, fences and trails (Laurance et al., 2015). The ecological impacts of other types of linear infrastructure, such as bird mortality due to collision with powerlines or barrier effects of certain types of fencing, can still be significant and should not be ignored. Nevertheless, transport networks (i.e.

Key information – Defining ecological connectivity

Ecological connectivity is defined as the unimpeded movement of species and the flow of natural processes that sustain life on Earth (CMS, 2020a). Conserving and restoring ecological connectivity depends on a strong foundation of formal protected and conserved areas working in conjunction with connectivity-specific measures, such as ecological corridors and ecological networks (Hilty et al., 2020). Connectivity conservation expands the traditional model of area-based conservation to recognise the important role of private lands, working lands and urban spaces in protecting biodiversity.

Achieving well-connected terrestrial, freshwater and marine ecosystems requires maintaining, enhancing and restoring processes by which genes, populations, nutrients and energy move among and between habitats and ecosystems. Connectivity is a key component of nature conservation and an essential strategy that allows species to adapt and be more resilient to the challenges posed by an expanding human population, unprecedented land-use change and a changing climate. Maximising ecological connectivity reduces human-caused fragmentation by linking land and seascapes, enabling species to move and ecosystems processes to flow. Key terms in this regard include:

Ecological connectivity: The unimpeded movement of species and the flow of natural processes that sustain life on Earth (CMS, 2020a).
Ecological corridor: A clearly defined geographical space that is governed and managed over the long term to conserve or restore effective ecological connectivity (Hilty et al., 2020). Ecological corridors can be continuous or patchy (i.e. stepping stones').
Ecological network (for conservation): A system of core habitats (protected areas, OECMs and other intact natural areas), connected by ecological corridors, which is established, restored as needed and maintained to conserve biological diversity in systems that have been fragmented (Hilty et al., 2020).
OECM (Other effective area-based conservation measure): A geographically defined area, other than a protected area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic and other locally relevant values are also conserved (IUCN WCPA, 2019).
Protected area: A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008; Stolton et al., 2013).

Forest clearing for construction of a toll road through rural land. The amount of land that needs to be cleared for infrastructure projects is often much wider than the roads, rails, or canals themselves. © Alex Traveler/ Adobe Stock

Machinery clearing a forest to make way for the Narayanghat-Butwal Road Project; a 113 km long upgrade of an existing two-lane road to a four-lane highway in Nepal. © Anthony P. Clevenger roads, railways and canals) can have significant additional impacts on natural systems and wild areas caused by increased human access, such as land clearing, human settlement, poaching, illegal mining and wildfires. In fact, many types of linear infrastructure are built together – for example, roads are typically required to support the construction and maintenance of railways, powerlines, pipelines and canals. All told, expanding LTI presents a major challenge to efforts working to maintain, enhance and restore effective ecological corridors that link larger ecological networks for conservation.

LTI enables people and resources to move more safely and efficiently across landscapes. As a consequence, it also increases access to areas that may have previously been inaccessible or difficult to access, especially PCAs, ecological corridors, and ecological networks. For example, studies of patterns of forest loss in frontier wilderness areas demonstrate a clear link between road development and the acceleration of wide-spread clearing (Southworth et al., 2011). For this reason, the first cut into an intact ecosystem is the most destructive and should be avoided as the highest priority safeguard (see for example Figure 3 of fishbone clearing in the Amazon, Chapter 2). Further, following road development, hunting of wildlife for local consumption and markets, along with poaching for illegal trade, often arise. For example, as habitats adjacent to roads in many parts of Asia, Africa and South America now frequently support lower species richness and abundance, habitats further from roads are increasingly encroached upon to harvest natural resources and wildlife (e.g. Laurance et al., 2006). Unfortunately, many developing countries lack the controls and regulations to prevent poaching and illegal logging, settlement and land clearing, and consequently, roads, railways and canals are often the harbinger of further ecological damage and ecosystem collapse. Recognising the likelihood and severity of indirect and flow-on effects is a critical part of planning, designing, constructing and operating new transport projects and avoiding these effects should always be the highest priority. And if they can't be avoided, decisions to build the infrastructure should be reconsidered.

A key global strategy for the conservation of biodiversity is to increase the extent, connectivity and integrity of PCAs and their associated lands and waters around the world (CBD, 2018b). As development pressures increase, many PCAs are facing greater threats from both within and outside their boundaries, including the wildlife that move in and out of them. One such factor is the development of LTI which can often put at risk much of the progress made over the last five decades to design and manage PCAs through ecosystem-based approaches and shift the emphasis from individual PCAs to protected area systems and ecological networks (Gross et al., 2016).

Building a community of transport ecologists and partners

The scientific community has issued repeated calls for improved policies and practices to reduce the impact of transport systems on nature (e.g. Laurance et al., 2014; van der Ree et al., 2015b; Ibisch et al., 2016; Laurance & Arrea, 2017; Ascensão et al., 2018). In response to this global concern, the IUCN World Commission on Protected Areas' (WCPA) Connectivity Conservation Specialist Group (CCSG) has established the Transport Working Group (TWG) (see Figure 2). Formed in 2016, the CCSG serves as the global hub for providing scientific, policy and technical advice that mainstreams connectivity conservation as a nature-based solution to enhance the integrity of PCAs, save biodiversity and increase resilience to climate change across terrestrial, freshwater and marine ecosystems. In turn, the TWG provides guidance to a wide diversity of audiences, including PCA managers and staff, government ministries and agencies, investors in linear infrastructure, connectivity conservation experts, land use and transportation planners, civil and construction engineers, communities, civil society organizations and businesses. Together, members of the Working Group seek to promote application of the mitigation hierarchy' through strategies that foremost avoid, and otherwise minimise, mitigate, restore and compensate (or offset) the impacts of linear transport systems on ecological connectivity. TWG objectives include:

- **Policy** – Informing legislative, administrative and regulatory efforts by providing examples of standards, laws, regulations, policies and other legal provisions for planning and implementing ecologically sensitive projects that meet community needs.
- **Science** – Identifying current and future research needs and increasing generation, compilation and dissemination of information including monitoring and analytical methods for assessment, identification and prioritization of mitigation locations and evaluation of measures taken.
- **Finance** – Collecting, evaluating and conveying understanding off financial tools that encourage design and implementation of best practices, including international funding institutions' safeguard mechanisms.
- **Culture** – Engaging and collaborating at international, regional, national and sub-national levels to achieve best practices sensitive to the needs and input of local communities and Indigenous peoples.
- **Practice** – Providing technical advice, design expertise and engineering techniques that support innovation, efficiency and effectiveness implementing the mitigation hierarchy.
- **Resilience** – Identifying strategies that promote ecological connectivity and address the need for infrastructure to be more resilient to natural disasters and the long-term effects of climate change.

Objectives of this Technical Report

As transport ecology is a rapidly growing science, the TWG has increasingly collaborated with global partners to provide improved guidance at various spatial and temporal scales for

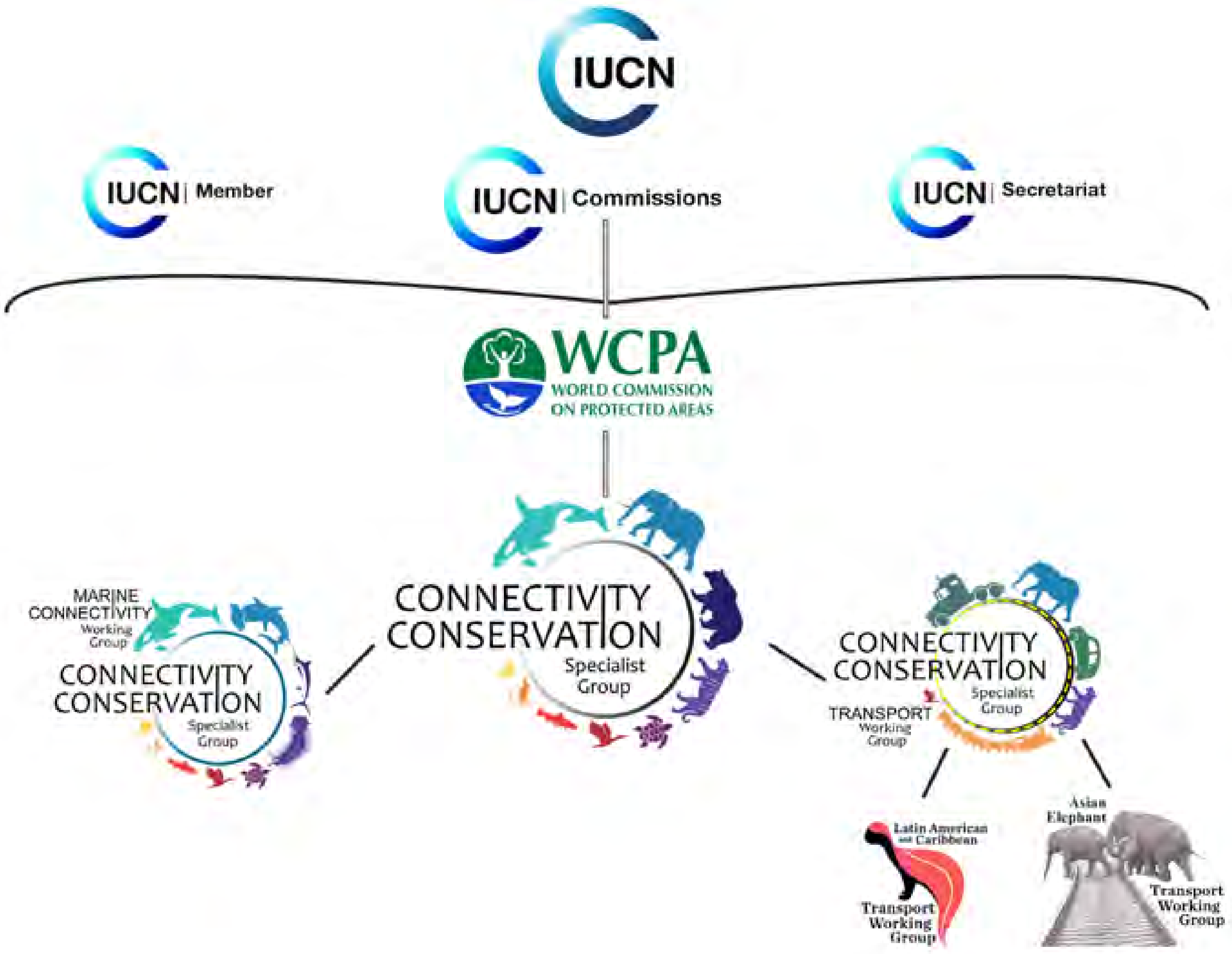


Figure 2: The Transport Working Group operates under the World Commission on Protected Areas – one of six IUCN expert commissions – and its Connectivity Conservation Specialist Group. © Kendra Hoff / CLLC

A site visit to a wildlife underpass in the Atlantic Forest of Argentina. © Diego Varela more ecologically permeable linear transport systems that are less lethal to wildlife. Building on publication of the IUCN *Guidelines for conserving connectivity through ecological networks and corridors* (Hilty et al., 2020), the objective of this Technical Report is to provide PCA managers, transport practitioners from government and private industry and other stakeholders with an overview of feasible, science-based and context-sensitive strategies that are practical and effective. Ultimately, these measures can be deployed in a variety of ways to limit the impacts of roads, railways and canals on biodiversity and achieve more effective avoidance, minimisation, mitigation, restoration and compensation (or offset) measures that maximize the ecological connectivity of PCAs, as well as reduce the direct mortality of wildlife caused by these transport systems. Each chapter includes at least one informative and illustrative box. Stories or examples in these boxes were chosen to represent diverse geographies, modes of transport, challenges and solutions. These contributions were collected from TWG members from around the world and are intended to highlight specific examples and practical applications of the concepts discussed in the text.

The publication is not intended to enumerate the many knowledge gaps that exist in the field nor develop a research agenda to address these shortfalls. The specific details of the numerous strategies and techniques to avoid, minimise, mitigate, restore and compensate (or offset) for the impacts of LTI on biodiversity, such as the size of a wildlife crossing structure (also often referred to as wildlife passages and wildlife overpasses and underpasses) for a certain species, is beyond the scope of this report. In addition, an in-depth treatment of the social impacts of infrastructure development is also beyond its scope. To learn more of impacts and their solutions that are not addressed here, readers are encouraged to consult the resources provided in Annex 2.

Chapter 2 of this report introduces the various direct and indirect impacts that roads, railways and canals can have on nature. These range from habitat loss to fragmentation, disruption of wildlife movement, and direct mortality. It also details the known similarities and differences between the impacts of such infrastructure and how ecosystems can be affected well beyond the direct areas of construction and operation.

To improve the ecological sustainability of LTI within and outside PCAs, Chapter 3 highlights the importance of having upstream policies and planning that reflect best-practices to balance environmental, social and economic benefits. This includes incorporating climate risk and applying the mitigation hierarchy to better safeguard PCAs and biodiversity. Further sections consider the environmental, social and cultural safeguard policies that are increasingly applied to manage risks of often large investments in infrastructure.

Chapter 4 emphasises the importance of more comprehensive understanding of ecosystems and development plans in and across countries, as well as

Pronghorn antelope (*Antilocapra americana*) killed by a collision with a train in the USA. © Kestrel Aerial Services

Key information – Objective of this publication

The objective of this Technical Report is to provide protected area managers, transport practitioners from government and private industry, and other stakeholders with an overview of feasible, science-based, and context-sensitive best practices. Ultimately, they can be deployed in a variety of ways to limit the impacts of roads, railways and canals on biodiversity and achieve more effective avoidance and mitigation measures that maximise the ecological connectivity of protected and conserved areas, as well as to reduce direct mortality of wildlife caused by these transport systems.

conducting formal environmental assessments for all projects to achieve no net loss or net gain of biodiversity. The role of strategic environmental assessments and project level environmental impact assessments is discussed, as well as the processes and practices that can better apply available scientific information to make decisions with the best possible environmental, social and financial outcomes.

Chapter 5 highlights the importance of public participation to avoid negative consequences often associated with LTI development. A number of existing international frameworks are discussed that emphasise full, effective and genuine participation of local communities and Indigenous peoples and are applicable to such projects to increase their potential to benefit all stakeholders. Additional sections detail the applicability of the legal principle of "Free, Prior and Informed Consent" including freedom to information, access to justice and engagement in environmental assessment processes.

The importance of investment decisions in achieving more sustainable outcomes is covered in Chapter 6. The various sources and mechanisms for funding LTI development are succinctly described, including the general types of public and private sector institutions that are active. Furthermore, the chapter covers specific lending policies of major institutions related to the environment and biodiversity and offers insights for improving related outcomes.

Chapter 7 covers the diversity of mitigation strategies that can be employed if project impacts are unavoidable when building new or upgrading existing LTI. Additionally, it emphasises the importance of defining mitigation objectives and discusses

Community members gather to celebrate one of the first wildlife overpasses in Asia, the 140m-long and 44m-wide Mandai Eco-Link@BKE ecological bridge in Singapore. Covered with native plant and tree species and incorporating specialised fencing, the overpass was designed for use by species such as Sunda pangolins (*Manis javanica*) and Palm civets (*Paradoxurus hermaphroditus*). © Rodney van der Ree

The highest railroad on Earth, the Qinghai-Tibet Railway transports visitors over China's Wubei Underpass. © Wenjing Xu

Tibetan antelope (*Pantholops hodgsonii*), an iconic species to the area, use the Wubei Underpass to migrate between wintering grounds in the Sanjiangyuan Nature Reserve and calving grounds in the Hoh-Xil Nature Reserve. © Nyanpo Yurtse / Environment Protection Association

these in relation to a diverse suite of species. A final section provides guidance on how best to determine the location of necessary mitigation measures.

Monitoring and evaluation is equally important for understanding the effectiveness of PCA management, as well as all mitigation, compensation or restoration measures that are implemented. Chapter 8 highlights why performance evaluation is so important, what can be assessed and approaches for designing and conducting effective studies.

Chapter 9 discusses best practices for the construction, operation and maintenance of LTI that can minimise environmental impacts of projects. A number of relatively simple measures are detailed that can limit negative effects from the first tree felled throughout the lifespan of a specific project.

Box 1

Salamander-friendly ramps and tunnels for safe passage in Waterton Lakes National Park, Alberta, Canada

Key lesson: Roads and curbsides can impede important annual migrations of slow-moving amphibians, but creative solutions are available to mitigate their blockage. This experience in Waterton Lakes National Park (Canada) is one of discovery, observation, community engagement, research and evaluation.

In 1991, a population of long-toed salamanders (*Ambystoma macrodactylum*) was first discovered in Waterton Lakes National Park when a park biologist observed that their migration to and from a nearby lake was interrupted by newly constructed curbs and sidewalks along a road. Salamanders had difficulty climbing the steep curbs, backing up large numbers along the road to be run over by vehicles.

Park biologists tested and monitored several alternatives to help reduce salamander road mortality. Ramps were an easy solution though salamanders still needed to cross the road surface. However, the amphibians had difficulty climbing some of the smoother curbs. Smooth curbs were replaced with new, gently sloped cement curbs, roughened' to provide toeholds for climbing salamanders. These were much more effective in keeping salamanders moving.

To preserve migrations, four tunnels were installed as wildlife underpasses for salamanders in 2008. Drift fences were used to direct salamanders toward tunnel entrances. Subsequent research showed that salamander road mortality decreased from 10% of the population to 2% following installation of tunnels and fences. In one season, researchers documented a total of 104 salamanders using tunnels, 23% of the immigrating population. Salamanders were 20 times more likely to use tunnels when traveling to the breeding site than when leaving the site and road-related mortality decreased from 10% of the population to <2%.

This case study is an example of how seemingly undetectable wildlife, and their critical annual migrations, can be interrupted by standard road features. Salamander-friendly curbs and tunnels are tools that have helped reduce mortality and provide safe passage.

Construction of a salamander-friendly underpass tunnel in Waterton Lakes National Park, Alberta, Canada. © Cyndi Smith, Parks Canada

Box 2

Stakeholder engagement to avoid railway impacts to Chitwan and Parsa National Parks, Nepal

Key lesson: Linear infrastructure projects can avoid critical landscapes through proactive planning, collaboration and coordination between project developers and conservation stakeholders.

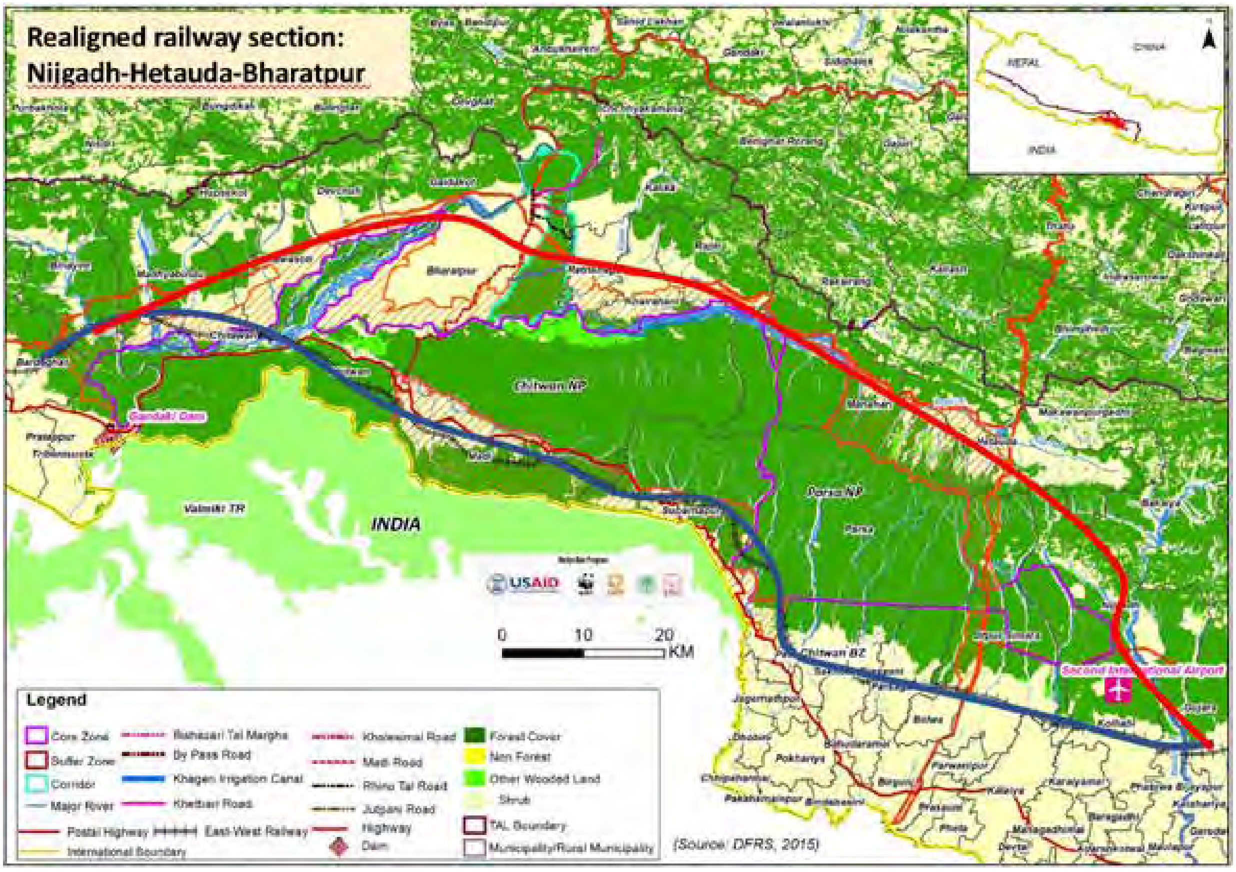
Nepal's Chitwan and Parsa National Parks are some of the most important protected areas in the Terai Arc Landscape, relatively unfragmented and rich in wildlife, especially tigers.

In 2010, this landscape, which includes a UNESCO World Heritage Site, came under threat. A feasibility study was conducted for a section of the proposed Asia East-West Electric railway alignment which would pass through southern portions of Chitwan and Parsa National Parks. This option would have had serious impacts on the ecological connectivity of the region. In total, two alignments were proposed; one through the parks (recommended) and one outside (alternate).

Nepal's national parks agency was against the recommended alignment and called for a re-assessment workshop. Alignment feasibility discussions were attended by many government and NGO stakeholders who ultimately agreed on the alternate alignment with the railway passing outside the national parks. While economics were not a primary factor in decision making, it was revealed after the fact that unit construction costs per km also were lower outside the protected areas and better served the local communities.

Several recommendations were made including wildlife crossing structures, tunnels, sound barriers and a lower design speed adjacent to the protected areas. As of 2023, an environmental impact assessment (EIA) is being prepared for this section. Of great concern is the railway alignment through the critically important Barandabhar corridor and proximity to Beeshazari Lake, a Ramsar site.

This case study is a successful example of the rarely used avoidance' part of the mitigation hierarchy. Meetings among stakeholders resulted in shifting the alignment outside the national parks and a success for conservation.



Proposed alignments of East-West Railway Section 4, Tamsariya to Simara. Recommended Alignment (red line) traverses the southern part and border of Chitwan and Parsa National Parks (dark green). The Alternate Alignment (blue line) follows the Mahendra Highway and was eventually adopted as the preferred alignment despite construction of several tunnels near Hetauda. © WWF-Nepal

In conclusion, Chapter 10 reiterates key messages and recommendations for the reader, along with an invitation to further advance this important field of science, policy and practice.

Key messages in this chapter

- **The ecological connectivity of the world's PCAs and other natural areas is being fragmented, and their effective management is at risk.**

- **LTI development, such as roads, railways and canals, is increasing around the world and more attention needs to be paid to reducing its negative impacts on biodiversity, PCAs, wildlife habitat and movement, and natural processes and ecosystem services.**

- **International organizations and conventions, such as IUCN, the United Nations Environment Program, Convention on Migratory Species, Convention on Biological Diversity, G7 and G20, are increasingly recognising the potential ecological impacts of transport infrastructure and the critical importance of planning, designing, building and managing such infrastructure using nature-based solutions.**

- **Collaborative networks of practitioners in government, NGO, academia, finance, and industry – such as the Transport Working Group – are needed to catalyse development and application of best practices.**

Part 2

The impacts of roads, railways and canals on wildlife, protected and conserved areas and ecological connectivity

African lions (*Panthera leo*) rest on the railway in Balule Nature Reserve, South Africa © Pete Eastwood / Hannah de Villiers

The construction and operation of roads, railways and canals have a range of diverse effects on wildlife, PCAs and natural areas in both intact and human-dominated landscapes (Dogherty et al., 1995; van der Ree et al., 2015a; Borda-de-Água et al. 2017). The impacts range from habitat loss and fragmentation to disruption of animal movement and increases in animal mortality. Described below are various types of impacts that these three modes of transport can cause to PCAs, associated habitats and the distribution of wildlife populations.

Habitat loss

The initial construction and subsequent widening and maintenance of LTI results in the loss of wildlife habitat by transforming the natural environment into pavement, dirt tracks, railway lines, canals and subsequent cleared rights-of-way. Low vagility wildlife, those found in relatively low densities, or others with low reproductive rates, tend to be the most sensitive to habitat loss. Other construction impacts include noise from blasting, machinery and pile-driving, night-lighting as well as off-site impacts such as quarries for gravel, sand and cement.

Roads, railways and canals and other infrastructure can have particularly deleterious effects, potentially opening a host of ongoing environmental problems (Laurance et al., 2015). Infrastructure plays a key role in opening otherwise intact forested regions to legal and illegal logging, hunting, mining and settlement (Figure 4; Laurance et al., 2014; Pedlowski et al., 2005). The impacts of infrastructure on wildlife and ecosystems are often exacerbated where laws or enforcement are limited. For example, there are nearly three kilometres of illegal roads for every kilometre of legal road in the Brazilian Amazon, and nearly 95% of all deforestation there occurs within 5.5 km of roads (Barber et al., 2014). Therefore, the proliferation of unplanned illegal roads and other infrastructure in remote and intact ecosystems is one of the most serious conservation problems in tropical countries today. In extreme cases, the construction of roads and railways may lead to the downgrading, downsizing or degazettement of the PCAs they pass through (Mascia & Pailler 2011; Qin et al., 2019).

Key information – Linear transport infrastructure: Opening Pandora's Box'

Road, railway and canal infrastructure expansion can have severe impacts on ecosystems and species, especially in and around protected and conserved areas. Some of these environmental problems include:

- The loss, fragmentation and degradation of habitat
- Increased rates of hunting and poaching of wildlife
- Illegal mining, logging and other extractive industries
- Pollution due to noise, light, vibrations and chemicals from vehicles and trains
- Increased frequency and intensity of wildfires
- Land speculation
- Illegal settlements

Figure 3: A typical pattern of fishbone' deforestation arrayed along the edges of expanding roads in the Amazon © Grégoire Dubois

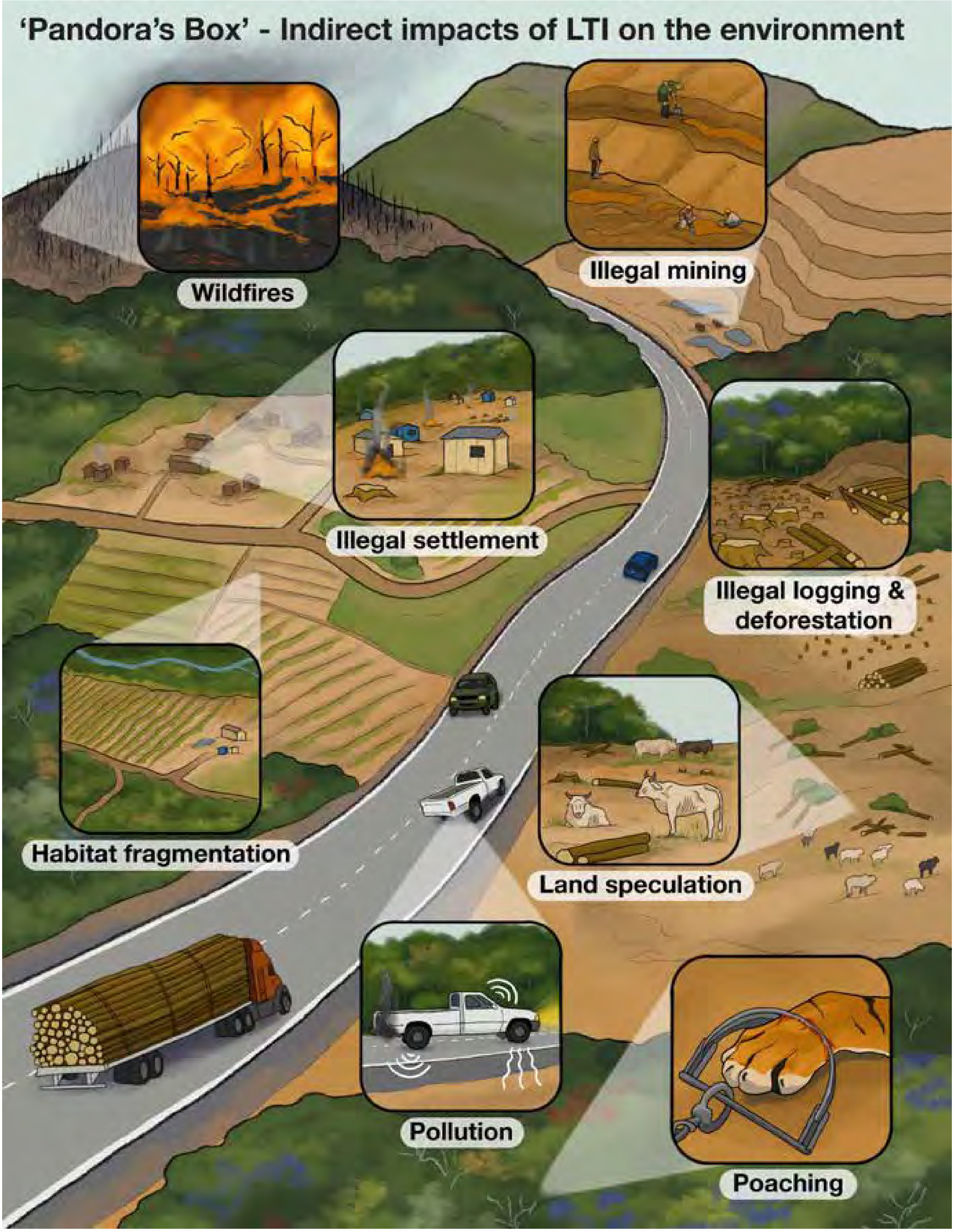


Figure 4: LTI often creates a Pandora's Box' effect on the landscape by providing easier access to natural resources, thus intensifying environmental exploitation and degradation. © Julie Johnson / Madison Mayfield, courtesy Center for Large Landscape Conservation

Two people hide behind excavation machinery as an Asian elephant (*Elephas maximus*) approaches on a recently cleared roadway in Sabah, Malaysia. © Gary Tabor

A serval (*Leptailurus serval*) crossing a road in South Africa. Species preferring cover or considered shy or elusive, such as many wild felines, can experience a barrier effect when approaching roads, rails or canals. Variations in noise, vibrations and vehicle movement can determine barrier effect severity. © Robert Ament

Habitat degradation

Habitat quality, which is especially important for the long-term management of PCAs, often declines near LTI. Roads creates edge effects, which are physical and biological changes associated with the often-abrupt edge of linear clearings, for example changing microclimates which can increase abundance of edge-dwelling wildlife or decrease abundance of interior species (Murcia, 1995). Railways have similar types of edge effects as roads, which typically increase the abundance of plant species that proliferate along edges, including facilitating the spread of invasive plant species. Canals are typically built and managed for water control and delivery, and their routes and edge effects can have varying impacts on habitat quality, as well as influencing availability of surface water and belowground reservoirs, depending on seasonal rainfall and management regimes.

Traffic noise, lighting and chemical pollution from vehicles and trains can decrease habitat quality by making areas unsuitable for the persistence of some organisms, such as the impact of pollution on native forest plants or by sensory disturbance that leads to behavioural avoidance by affected species (Benitez-Lopez et al., 2010; Parris, 2015; Blackwell, 2015). The ecological impacts of vehicle and train noise can extend for many hundreds of metres into adjacent habitats, and there is increasing recognition of its significance at influencing wildlife populations, especially birds and amphibians (e.g. Cooke et al., 2020). The severity of the impacts of noise is a function of the type, volume and speed of vehicular traffic and trains, as well as topography and the design of the road or railway (Ware et al., 2015). While the amount of artificial lighting is greatest in urban areas, even relatively small amounts of lighting in natural areas can have significant impacts on light-sensitive species of wildlife (Longcore & Rich 2004). Roads, railways and canals also impact the hydrological, geomorphological and chemical features of a landscape by altering the flow of water, chemicals and sediment across the landscape and increasing erosion and landslides. Impacts vary according to rainfall, soil stability and topography, and each physical change affects how floodplains function and the condition of aquatic systems.

Barrier and filter effects

Structural ecological connectivity is a measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances and other landscape elements important for organisms to move through their environment (Hilty et al., 2019). For wildlife populations to persist, they rely on functional connectivity, a description of how well genes, gametes, propagules or individuals actually move through the land (Rudnick et al., 2012). High levels of functional connectivity occur when the areas within and between important habitats are free of barriers, allowing wildlife to move through them to meet their biological needs. Reduced connectivity and limited movement due to LTI may result in higher wildlife mortality, lower fitness and reproduction rates, ultimately smaller populations, and overall lower population viability. These harmful effects have underscored the need to maintain, enhance and restore wildlife movements across LTI to sustain genetic interchange.

High-volume and high-speed roads and railways can be considerable barriers to animal movement and population interchange. Some studies have shown that even lesser, secondary highways and unpaved roads can impede animal movements by acting as complete barriers or partial filters. Even the smallest roads with low traffic volumes can be significant barriers and cause mortality to susceptible species, such as amphibians and reptiles. Generally, this barrier effect increases with road width, traffic volume and speed, as well as noise, vibration and habitat alteration (Figure 5).

Wildlife avoidance of gaps in habitat due to LTI is a primary cause of connectivity loss, and the avoidance of actual road surfaces can also play a role for some species (Ford & Fahrig, 2008; D'Amico et al., 2016). Canals can be significant barriers to animal movement, particularly if they do not swim or if there are swift currents or steep embankments. As a type of priority infrastructure in an increasingly water-thirsty world, canals deserve more attention with regards to their impacts on wildlife and ecological connectivity. The global extent of reduced movement of mammals in areas with a high human footprint has recently been documented, with reductions of one-half to one-third observed (Tucker et al. 2018). Roads, railways and navigable waterways are also significant contributors to the Human Footprint Index and are thus major drivers of changes in wildlife movements, population persistence and ecosystem processes.

Animal mortality

Mortality from collisions is the most visible and arguably the most significant impact of vehicles and trains on wildlife.

Figure 5: Factors influencing the severity of barrier effects on species and their free movement across LTI © Mary Collins / CLLC, adapted from Wildlife Institute of India

With increasing lack of forest canopy connectivity over LTI, arboreal species risk mortality when forced to cross on the ground. A white-faced capuchin (*Cebus imitator*) lies dead along Route 32 in Braulio Carrillo National Park, Costa Rica. © Daniela Araya-Gamboa / Panthera

Similarly, many species drown in canals when attempting to cross or accessing water for drinking. This has an immediate effect on populations and can have severe consequences for the long-term survival of wildlife that are rare, occur at low-densities or have low reproductive potential. Species that are active during the day or have peaks of activity at dawn and dusk, which corresponds to higher volumes of traffic, are typically more prone to collisions than nocturnal species. For example, day-active langurs are susceptible to road mortality in parts of Asia (Areendan & Pasha, 2000; Rajvanshi et al., 2001), and the highest rates of collision between Eastern Grey Kangaroos and trains in south-east Australia occur at dawn and dusk (Visintin et al., 2018). However, nocturnal species that hunt along roads, such as owls, can experience high rates of mortality, even though traffic volumes are relatively low. On railways, the rate at which a species moves and the propensity of some species to travel along railways also influences mortality and crossing success (Hels & Buchwald, 2001; Dorsey et al., 2015). In the case of canals, wildlife can become trapped if they enter the canal and are unable to climb out. Many species of wildlife drown while attempting to cross canals in a variety of landscapes, many of which go undetected (Rautenstrauch & Krausman 1989; Peris & Morales 2004; Albanesi et al., 2016). Wildlife mortality directly affects population size and the risk of extinction, but also contributes to the overall barrier effect and loss of genetic diversity (Jackson & Fahrig 2011; Ascensao et al., 2013).

Attraction and corridor effect

Roads, railways and canals can attract animals which benefit from the resources produced directly or indirectly in the linear corridors (Lambertucci et al., 2009). Carcasses from WVC, grain spillage on railway tracks (e.g. Gangadharan et al., 2017), pavement surfaces that are warmer than the adjacent habitat (e.g. Tanner & Perry 2007), and freshwater sources can attract a variety of wildlife. Attraction can also be a result of conditions related to adjacent habitat (nesting, living space) or food found in the cleared areas adjacent to linear infrastructure, often called verges. In some cases, verges support abundant populations of small mammals, insects and birds, as well as native plant species. Verges of roads, railways and canals can be important habitat and possibly the only remaining functional habitat for some species in highly developed and fragmented landscapes (e.g. Bennett & van der Ree, 2001). The verge habitat can also serve as travel corridors between patches of important habitat, facilitating dispersal and range extensions of some species. However, this attraction to the infrastructure can result in the creation of sink' habitats where the rate of

Juvenile bighorn sheep (*Ovis canadensis*) habituated to a road in the western USA. In winter months, salted roads attract animals seeking minerals but increases exposure to traffic strikes. © Adobe Stock

African wild dogs (*Lycaon pictus*) using a rail line as a movement corridor in the Balule Nature Reserve, South Africa © Hannah de Villiers

A community of western chimpanzees (*Pan troglodytes verus*) crossing a road in Bossou, Guinea. The negative impacts of major roads on chimpanzee populations across West Africa can extend for more than 17 km on both sides. © Dr Kimberley Hockings

mortality from WVC exceeds the benefits provided by the verge habitat, resulting in an overall decline in the population (Mumme et al., 2020).

Impacts extend beyond the infrastructure corridor

The spatial extent and severity of many of the ecological impacts of LTI is, among others, influenced by the size of the road, rail or canal, density of the network, the type, volume and speed of the vehicles, type of road surface, and other design features (Jaeger et al., 2005). These impacts extend well beyond the footprint, in some cases thousands of metres away (Benitez-Lopez et al., 2010), and form an effect zone' (Forman & Alexander, 1998; see also Figures 6, 7, 8). This concept has been applied to railways (e.g. Lucas et al., 2017) and could similarly be applied to canals. The road effect zone has been quantified for many species, including African forest elephants (Barnes et al., 1991), impala (Mtui, 2014), frogs (Eigenbrod et al., 2009) and insectivorous bats (Bhardwaj et al., 2021), and all exhibited lower densities or activity levels near roads. In China, the road effect zone for Siberian weasels extended 50 metres beyond the edge of the road (Kong et al., 2013). In the same study, the effect on 17 bird species was variable, with the largest road effect zone extending greater than 150 metres from the road. In India's Bandipur National Park, research indicates that each kilometre of road impacts at least 10 hectares of adjacent habitat (Raman, 2011). In Swedish Natura 2000 areas – the network of PCAs that is a cornerstone for biodiversity conservation within the European Union – substantial habitat degradation and reduced wildlife densities are found within one kilometre of roads and railways (Helldin, 2019). Recent work has shown that these effect zones can be extremely large – up to 17.2 km for the critically endangered Western Chimpanzee (Andrasi et al., 2021) – and that these effects must be better accounted for in impact assessments of projects.

Differences in impacts among roads, railways and canals

Less is known about the impacts of railways on PCAs, wildlife and their habitats than roads, and canals even less so. Nonetheless, there is clear overlap in many of the impacts and procedures applied to the management of roads that are frequently applied to railways and can also be applied to canals. Different mitigation approaches may be used where the two differ (Borda-de-Água et al., 2017; St Clair et al., 2017). While the types of impacts of railways are broadly similar to roads (e.g. habitat loss, habitat degradation, barrier and filter effects, wildlife mortality, sensory disturbance, hydrological modification, chemical pollution), they are generally considered less severe.

However, there is increasing evidence that some impacts of railways and trains can exceed those on roads. For example, many high-speed railway corridors may be continuously fenced for tens or even hundreds of kilometres, creating an impermeable barrier for many species. In these situations, wildlife crossing structures should be installed (see Chapter 7). In Sweden, the number of reported ungulate deaths per kilometre of generally unfenced railway exceeds that of highways, many of which are fenced (Seiler & Olsson, 2017). Railways cause similar edge effects as roads, which typically increase the abundance, diversity, and growth rates

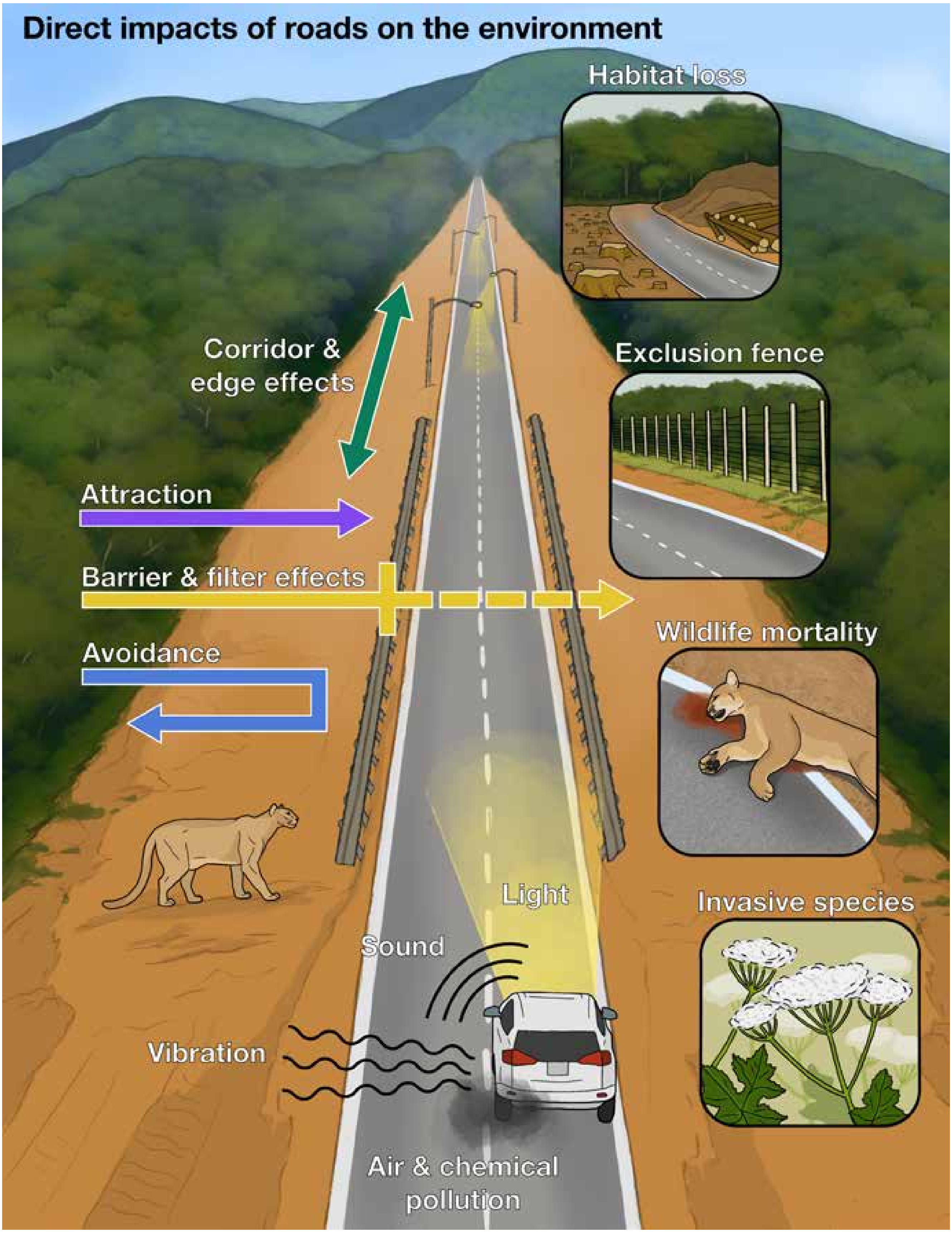


Figure 6: Impacts of roads on the environment © Julie Johnson / Madison Mayfield, courtesy Center for Large Landscape Conservation

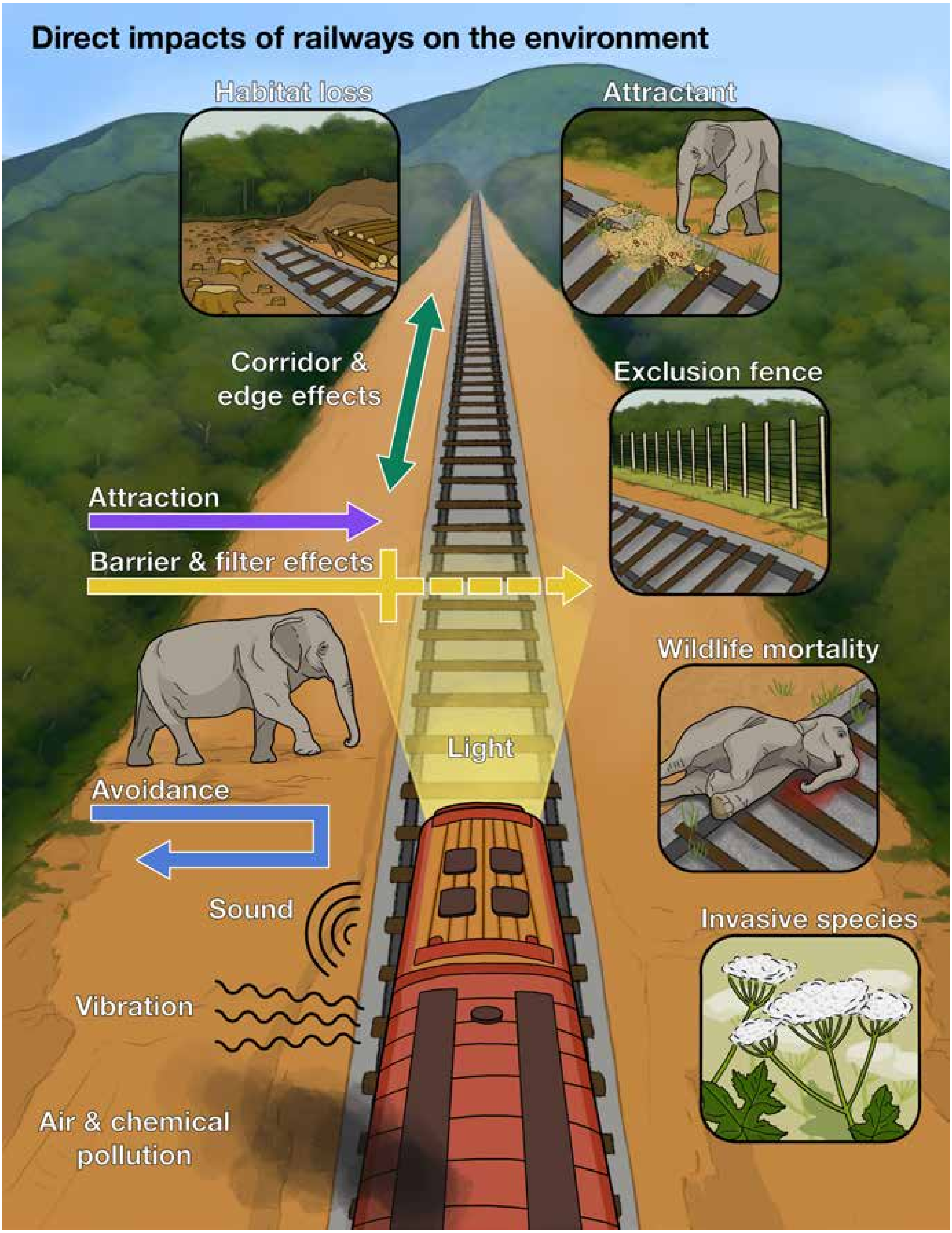


Figure 7: Impacts of rails on the environment © Julie Johnson / Madison Mayfield, courtesy Center for Large Landscape Conservation

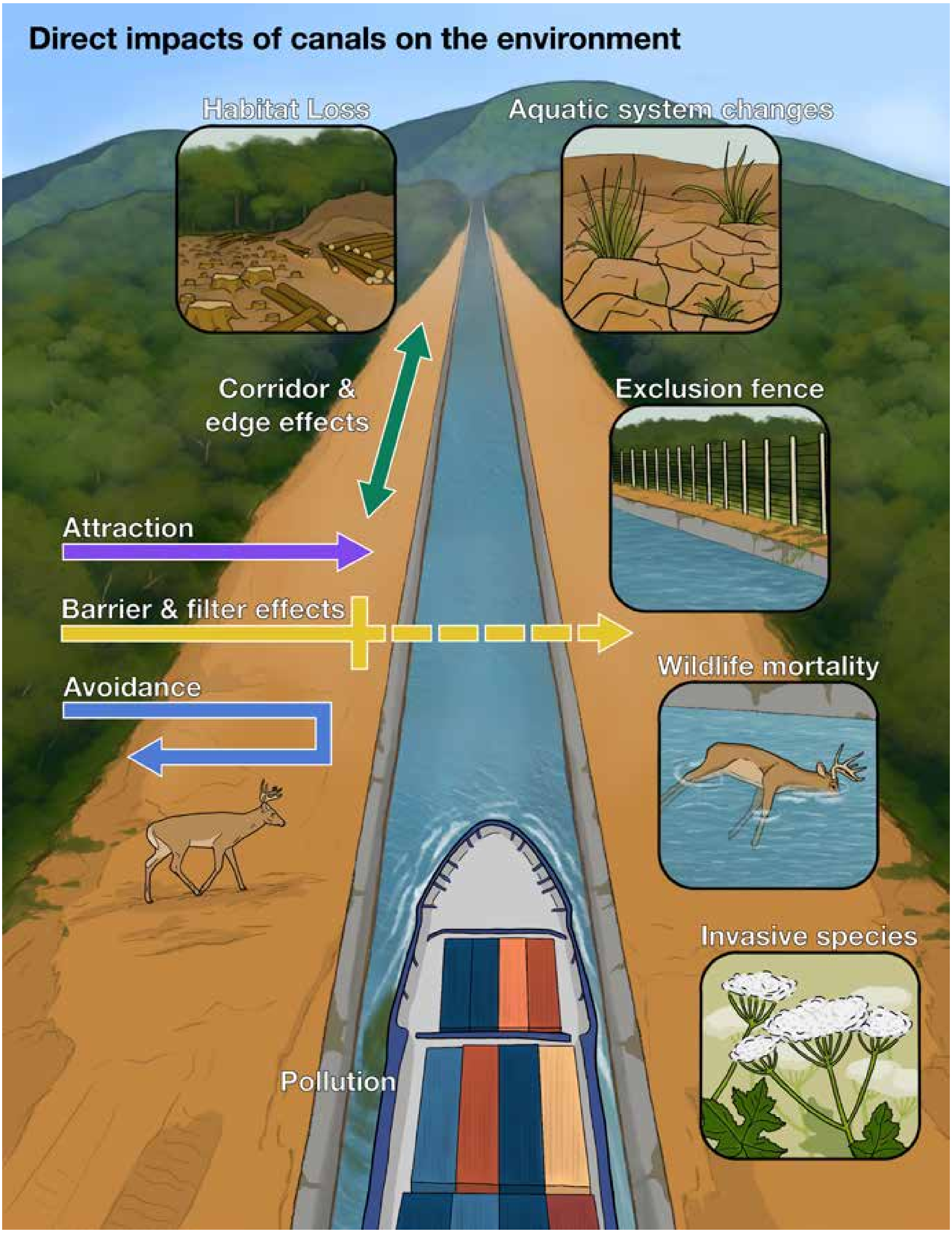


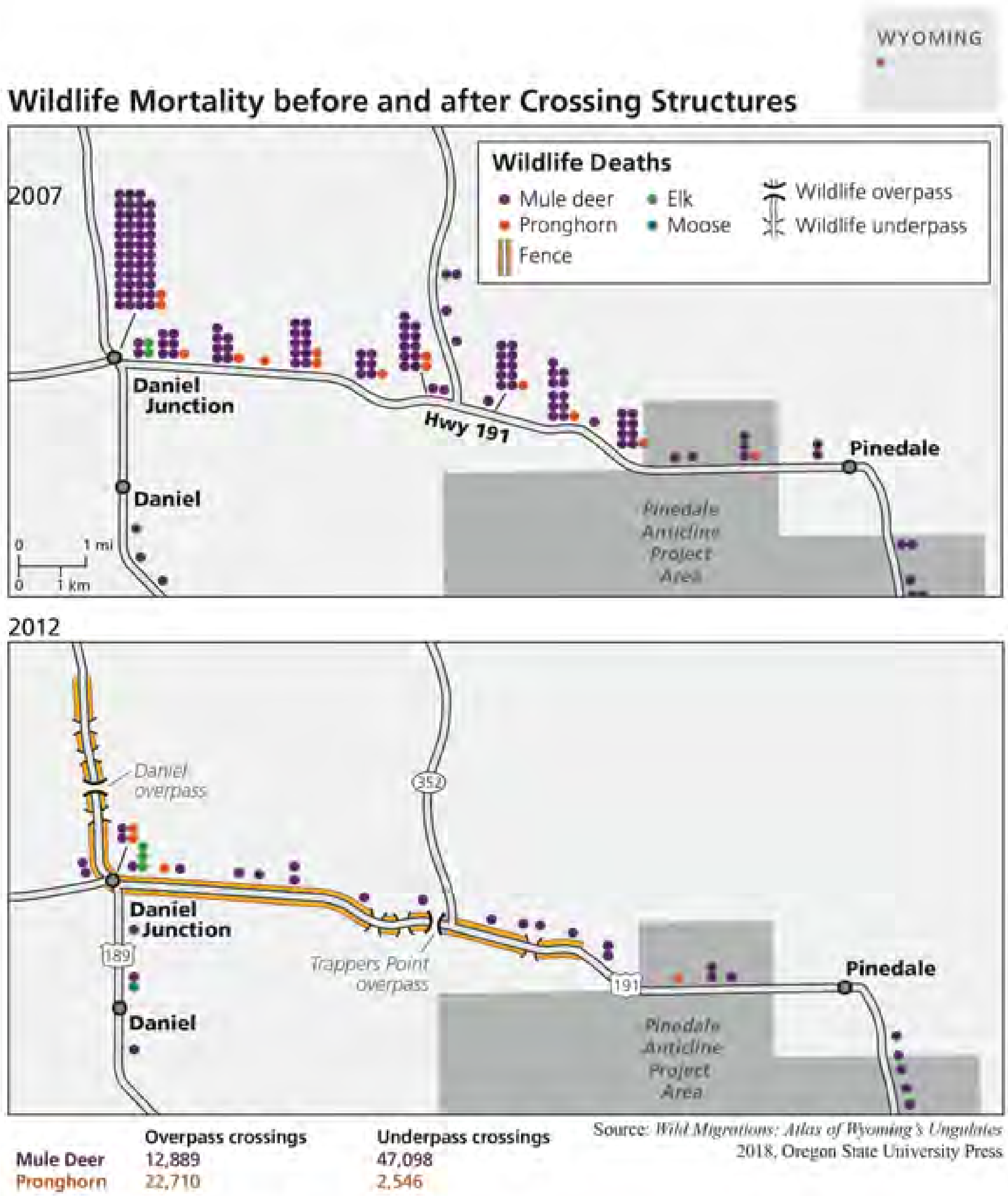
Figure 8: Impacts of canals on the environment © Julie Johnson / Madison Mayfield, courtesy Center for Large Landscape Conservation

Box 3

Addressing wildlife-vehicle collisions with mule deer and pronghorn on Highway 191, Wyoming, USA

Key lesson: The influence of roads on migratory movements can be mitigated with species- and context-dependent measures.

The installation of wildlife crossing structures can reduce WVC and maintain ecological connectivity. In many projects, wildlife underpasses are the most common type of crossing structure due to their relatively low construction cost compared to overpasses, and their greater flexibility in varied topography. However, species-specific use must be considered to ensure that they are effective and maximally beneficial.



A map of five-year reduction in animal deaths, represented by dots, in the area near Trappers Point, Wyoming, after over- and underpasses were installed along US Highway 191. Reproduced with permission from *Wild Migrations: Atlas of Wyoming's Ungulates,* Oregon State University Press

Box 3 (continued)

US Highway 191 is located in western Wyoming, USA. The two-lane highway bisects important summer and winter habitat for migratory mule deer (*Odocoileus virginianus*) and pronghorn (*Antilocarpa americana*). To better protect key migratory paths along this increasingly popular tourist route to Grand Teton and Yellowstone National Parks, the Wyoming Department of Transportation installed six underpasses and two overpasses. Prior to installation, WVCs with all species averaged about 85 per year. After the first three years, WVCs were reduced by 81% and total average road-killed to 16 per year. Post-construction monitoring revealed that 93% of observed pronghorn crossings utilized the overpasses compared to underpasses, highlighting the importance of overpasses for this species and the need for species-specific design planning Sawyer et al., 2016). While overpasses can carry a significantly higher construction cost, the reduction of WVCs and cost savings associated with accidents (property damage, human injury or fatality) made a strong case for these safe passage investments by road agencies.

Reference

Sawyer, H., Rodgers, P.A., and Hart, T. (2016). Pronghorn and mule deer use of underpasses and overpasses along U.S. Highway 191. *Wildlife Society Bulletin* 40(2):211–216. https://doi.org/10.1002/wsb.650.

Mule deer (*Odocoileus hemionus*) buck on the edge of a road © Adobe Stock

of adjacent vegetation (St Clair et al., 2019) and the spread of invasive plant species. Like roads, train collisions with wildlife produce carcasses that can attract and increase mortality risk for scavenging species (Whittington et al., 2005). Trains can also provide additional food attractants via spilled agricultural products from cars and gates (Gangadharan et al., 2017). In combination, these features attract wide-ranging, omnivorous species like bears, and are likely to contribute to train-caused mortality of brown bears in many areas (Waller & Servheen, 2005; Dorsey et al., 2015; Gangadharan et al., 2017, St Clair et al., 2019).

The position of canals in the landscape is reliant on topography for water flow and they are usually independent of paved roads or railways. The very few studies about the impacts of canals on wildlife have shown they can be a significant cause of mortality, primarily for small- and medium-sized wildlife. For example, drowning in canals has been found to be the second highest cause of mortality for wild boars in Spain (Rosell et al., 2001). The rate of wildlife mortality due to drowning in canals is likely related to the speed of water flow and the height, gradient and surface of the embankment, as well as species-specific traits. Like roads, canals can fragment habitat for many species, especially if very wide or if fences are used to reduce human entry. Unlike roads and railways, canals have less potential to spread chemical pollutants and emit noise, and also have negligible vibration. Despite the growing need for irrigation worldwide, the density of canal networks on the landscape is relatively low, unlike the growing road and rail networks throughout many parts of the world today.

Key messages in this chapter

- **The construction, operation, and maintenance of roads, railways and canals have a range of direct impacts including the loss, fragmentation and degradation of habitat, as well as disrupting animal movement and increasing rates of wildlife mortality.**

- **Edge effects' causing physical and biological changes in adjacent ecosystems, and hydrological, geomorphological and chemical changes are common impacts of LTI.**

- **LTI increases barrier and filter effects reducing the ability of wildlife to move within and among habitats.**

- **Roads, railways and canals attract some species of wildlife, increasing the rate of mortality due to collisions and drowning, ultimately reducing population sizes and increasing the risk of extinction.**

- **The ecological impacts of LTI extend beyond the direct footprint of the road, railway, or canal to form an effect zone', impacting species and adjacent habitats for hundreds to thousands of metres.**

- **Many of the impacts of roads, railway and canals are similar but vary in severity and extent. However, knowledge of the impacts vary among the three modes of transport and additional research, especially on railways and canals, is urgently required to accurately quantify impacts.**

Part 3

Legislation, policies and planning to improve the sustainability of linear transport infrastructure

A male caribou (*Rangifer tarandus*) walks across a river valley in the Arctic National Wildlife Refuge in Alaska, USA, one of the least disturbed ecosystems on Earth. © Joris Beugels / Unsplash

Laws, regulations, policies and guidelines are fundamental to improving the ecological sustainability of LTI within and outside PCAs and ecological corridors to ensure maximum functionality of ecological networks. Sound guidance can provide proponents, regulators and financial investors with a framework to assess potential impacts, make informed planning and design decisions and approve and fund projects that meet strict criteria. The use of best practices should be supported by legislation and policies that require consistently high standards of planning, design and operation of transportation projects that can be applied to new projects and as retrofits to existing infrastructure. All levels of government should develop and adopt these policies and guidelines as a matter of priority, and ensure they are regularly updated with robust, science-based evidence and understanding.

The importance of upstream planning: A land use planning approach

The primary strategy to avoid the negative environmental and social impacts of new linear infrastructure is to develop projects in locations which optimise social and economic benefits, while minimising environmental and biodiversity impacts. Integrated land use planning is a proven approach that has the potential to assist in achieving this win-win outcome, especially in conjunction with long-term PCA planning (Spoelder et al., 2015). An integrated land use planning approach is "essentially a mechanism for decision support to guide stakeholders in selecting the best sustainable land use options which are consistent with their objectives. This approach is participatory and recognises the

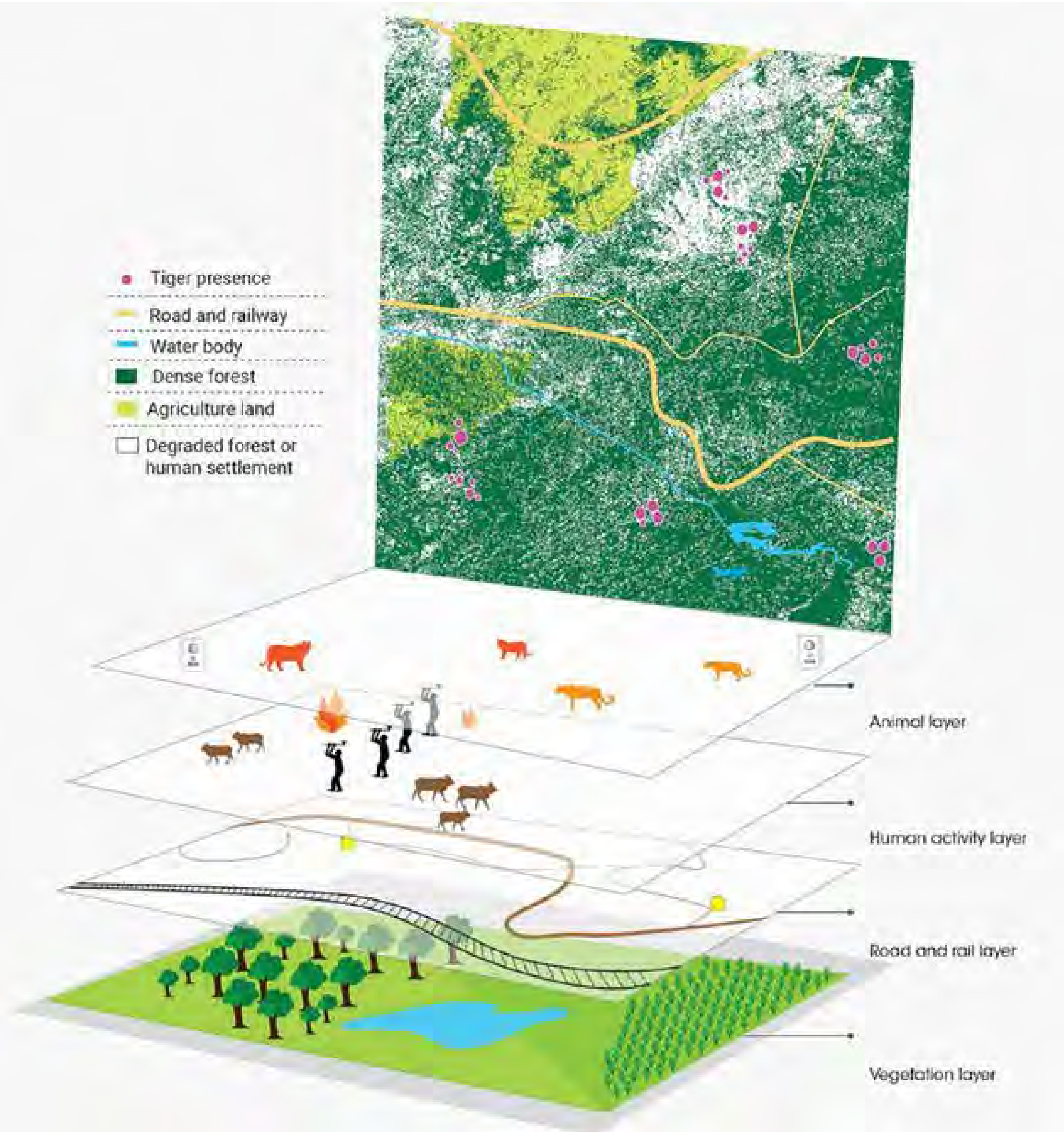


Figure 9: An example of the diversity of spatial land use layers that can be considered in upstream planning, including ecological, social and economic factors © Wildlife Conservation Trust

rights of all stakeholders" (FAO, 1999). A key part of such an approach is ensuring that infrastructure planning considers a wide range of information to ensure that investment maximises utility and provides social, environmental and economic benefits. Some tangible ways to achieve this is to take a whole-of-landscape approach, bundle multiple projects within the same development corridor and use multi-criteria analyses to aid in transparent and objective decision making (Vilela et al., 2020). Ensuring that environmental and social aspects are considered early in planning processes can reduce negative impacts and lessen the need for investment in social and environmental mitigation measures. To achieve this, plans, policies and programmes (PPPs) that promote sustainable land use and a comprehensive and strategic approach to infrastructure are necessary and will be strongest when enshrined in national law (UNEP, 2022b,c,e). This includes strategic environmental assessments (SEAs) at the earliest stage of decision making (see Chapter 4). Therefore, an integrated approach requires coordination and collaboration among key stakeholders (e.g. Ament et al., 2021; Simeonova et al., 2019).

Reliable and comprehensive information can help to identify the social, environmental and economic costs and benefits of proposed infrastructure projects. Transparent accounting of the economic value of the traditional costs and benefits of a project, such as construction costs and improved travel times as well as environmental costs, such as the loss of ecosystem services, will ensure that decisions are made using all available information. Integrated planning also involves quantifying the ecosystem services potentially affected by a project that should also be an integral part of the assessment process (Mandle et al., 2016). In such cases, ecosystem services are simply "the benefits people obtain from ecosystems," (MEA, 2005), and the benefits that infrastructure derives from ecosystem services can include, for example, sediment retention and flood regulation, which significantly lower the risk of floods, landslides, and erosion. Evaluation of the critical benefits that specific locations confer to development along with their value for ecosystem services, such as air and water purification, and habitat, can then inform infrastructure planning. This type of assessment underpins land use planning, given that infrastructure is often linked to other forms of anthropogenic intensification including agriculture, mining, and settlement (Laurance et al., 2009). Including ecological connectivity in planning processes for LTI can assist to maintain ecosystem functions, reduce WVC, and safeguard biodiversity.

Incorporating climate risk in infrastructure planning and policy

According to the 6th report of the Intergovernmental Panel on Climate Change (IPCC), the increasing intensity and frequency

Flooded road and rail intersection. Building resilient infrastructure can reduce vulnerability to ongoing and predicted catastrophic threats of climate change.

of climate and weather extremes, such as droughts, floods, cyclones, heat waves, and fires pose a significant threat to infrastructure and "[…] are increasingly vulnerable if design standards do not account for changing climate conditions" (IPCC, 2021). To reduce risks, governments are increasing and expanding climate change adaptation plans and policies that, in part, protect long-term investments in transport systems. If thoroughly considered, building resilient infrastructure systems can reduce vulnerability to the predicted ongoing and often catastrophic threat of climate change, such as severe weather events (Gariano & Guzzetti, 2016). Therefore, ecosystem-based adaptation approaches to planning should become a cornerstone of LTI development to protect nature, people and infrastructure. Other important considerations relate to the contribution of new or expanded infrastructure on processes that may accelerate climate change, such as land use and land clearing (Reymondin et al., 2014).

Information about climate risk must be incorporated into the decision making by financial institutions, transport planning organizations and contracting companies. Evaluating how changes in temperature and precipitation increases the risk of floods and landslides and thereby threatens infrastructure and the financial investment is critical. Furthermore, an evaluation of this type and incorporation into EIAs can inform the location of infrastructure projects to avoid PCAs, other high-risk natural areas and to conserve others that contribute toward reducing the frequency and severity of extreme events. Climate risk should also be translated into the context of ecological connectivity and infrastructure development as biodiversity must move in response to global climate change.

The mitigation hierarchy

The mitigation hierarchy (Figure 10) is key to EIA processes (see Chapter 4), as well as for achieving the desired result of planning and designing infrastructure that better safeguards PCAs, ecological connectivity, biodiversity and ecosystem services. This hierarchy is a simple framework that allows proponents to assess and address the impacts of infrastructure with an initial focus on avoidance, and if not possible, followed by minimisation, mitigation, restoration and finally, compensation (or offsetting) of residual impacts. There is some variation globally in the naming and exact terminology, with some jurisdictions combining minimisation and mitigation into the same approach, and others including reduction, rectification, or rehabilitation. In New Zealand, for example, the approach is dubbed the Effects Management Hierarchy' (CSBI, 2015), while the US Council on Environmental Quality includes the hierarchy as part of its definition of mitigation' (Protection of Environment, 2023).

The hierarchy is central to the International Finance Corporation's *Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources* (IFC, 2012). This performance standard has been adopted by many development banks and other financial institutions, as well as governments and private industry as a decision-making framework. When the mitigation hierarchy is applied according to IFC Performance Standard 6, decisions can be made to achieve no net loss (NNL) in ecological value as a minimum, or a net gain in value as an aspirational goal. In recent years, biodiversity net gain (BNG) has been embraced as the ultimate goal in many countries, particularly the United Kingdom (Bull & Brownlie, 2017; PAS, 2021). When applied conscientiously, alone or in combination, the following hierarchy facilitates cost-effective and timely project implementation with measurable positive conservation outcomes.

Avoid impacts of development altogether as the first and most important approach in the mitigation hierarchy. Not taking an action or parts of an action by preventing an impact is the most effective way of safeguarding biodiversity. Avoidance may be accomplished through spatial adjustments, such as the relocation of activities or infrastructure away from critical habitats. Infrastructure projects that avoid sensitive biodiversity areas may be longer than the most direct routes, however they will have less need for expensive mitigation measures or other offsets with lower ecological impacts overall. Alternative alignments outside PCAs and avoiding ecological corridors can also best-consider constructability, economics, environmental impact, and access of local populations to benefit. The remainder of the mitigation hierarchy must still be considered even when proposed infrastructure has been relocated because there may still be impacts that require minimisation, mitigation, restoration or compensation (or offsetting).

Minimise is applied when impacts cannot be completely avoided. Similar to avoidance, minimisation is a preventative approach achieved through proactive measures to limit the degree or magnitude of actions. Minimisation measures may include short-term actions during construction to reduce soil erosion or more permanent efforts during operation to reduce contamination from pollution. Minimisation activities are often carried out under an environmental management plan (EMP) geared to reduce the project footprint. An EMP includes directives to reduce disturbance, such as the preservation of tree canopy adjacent to roads, or a shortened construction period.

Mitigate is applied only when genuine efforts to avoid and minimise impacts have taken place. Mitigation measures are often technological or construction strategies that are enacted to moderate, reduce or eliminate unavoidable impacts over time. Commonly used mitigation measures in infrastructure projects are noise and light barriers to prevent spillover into adjacent habitats, wildlife underpasses and overpasses with associated directional and exclusionary fencing to provide for ecological connectivity and minimise WVC, and escape ramps in canals to prevent wildlife from drowning.

Restore refers to efforts within or adjacent to the construction footprint that address unavoidable impacts to achieve NNL of biodiversity value or ecosystem services. Restoration involves measures to repair and rehabilitate ecosystem structure such as reforestation, or ecosystem function such as functional ecological connectivity. Restoration is aimed

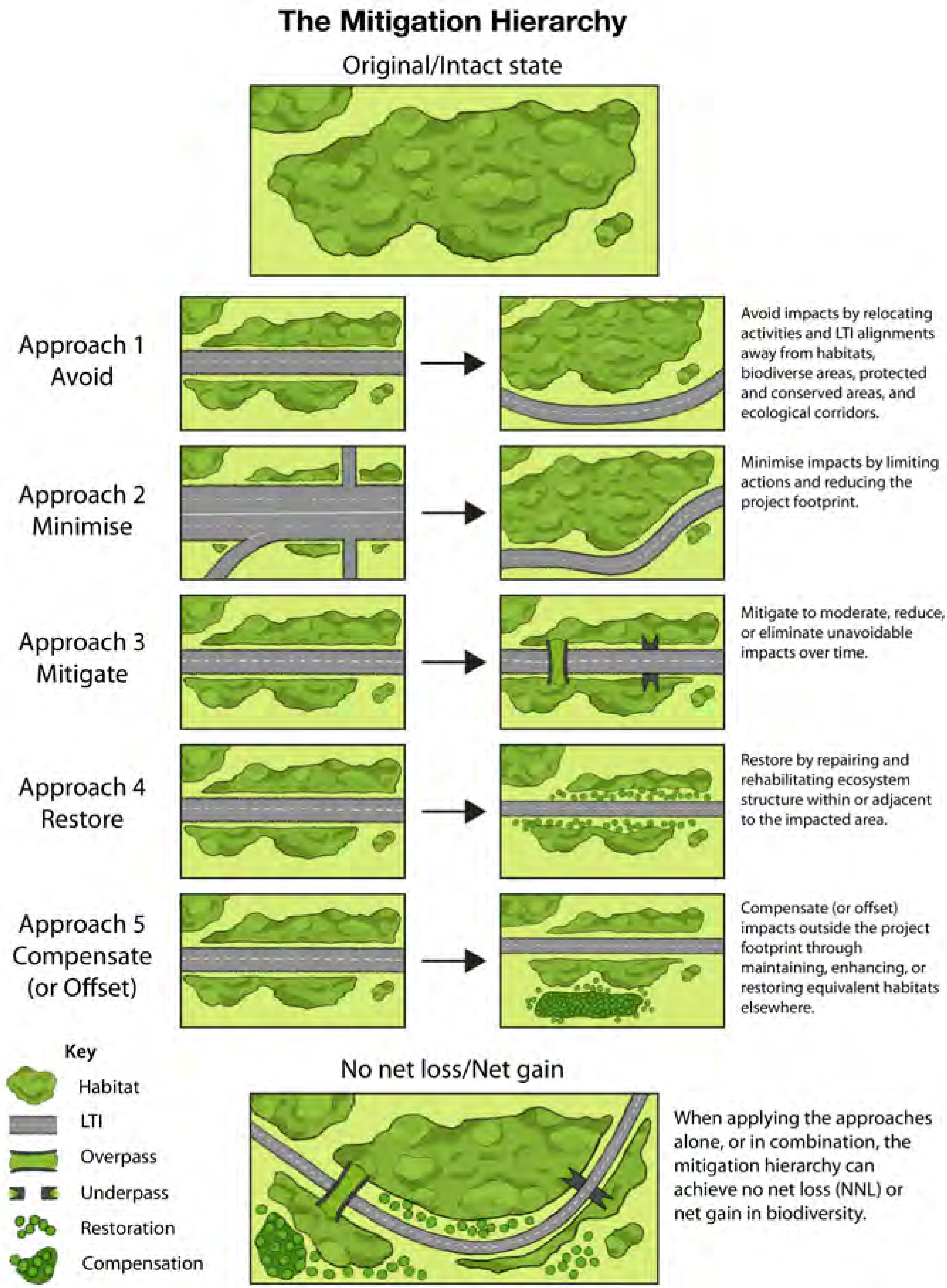


Figure 10: A depiction of varying approaches for applying the mitigation hierarchy © Julie Johnson / Madison Mayfield, courtesy Center for Large Landscape Conservation

A herd of plains zebra (*Equus quagga*) graze below the Nairobi-Mombasa Railway. Bisecting Nairobi National Park, the rail design allows for wildlife movement under the tracks, but avoidance of the protected area was not taken into consideration. Consequently, the impacts of construction, maintenance and rail effects such as noise, vibrations and movement, are now pervasive. © Martin / Adobe Stock

at reversing habitat degradation and typically occurs at or nearby to the site of an infrastructure project. Restoration is most effective when well-established, practical techniques are maintained and monitored for long-term success (IFC, 2012). Nevertheless, on their own, restoration measures are rarely sufficient to achieve NNL consistent with biodiversity baselines (IFC, 2012). As result, a goal of NNL often necessitates the pursuit of offsets.

Compensate (or **Offset**) addresses impacts by replacing or substituting resources or environments that are typically outside of the footprint of an infrastructure project that cannot be avoided, minimised, mitigated or restored on site. Offsets should be measurable and significantly tip the scale' toward achieving NNL of biodiversity and ecosystem services. Offsets are generally characterised as: i) *restoration offsets* that rehabilitate degraded habitats, ecosystems, or ecosystem function, or ii) *protection offsets* that maintain biodiversity under threat of loss (CSBI, 2015). Compensation usually involves payments as offsets, such as to fund and implement management plans for PCAs, support research that enhances biodiversity protection, or enhance enforcement activities and infrastructure.

Safeguards and performance standards

Around the world, LTI projects are funded through a variety of mechanisms, including government appropriations, bilateral agreements between two countries, multi-lateral banks (e.g. World Bank, Asian Development Bank, InterAmerican Development Bank, African Development Bank and European Bank for Reconstruction and Development), private developers (e.g. toll roads) and private equity investors (e.g. multinational companies, pension funds, and sovereign wealth funds) (*see* Chapter 6 for a comprehensive summary). Globally, lenders and sponsors are increasingly developing and adopting requirements that include the protection of biodiversity as a condition of project approval or funding, part of what is often known as environmental, social and governance (ESG) policies.

The International Finance Corporation (IFC) Performance Standards (Figure 11) outline a widely adopted framework for managing social and environmental risks. This comprehensive and practical approach is considered the international benchmark. Based on the IFC Performance Standards, the Equator Principles' are a framework for financial institutions to manage environmental and social risk in projects they fund. Whereas all IFC Performance Standards are relevant to infrastructure planning, Standards 1, 3, 4 and 6 are of particular interest to planning LTI because they outline the need for an integrated approach that addresses resource efficiency and biodiversity. IFC Performance Standard 1 establishes the importance of using an integrated assessment to identify environmental and social impacts, risks, and opportunities. It also ensures the use of the mitigation hierarchy, promotes engagement with affected communities and supports the use of grievance mechanisms. IFC Performance Standard 3 outlines a project-level approach to resource efficiency and pollution prevention

Wildlife overpass across National Route 101, part of the Urugua-í-Foerster Biological Corridor in Argentina © Adobe Stock

Figure 11: International Finance Corporation (IFC) Performance Standards
© Mary Collins / CLLC

to avoid or minimise adverse impacts on human health and the environment, and to reduce greenhouse gas emissions. IFC Performance Standard 4 addresses the responsibility of avoiding and minimising risks and impacts to community health, safety and security, with special attention to vulnerable groups.

Of specific importance, the objectives of IFC Performance Standard 6 are to: (i) protect and conserve biodiversity, (ii) maintain benefits from ecosystem services, and (iii) promote sustainable management of natural resources via practices that integrate conservation with development priorities. This standard provides a framework for the classification of habitats within proposed development areas and sets acceptable limits for impacts to modified, natural, and critical habitats, respectively. This classification ensures that specific actions occur within the different areas of habitat during the planning phase of projects.

When applied diligently to project planning, design and implementation, the mitigation hierarchy and outcome goals described in IFC Performance Standard 6 (2012) provide lending institutions, governments and NGOs assurances for transparent, data-driven, and sustainable development that balances conservation with development. Without the conscientious application of these standards and thorough EIAs, there is a high likelihood that infrastructure and other types of development projects will fail to adequately protect the environment (Laurance, 2015; Rainer et al., 2018). As of 2023, 138 financial institutions have signed onto the Equator Principles. Other institutions also have additional environmental and social safeguard policies. Recent analyses demonstrate their widespread acceptance, with 69 countries having adopted or currently developing NNL mitigation outcome policies for development projects (Maron et al., 2016; Arlige et al., 2018).

While LTI planning processes that either incorporate or provide LTI safeguards may appear robust on paper and follow recognised performance standards, they sometimes fail to deliver environmentally responsible outcomes (e.g. Hedge et al., 2022). Plans and commitments can be derailed by a wide range of complications, including economic considerations, corruption and political intervention.

Project certification

A range of third-party certification programs are being developed and implemented around the world to assess the overall sustainability of infrastructure projects. The programs develop measures that rate a project's environmental, social and economic performance, often referred to as the triple bottom line (Elkington, 1998), with some including specific ecological considerations. The programs are highly variable, with one that focuses solely on pavement maintenance (Zhang & Mohsen, 2018). Six different US-based highway rating systems were reviewed and some cover only the construction phase, while others evaluate the operations and maintenance phases of a project (Nikumbh & Aher, 2017). A more comprehensive program developed for Australia and New Zealand by the Infrastructure Sustainability Council assesses planning, design, construction and operation phases (ISC, 2022). Such schemes seek to influence the financing of LI and encourage designs and their implementation that consider life cycle assessments, encourage the use of recycled materials, the reduction of greenhouse gas emissions, as well as further or protect many other societal values. In the future, if the issue is properly promoted, the managers and decision-makers of such programs could incorporate the protection of ecological connectivity explicitly into their sustainability rating systems.

Underlying social and cultural values and the rights of local communities and Indigenous peoples

Developmental priorities vary regionally and countries undergoing rapid infrastructure development may prioritise economic and social development over environmental conservation. Nevertheless, there is growing consensus that social and environmental considerations need to be better integrated into infrastructure investment and development that is often motivated by the aspiration to provide employment opportunities and increase economic growth (Thacker et al., 2019). While more sustainable infrastructure may come at a higher initial cost, the long-term monetary and time savings of reduced repair, social upheaval and environmental damage are significant and can often outweigh the extra up-front cost. Despite these advantages, developing countries with limited budgets and planning horizons may find it challenging to design and build sustainable infrastructure, and many proposed projects will fail to deliver the promised social, environmental and economic benefits (Vilela et al., 2020). This difficulty should be considered in the development, implementation and, sometimes, enforcement of good

Box 4

A green toolbox' to mitigate the impacts of railways on Asian elephants, Bangladesh

Key lesson: It is imperative that roads are designed and constructed with the best available science and with external oversight to apply context-specific environmental safeguards.

The Chittagong – Cox's Bazar Railway Project crosses through three of Bangladesh's 24 legally defined protected areas (PAs; Ministry of Railways, 2016). All three are known to support endangered Asian elephants (Elephas maximus). A baseline biodiversity assessment (BBA) was commissioned as part of the project EIA to determine the status of Asian elephants in the project area, inventory elephant crossings, assess human-elephant conflicts, and propose environmental safeguards to promote elephant connectivity and minimise elephant-train collisions (Dodd & Imran, 2018).

A toolbox' of green infrastructure and use of best available science was developed to address the impacts on wildlife and biodiversity (Dodd & Imran, 2018). Wildlife crossing structures (overpasses and underpasses), elephant detection system technology, and funnelling treatments (e.g. fencing and alternatives) were recommended. An international biodiversity consultant who helped conduct the BBA serves as an independent monitor during construction and will conduct a minimum two years of post-construction monitoring for the Asian Development Bank.

As of 2023, construction is well underway. Two underpasses have been completed. One is a 10 m wide by 5 m high reinforced concrete box culvert that has already received use by elephants, even though funnel fencing has not yet been installed. Construction of the elephant overpass, the world's first designed specifically for elephants, is now complete. The 50 m wide reinforced concrete box overpass creates a tunnel through which trains will pass below the revegetated elephant corridor above. Approximately 4 km of 2.2 m high (and 2.2 m below ground) durable and low-maintenance concrete elephant barrier fence is being constructed along the railway to link the two underpasses, five upsized culverts, and the overpass; this will prevent elephant-train collisions and funnel elephants to the structures.

Cox's Bazar railway underpass, Bangladesh. The project increases connectivity between three protected areas that support endangered Asian elephants (*Elephas maximus*). Prints in the ground indicate that elephants are already using the box culvert underpass. © Norris Dodd

Box 4 (continued)

Top and bottom: The overpass is the world's first designed specifically for elephants. Construction as of 2023 © Tapan Kumar Dey.

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Box 5

Protecting environmental values and preserving connectivity while developing new roads in Bhutan

Key lesson: In the small yet biodiverse country of Bhutan, ecological connectivity is manifest in designated biological corridors and a commitment to highway mitigation measures. Although not yet built, the proposed highway was aligned to avoid the most critical habitat for endangered species..

Bhutan is a small country in the Himalayan Mountains who have demonstrated that even a relatively poor and developing nation can make ecological connectivity conservation a priority. Bhutan's mountainous terrain supports tremendous biodiversity due to its location at the intersection of two biogeographic zones, coupled with an extreme elevation gradient of nearly 7,300 m across a distance of 135 km. Importantly, 52% of Bhutan's land area is conserved within PAs, all of which are interconnected by designated biological corridors.

Prior to 1960, Bhutan had no paved highways. There are now 1,975 km of national highways, with the primary East-West National Highway crossing the centre of the country in large part as a narrow and winding road. Bhutan's 2007–2027 Road Sector Master Plan prioritizes construction of a second east-west highway to connect communities and support economic development in the south. To date, five segments of this highway totalling 183 km have been completed, two of which pass through habitat for endangered Asian elephants (Elaphus maximus) and other species. To minimise barrier effects, wildlife crossing structures have been integrated into designs, allowing for unobstructed elephant movement.

Prior to construction of the southern East-West Highway, wildlife surveys were conducted to determine locations for large underpasses; based on results they were situated at waterway crossings where elephants travelled regularly. Elephants

Technicians install a wildlife camera on an underpass in Bhutan. © Norris Dodd / ADB

Box 5 (continued)

Camera trap monitoring showed that Asian elephant (*Elephas maximus*) crossed safely through the underpass. © Norris Dodd / ADB

were the focal species because their conservation is considered to also benefit other species. Transboundary, Indo-Bhutan wildlife connectivity considerations for elephants and other endangered species were also incorporated into the planning and design of road segments and corresponding crossing structures by the Bhutan Department of Roads and multilateral funding institutions. Each of the four underpasses monitored were used by wildlife soon after construction. Measured as successful crossings per total road approaches, the average success rate for elephants was 75.5% (Chogyel et al., 2017).

Initial proposals for a segment of the second East-West highway crossed the length of the Phipsoo Wildlife Sanctuary, located along the border with India. A baseline biodiversity assessment confirmed the presence of 27 IUCN Red List species in Phipsoo, including two critically endangered species. This meant that a significant proportion of two proposed segments would pass through critical habitat and potentially render them non-compliant with the funding institution (ADB, 2018). As biodiversity was highest in the sanctuary core and lowest along the border due to previous human impacts, biologists advocated for an alternative alignment along the border that avoided critical habitat. Along with aforementioned mitigation and other conservation offsets, the final alignment resulted in NNL of biodiversity, showcasing an avoidance approach and viable alternative for conservation and development.

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legislation. Moreover, these types of limitations underscore the need for thorough consultations and the participation of key stakeholders early in planning processes.

Conservation efforts by local communities, Indigenous peoples, women and youth are increasingly acknowledged as critical to successful conservation and climate change adaptation (WWF et al., 2021). Yet, recognition of the contributions of Indigenous and local community groups is often missing from government policies and planning practices, including those for infrastructure development (e.g. Yang et al., 2021; Vilela et al., 2020). Just as policies to increase coverage of PCAs may conflict with the rights of Indigenous peoples to manage and conserve their own lands, infrastructure development may threaten Indigenous lands, traditions and values. Therefore, the rights of Indigenous peoples must be respected in land use planning, development and conservation activities. Furthermore, policies for natural resource management, infrastructure development, and mitigation need to increasingly promote consultation and participation by Indigenous groups to achieve this requirement (e.g. Clements et al., 2018).

Key messages in this chapter

- **Building new, and upgrading (or removing) existing roads, railways and canals should be part of a comprehensive and coordinated plan that integrates all land-use planning. Ad hoc and unplanned actions rarely lead to good environmental outcomes.**
- **Future risks from a changing climate must be identified and explicitly considered in land-use and transportation planning.**
- **The mitigation hierarchy should always be genuinely applied in the proper order to achieve the best possible social, environmental and economic outcomes.**
- **All countries, regions and municipalities, as well as lending institutions and private contractors must develop and adopt minimum safeguard and performance standards that are followed to ensured best practice outcomes.**
- **Indigenous peoples and local communities are often significantly and negatively impacted by new infrastructure development, and their wishes and rights must be properly considered.**

A wildlife overpass and bilingual signage constructed along US Highway 93, which passes through lands of the Confederated Salish and Kootenai Tribes (CSKT) of the Flathead Reservation in Montana, USA. This mitigation measure is one of 41 wildlife crossing structures built along 90 km of road, which makes this area one of the most thoroughly mitigated road stretches in the United States. The Tribes’ leadership on the project – and commitment to safety improvements for both motorists and wildlife – grew out of a philosophy that every species has value as an integral part of the whole ecosystem. While collaborating with state and federal agencies, the sovereign CSKT ensured that the project outcomes aligned with their values. © Luca Guadagno

Part 4

Environmental assessments for linear transport infrastructure

Indian rhinoceros (*Rhinoceros unicornis*) on the side of a road in Kaziranga National Park, Assam, India © Grégoire Dubois

Even the most well-planned, designed and built LTI projects may still have a diversity of impacts on PCAs, biodiversity (Chapter 2), and vulnerable communities (Chapter 5). To reduce undesirable effects, the mitigation hierarchy (IFC, 2012)—avoid, minimise, mitigate, restore and compensate (or offset) — should be applied as a fundamental guiding principle (Chapter 3). If complete avoidance of adverse impacts is infeasible, then minimisation, mitigation, and compensatory measures should be developed and implemented to achieve no net loss or a net gain in biodiversity. Strategic environmental assessments (SEAs) and environmental impact assessments (EIAs) are formal planning processes that often use the mitigation hierarchy as a procedural tool for environmental decision making and achieving more sustainable development (Benson, 2003; Marshall et al., 2005).

Both types of assessments need to increase their focus on integrating connectivity and biodiversity more systematically into their evaluation processes (Torres et al., 2022). As a best practice, more frequent and intensive appraisal of the impacts on connectivity and biodiversity must be undertaken for all LTI projects. This includes selection of multiple target species, evaluating scale optimisation, and applying adaptive management for maximising application of the mitigation hierarchy for better evidence-based evaluation and to more fully understand the potential impacts of each of the development options, including the no-action alternative (Gonçalves, et al., 2022).

Although there is a diversity of approaches for transport planning across the globe, it is important that LTI projects increasingly be identified through strategic evaluation. The LTI projects identified in such strategic evaluations can then be further developed in transport sector plans. Ideally, these strategic evaluations should help incorporate needs assessments based on future transport demand, analyses and modelling that result in alternative solutions and budgets (see Box 6: A path to more wildlife-friendly roads in Costa Rica). They should also advance national, regional or sub-national development goals – often referred to as plans, policies and programmes (PPPs) (Noble, 2000).

Strategic environmental assessments

SEAs can improve transport sector plans and their resulting LTI projects. An SEA has been defined as "the proactive assessment of alternatives to proposed or existing PPPs, in the context of a broader vision, set of goals, or objectives to assess the likely outcomes of various means to select the

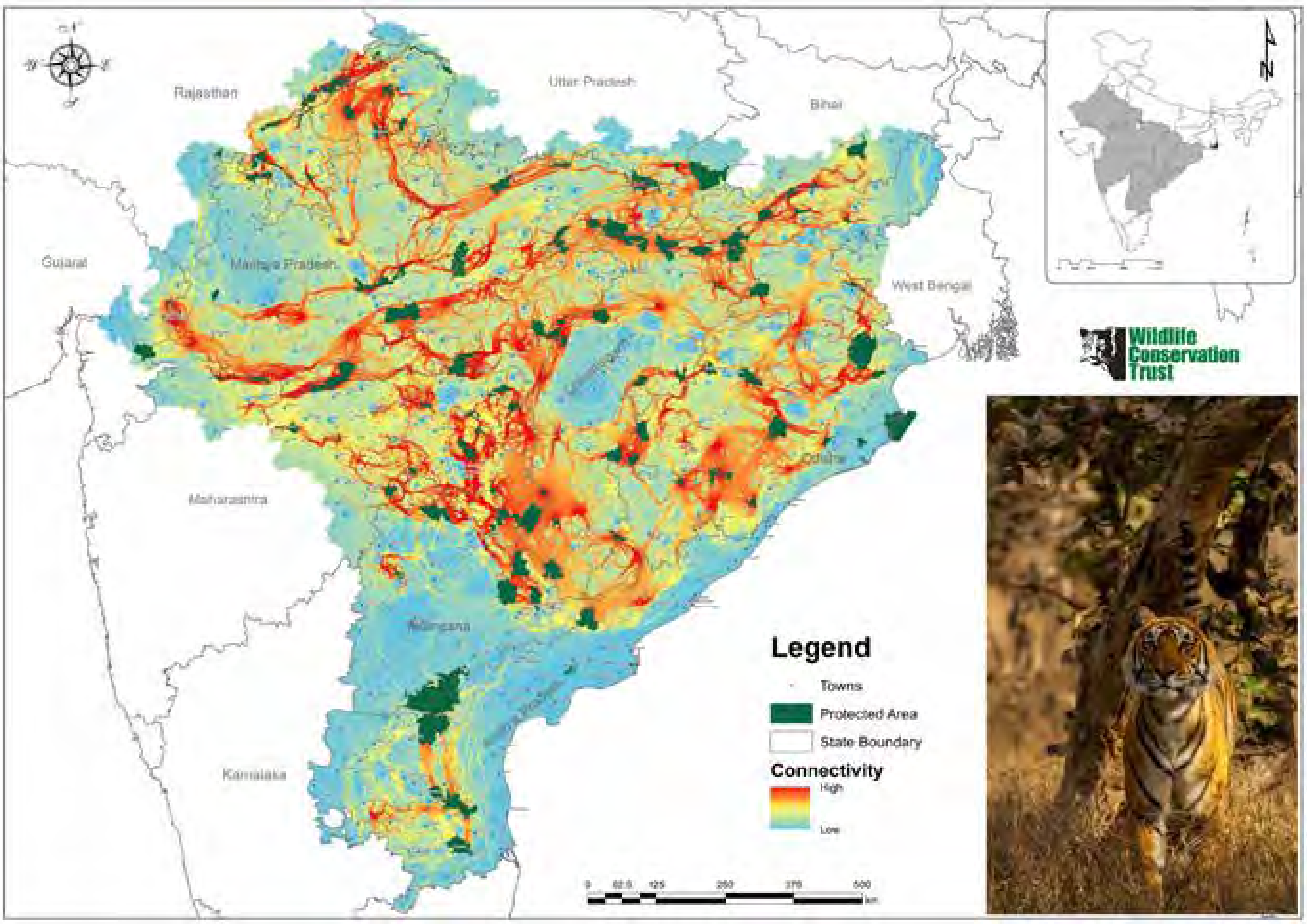

Figure 12: A map identifying corridors in the Central Indian and Eastern Ghats tiger landscapes connecting existing protected areas and Bengal tiger (*Panthera tigris tigris*) population source sites, with available data up to 2018. The areas shown in red and orange indicate where tiger movement remains most viable.

best alternative(s) to reach desired ends" (Noble, 2000). Thus, SEAs seek to effectively mainstream environmental, social, economic, and health issues while ensuring the sustainability of their decisions (IAIA, 2009). SEAs are considered a family' of approaches that can be used to prioritize and balance development with environmental stewardship across large spatial scales and multiple jurisdictions. Moreover, they are considered an essential tool for evaluating and incorporating scientific information, such as species distribution maps, into decision making. In addition, they can identify and prioritise the protection of roadless areas and PCAs, ecological corridors and the overall ecological connectivity of landscapes at regional, national and international scales (Iuell et al., 2003; Hlaváč et al., 2019).

Development of strategic environmental assessments

SEAs can provide for more informed decisions in transport sector plans, providing them with a broader context of visions, goals, and objectives, that serve to address a wider range of potential impacts from LTI projects at multiple scales (see Chapter 2 for a discussion of the direct and indirect impacts of LTI development). The more comprehensive and flexible strategies in SEAs have the potential to help facilitate the development of a larger range of alternatives at earlier stages of transport plan development that result in the creation of more preferred options for EIAs that evaluate LTI projects.

SEA processes need to be structured according to their terms of reference and developed to address specific needs and scopes. Therefore, they lack universally defined steps or phases. Depending on the level of formality in a country's legislation, regulation and practice, SEAs can be applied in different ways using a variety of methods that better mainstream environmental considerations. They can significantly inform the EIAs of specific projects and their decisions, and promote good governance approaches (Thompson et al., 2013). For example, the Convention on Biological Diversity has identified "stakeholder involvement, transparency and good quality information" as key principles of SEA development (Slootweg et al., 2006). Many countries have established guidelines and procedures for SEAs, and best practices have been described for four basic stages, and these can be applied to LTI planning as follows:

1. Create *transparency* by establishing the context for the SEA, including screening, setting objectives and identifying stakeholders;
2. *Technically* assess and carry out the SEAs in dialogue with stakeholders: collect baseline data, identify alternatives, identify opportunities to mitigate impacts, provide quality assurances and author excellent reports;

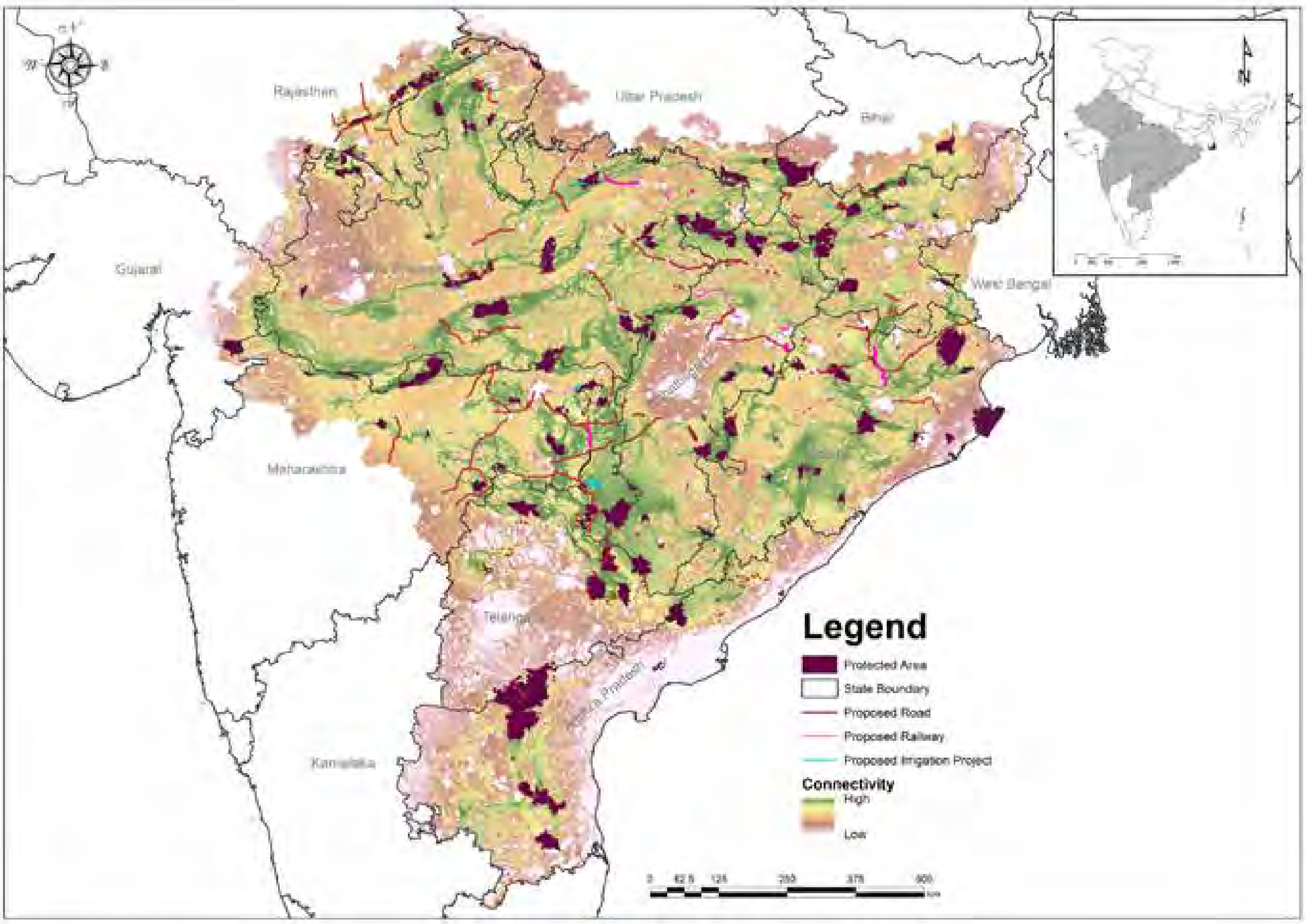

Figure 13: The identified tiger corridors with protected areas overlaid by proposed LTI including roads, rails and canals © Wildlife Conservation Trust

Stakeholders collaborate at the Hanoi International Forum on Sustainable Infrastructure: Integrating Climate Resilience and Natural Capital into Transport Infrastructure Planning and Design © Rodney van der Ree

3. Use *the information* from the technical assessment to inform decision making in dialogue with stakeholders; and
4. *Monitor and evaluate* the decisions made in PPPs and SEAs and their implementation (Slootweg, et al., 2006; OECD, 2006).

Environmental impact assessment

EIA is defined as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (IAIA, 2009). As a systematic process, an EIA examines, in advance, the environmental consequences of a specific project or development.

A quality EIA will provide and assess multiple alternatives (including a no action alternative) and include often highly detailed and technical appraisals that can inform how best to apply the mitigation hierarchy to a development project and to optimise positive outcomes (Stokes, 2015). After assessing various general requirements and recommendations, and preparing a project description and design, all EIAs should consist of the following fundamental phases (Slootweg, et al., 2006; Pavlyuk et al., 2017):

1. *Screening and/or a complete feasibility study* to ascertain the need for, and determine the type of, assessment required, such as a full or partial impact assessment;
2. *Scoping* to identify components, boundaries, and baselines for what impacts are relevant to evaluate and to identify alternative solutions;
3. *Assessment and evaluation* to predict and identify likely impacts, including their significance and elaboration of alternatives;
4. *Report* on the determination of the EIA, including communication to the public of identification of impact mitigation measures and an environmental management plan (EMP);
5. *Review* by technical experts and the public based on the original scoping;
6. *Decision making* on whether to approve or not approve a project, including conditions for approval; and
7. Monitoring, compliance, enforcement, environmental auditing, and adaptive management of the impacts and mitigation measures as defined in the EMP to verify compliance and address deficiencies in implementation.

Figure 14: Map of international protected areas that would be directly (red) and indirectly (orange) impacted by the E40 waterway, a 2,000 km navigable transport project planned to connect the Baltic and the Black Seas. Such canal projects can alter hydrologic systems and destroy habitats in their path, such as wetlands and free flowing rivers. To date, neither an SEA nor an EIA have been conducted. © Save Polesia / Mapbox

Recommendations for applying strategic environmental assessments and environmental impact assessments to linear transport infrastructure

While the use and overall quality of SEA and EIA processes is increasing around the world, there are a diversity of improvements that can be made concerning LTI (Laurance, 2022). Following are some of the most crucial insights for enhancing the application of these processes when developing LTI:

- Conventional approaches to EIAs for LTI projects in the feasibility stage often lack consideration of impacts on threatened and non-threatened species and ecosystem functions, including ecological connectivity. Ideally, enhanced approaches would contribute such important ecological information into the overall determination of the technical, environmental and financial/economic feasibility of the project (Hyari & Kandil, 2009; Jaeger, 2015). At the earliest stages, such as in the feasibility analysis, it is essential to accurately document ecological corridors that reflect migration and other wildlife movement needs (see Box 7: Statutory requirements help protect wildlife from transport development in India).

- Before an investment decision is made, preliminary engineering designs and EIAs should be conducted according to any safeguards set by the proponent and funders (see Chapter 6). This should include production of reliable budget estimations that include costs of engineering, construction, environmental and social mitigation and possible resettlement compensation.

- The cost of each approach in the mitigation hierarchy, and all efforts to meet no net loss or net gain in biodiversity requirements, should be identified early in the planning process to ensure that adequate funding is allocated in the project budget (see Box 6: A path to more wildlife-friendly roads in Costa Rica). Too often budgets are set before mitigation measures are identified or ecological aspects are cut from the project when funds become constrained.

- EIAs should include an integrated synthesis of the studies conducted for the project, with a clear and concise summary of anticipated impacts on the environment for each alternative (Jaeger, 2015; Stokes, 2015). Additionally, the EIA report or statement should specify the required measures that will be needed as conditions for implementation, including a Biodiversity Action Plan. This should include a rating of project impacts before and after the application of the recommended mitigation measures (Stokes, 2015).

- Increase the awareness among decision-makers, funders and practitioners that SEAs provide many benefits by incorporating environmental issues and constraints early in the planning stages, and strengthen governments' ability to increase institutional frameworks for applying SEA processes. This can include bolstering technical expertise and knowledge of cumulative impacts of projects, supporting administrative capacity, providing practical guidelines and enhancing clarity about the roles and responsibilities of different agencies in SEA development (Slootweg, et al., 2006; OECD, 2006).
- Improve the collection of high-quality data to evaluate the impact of PPPs and LTI projects on PCAs and surrounding habitat, ecological connectivity, rare species or those of conservation concern in SEA and EIA

Figure 15: Locations of wildlife crossing structures (green) across Dutch national highways (red) and railroads (black); part of Netherlands' Multi-Year Programme for Defragmentation (MJPO). Concluded in 2018, the programme was able to mitigate approximately 60% of all the ecological barriers caused by the national infrastructure system, and as of 2017, there were almost 2,100 wildlife crossings for motorways and provincial roads. © Sijtsma et al., 2020

processes. This includes allocating longer time periods for field surveys (Jaeger, 2015; da Silva Dias, 2017) and undertaking biological evaluations to directly measure the amount of habitat cleared or number of animals killed during construction (Gannon, 2021). This can ensure greater attention to monitoring of gene flow or underlying ecological processes and functions that support the long-term health of a species (Bigard et al., 2017) to strengthen conclusions, and deliver more adequate mitigation measures and more positive environmental outcomes.

- EIAs need to increase their application of state of the art' modelling methods, based on robust data collection, for environmental impact prediction (Jaeger, 2015; da Silva Dias, 2017). These models will serve to enhance impartiality in the biological evaluation on the part of private contractors often carrying out the EIAs and to reduce the influence of project proponents on political and governance processes (Laurance & Salt 2018).

- Improvements in cumulative effects analyses are needed for both SEAs and EIAs. This requires more fully incorporating the impacts of development that arise beyond the LTI alignment footprint (i.e. construction access and support facilities, presence of laborers, and supply chains). For example, recent meta-analysis of biodiversity considerations in EIAs in France found that, although EIAs have recently shifted towards acknowledging cumulative impacts, they "do not propose adequate measures to reduce them" (Bigard et al., 2017).

Box 6

A path to more wildlife-friendly roads in Costa Rica

Key lesson: In Costa Rica, road planning now begins at the ministry level and effectively incorporates environmental and social considerations.

The Ministry of Transportation in Costa Rica is increasingly making its roads wildlife-friendly by applying rigorous SEA and EIA processes. An important reason for this progress is the Ministry's Process of Environmental and Social Management team (PROGAS, in Spanish). PROGAS was created in response to a request from the Inter-American Development Bank in 2011 and is now responsible for the environmental and social components of road project planning. PROGAS has many functions; the team enforces laws, supports scientific studies, sets the Terms of Reference for environmental studies, provides training, coordinates with the National Technical Secretary of Environment, and evaluates road projects.

When PROGAS began operation, only one road in Costa Rica had wildlife underpasses. As of 2020, 39 underpasses had been developed along five roads; underpasses built since 2015 have been designed and located based on data collection and analysis of wildlife at each project site. Incorporating environmental and social needs early in the planning process helps assure that PCAs and wildlife concerns are properly addressed and adequately funded.

In the past, mitigation measures were considered an additional and optional expense within transportation budgets. This often led to insufficient funding to safeguard the environment. Now, all new road projects in Costa Rica are included in the country's National Plan and placed in the portfolio of the Ministry of Planning. This has allowed for adequate budget allocation for environmental mitigation and is a significant change in policy and practice for transportation projects across Costa Rica. The Costa Rican experience in improving mitigation measures that protect wildlife and ecological connectivity demonstrates that developing countries can achieve substantial progress in transport planning and implementation.

An interdisciplinary team consisting of members of PROGAS (Ministry of Transportation), a construction company, and an NGO setting up camera traps in a modified culvert to measure wildlife crossings © Daniela Araya-Gamboa

Box 7

Statutory requirements help protect wildlife from transport development in India

Key lesson: National legislation in India has created a strong legal basis for performing environmental assessments and gaining clearance to undertake infrastructure projects.

In India, the importance of ecological connectivity was neglected until recently, due in part to the absence of a legal definition of corridors or connectivity. In 2006, the Wildlife Protection Act of 1972 was amended to address corridors for tigers, which are defined as "areas connecting one protected area or tiger reserve with another protected area or tiger reserve" (Wildlife Protection Act, 2006). Consequently, all projects that affect tiger corridors must attain a Wildlife Clearance (WC) and approval from the National Tiger Conservation Authority.

In 2016, this concept was extended when the Ministry of Environment, Forest and Climate Change (MoEFCC) adopted guidelines for mitigating the negative impacts of linear infrastructure, thereby ensuring infrastructure projects comprehensively address important environmental impacts. Despite these guidelines, most EIAs fail to adequately evaluate all potential impacts of a project, including impacts on ecological connectivity because of: (i) their short duration; (ii) minimal budgets; and (iii) the multitude of natural resources impacted, including soil, water, and air, along with complex social factors.

New concerns have been raised as more recent measures have eased the process of obtaining a WC or Forest Clearance (FC), such as allowing the project proponent to self-determine whether an FC or WC is required. In the Central Indian Landscape, 399 LTI projects applied for an FC and nearly 86% of these should have required WCs (Pariwakam et al., 2018). Having project proponents self-determine the need for a WC therefore reduces evaluations to protect wildlife.

A total of 202 EIAs for projects (151 roads, 10 railway lines, 41 power transmission lines) in central India have been submitted to MoEFCC seeking WCs since the adoption of mitigation guidelines for linear infrastructure. While most of these proposals are still under review, 18 (10 roads, three railway lines, and five power transmission lines) have been approved with mitigation strategies, three road projects were approved without any strategies and one railway line has been rejected outright.

Although India has the second largest network of roads and the fourth largest railway network in the world, no railways and only two highways have used wildlife crossing structures in their mitigation strategies. Of these, the best-documented are along a 60 km section of National Highway 7, where six wildlife crossing structures have been constructed, including two of the world's longest underpasses (750 m long each). The six structures help maintain connectivity between the Kanha and Pench Tiger Reserves and are the result of a protracted legal challenge brought by individuals and civil society organizations.

As new systems and procedures are put in place to ensure WCs maintain connectivity for wildlife, an improved spatial framework to assess the needs of wildlife and connectivity is needed. This will help ensure that appropriate mitigation measures are included in transportation project proposals. In the future, proponents will need to allocate adequate funds in their budgets to first avoid, or when impacts cannot be avoided, seek to fully mitigate negative impacts on ecological connectivity. This will make certain that funds for thorough EIAs and their resulting mitigation measures are adequate to better safeguard biodiversity.

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Box 7 (continued)

A wildlife underpass sized appropriately for Asian elephants (*Elephas maximus*) in India © Robert Ament

Key messages in this chapter

- SEAs are comprehensive processes that are aimed at mainstreaming environmental, social, economic and health issues while ensuring the sustainability of strategic decision concerning LTI development. Individual projects and their EIAs are more effective when nested within SEAs which have broader scopes and incorporate multiple projects and the concerns of a variety of sectors and actors at national or regional scales.

- EIAs are processes intended to provide for sound scientific information, transparent public participation and informed decision making.

- Well-developed and executed SEAs and EIAs should be undertaken for all LTI projects to better integrate ecological connectivity and biodiversity considerations at multiple scales. This includes allocating ample capacity, undertaking effective scoping, considering the full potential of the mitigation hierarchy, proposing a full spectrum of sustainable alternatives and delivering assessments at critical junctures in the decision-making processes.

Part 5

Social consequences and public participation

A moose (*Alces alces*) crosses a road in Alaska, USA. © JT Fisherman / Adobe Stock

Around the world, there are many communities who derive their livelihoods and well-being from natural resources and the benefits provided by PCAs, such as from ecosystem services and tourism. While LTI projects can provide many social and economic benefits to local communities, they can also impact communities in a myriad of devastating ways. All rightsholders, stakeholders and affected people should be genuinely and appropriately consulted and given opportunities to be involved in the planning process.

The potential social consequences of linear transport infrastructure projects

LTI projects can disrupt the livelihoods of people through resettlement, economic displacement, and social and cultural changes, including through the arrival of new migrants and settlers. The social, economic and cultural aspects of a development project are to be managed through a holistic and integrated approach that aims to accommodate the needs and wishes of those who are interested in or affected by the project.

Resettlement may occur when individuals or communities need to voluntarily, or involuntarily, vacate their lands (IFC, 2002). Involuntary resettlement should come as a last resort and be employed only if no other viable alternative exists. In some instances, communities may benefit through improved housing and better planned settlements. Many rural, marginalized and Indigenous communities do not possess title deeds to their lands despite being the rightful owners, such as in ancestral lands passed down through generations. Communal lands that belong to the whole community may also lack titles. Therefore, authorities need to exercise utmost vigilance, caution and due diligence to avoid inaccuracies, mistakes and unfair practices during resettlement. These include situations where bona fide members of a community are left out of resettlement plans or compensation, while imposters benefit. Best practices include alternatives to resettlement; fair, adequate and timely compensation of a range of values, including physical assets such as crops, buildings, natural resources and ecosystem services, as well as intangible cultural and spiritual values; asset inventory and valuation of both communal and individual assets in compensation calculations; and an approach that upholds human rights. Displaced persons should be able to provide input into the resettlement process, and resettlement must also be practical for the socio-economic livelihoods of the persons or community that may be resettled.

Economic displacement may also occur due to temporary or permanent loss of livelihoods or income during the disruption caused by resettlement (Picciotto, 2013). For instance, a family that depends on resources like fruit, bee keeping,

Children walk along the roadside in Alto Conte, Costa Rica, where proposed road improvements would provide year-long access for an Indigenous community and a nearby town. Avoiding disruption of people and their communities by LTI projects needs to be carefully considered for balancing the negative and positive social, cultural and environmental changes that they may experience. © Andrea Avila Alfaro firewood collection, farming, or herding on land earmarked for compulsory acquisition may be destabilized. The restoration of livelihoods should thus include a range of measures to mitigate the effects of economic displacement and provide opportunities for affected communities (Picciotto, 2013).

Furthermore, LTI projects may also contribute to sudden changes in the demographics of rural, marginalised or Indigenous communities during construction and operation. Population increases from relocation of construction and operations workers can affect communities that may not be resilient to the sudden influx of new cultures, which can lead to a cultural weakening of local communities. These fluxes can also occur after the road or railway has been built as new migrants arrive and settle.

Frameworks for participation

The right to public participation in public affairs and governance, including in proposed LTI projects, is enshrined in various international frameworks, including the International Covenant on Civil and Political Rights (ICCPR, 1966) and the Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters. Public participation ought to be full, effective and genuine and ensure that the public is wholly informed of the proposed infrastructure project and its likely impacts (Aarhus Convention, 1998). Public participation must therefore allow for the timely airing of views, ideas, sentiments and concerns when decisions about projects are being made especially with regard to communities adjacent to the infrastructure right-of-way. For instance, any changes in construction routes or schedules, constraints on the types of land use, restrictions on activities in easements or lands near linear infrastructure, risks associated with the linear infrastructure and possible emergency responses should be explained to the public.

Public participation allows local, traditional and Indigenous knowledge to enrich project design and inform decision making, thus helping to avoid, minimise, mitigate, restore and compensate (or offset) for potential impacts (UNEP, 2002). Local knowledge of social or cultural activities (e.g. religious shrines), local information on daily non-motorized routes of a community (cycling, walking or running), wildlife migration routes and livestock dispersal, as well as grazing routes among others can help project designers to mitigate disruptions from the project.

Free, Prior and Informed Consent

Free, Prior and Informed Consent (FPIC) is a legal principle (UNDRIP, 2007), framework and process that should be applied to all development projects that may affect livelihoods,

Community members gather under Route 1 in a wildlife underpass used by jaguar (*Panthera onca*), part of road ecology training for practitioners in the greater Mesoamerica Region, Guanacaste, Costa Rica. © Daniela Araya-Gamboa

Stakeholders gather at the Hanoi International Forum on Sustainable Infrastructure: Integrating Climate Resilience and Natural Capital into Transport Infrastructure Planning and Design. © Rodney van der Ree

Key information – Free, Prior and Informed consent consists of the following:

- **Free –** Consent should be voluntary. Negotiations towards consent should be devoid of coercion, bribery, intimidation and manipulation (FAO, 2020).
- **Prior –** Negotiations for consent should sufficiently precede any development or infrastructure project that affects the lands and livelihoods of Indigenous, marginalized, rural or local communities. Consent ought to be given before any projects are authorized or commenced (OHCHR, 2013).
- **Informed –** Indigenous, marginalized, rural, or local communities must be provided with full and accurate information about a proposed project and its impacts. Information provided must be in a language and manner that the community understands (OHCHR, 2013).
- **Consent –** Refers to decisions made collectively by affected communities. Consent can be the result of formal or informal decision-making processes, whichever are commonly used by a community to make decisions. Communities may grant consent, give conditional consent or withhold consent (OHCHR, 2013).

resources or lands of Indigenous, marginalized, local or rural communities. FPIC as a best practice can also be applied to LTI development in and around PCAs, areas important for ecological connectivity, and among communities of people living adjacent to or within such areas. FPIC is based on the principle and right of self-determination that allows communities to control their own destinies and resources by determining the sort of development they desire, rather than having it imposed on them (UNDRIP, 2007). Additionally, FPIC has been highlighted as a fundamental component of sustainable development in multiple international legal principles, norms and policies, including the United Nations Declaration on the Rights of Indigenous Peoples. Regional conventions like the Revised African Convention on the Conservation of Nature and Natural Resources (Maputo Convention, 2003) also require prior, informed consent of affected communities. Importantly, FPIC should not be used as a form of inclusionary control, in which project details and impacts are glossed over and subsequent consultations manipulated towards a specific end.

Community members gather to consult with the Ministry of Public Works and Transportation on road improvements, including paving and the construction of three bridges, to provide year-long access between an Indigenous community and the nearby town of Alto Conte, Costa Rica. © Andrea Avila Alfaro

Relevant and readily available information

Access to timely and relevant information is a precondition for public participation and for FPIC to be viable and legitimate (Creighton, 2005; UN-REDD, 2013). Such information includes the proposed route and design of a project, as well as anticipated environmental, social, economic and cultural impacts (Rio Declaration, 1992). This is because the public can only make an informed decision after being fully briefed (UNCHR, 2005) and information should be relayed in a language and manner that communities are able to follow and comprehend (Saramaka People v. Suriname, 2007). Access to public information therefore obligates governments and project proponents not only to abstain from restricting the flow of information, but also to publicise and impart knowledge. Additionally, information should be available to any person upon request without their having to justify their interest. In view to shaping LTI projects, information about the financial and commercial contracts and transactions that affect the public, PCAs, ecological connectivity and wildlife should also be made available. Importantly, the role of corruption in large-scale infrastructure projects involving multinational companies and governments cannot be ignored, since opacity of contracting in some infrastructure projects may facilitate corrupt practices in public participation, land acquisition, population resettlement, and EIA licensing, or even in the initial justification for the proposed infrastructure.

Access to justice

Access to justice is recognised as a right in the Universal Declaration of Human Rights and in the International Covenant on Civil and Political Rights. International conventions like the Aarhus Convention, Escazú Convention, and Rio Declaration (Principle 10) and the UN Sustainable Development Goals (Goal 16) also affirm this right. This principle is critical to safeguarding the rights of access to information, public participation and FPIC, which together ensure that the public and nearby communities can contribute to decisions about infrastructure projects that affect them (Rio Declaration, 1992). Such access refers to the availability of legally recognised systems to resolve disputes and the ability to engage in dispute resolution without systemic barriers such as the cost of legal advice and representation (Rio Declaration, 1992). It guarantees the availability of a review procedure to challenge a decision, act, or omission by a private body or public authority before a court or independent and impartial body (Ebbesson & Okowa, 2009). For instance, if the right of access to information has been contravened or an EIA licence irregularly issued, the public should have an avenue to challenge such acts or omissions.

In such cases, an administrative or judicial dispute resolution process should be expeditious to avert a potential danger or wrong by avoiding environmental damage before it occurs or by restoring damages sustained and determining other punitive measures for perpetrators. National administrative, legal and judicial systems and mechanisms that guarantee timely access to justice must therefore be in place. However, access to justice is frustrated if a dispute resolution process drags on while an alleged wrong is ongoing and environmental damage continues unabated. Governments, public bodies and project proponents must adhere to the decisions made by dispute resolution bodies and be prepared to enforce them.

The role of public participation in environmental impact assessments

EIAs are a systematic and methodical process to examine and predict the likely effects of a proposed development project on people and the environment and to maximise positive environmental and social outcomes (see Chapter 5). The format, practical details and terms of reference of an EIA are determined by national laws and may differ among jurisdictions and proponents (Hasan et al., 2018). For example, some jurisdictions specifically mention social considerations in the title (i.e. Environmental and Social Impact Assessment (ESIA)) to ensure social aspects are thoroughly considered and not ignored, despite the fact that an EIA should address social, environmental and economic impacts. In other contexts, cumulative impacts may also be considered. In all cases, public participation in the EIA process needs to occur throughout and, as an absolute minimum, via public exhibition of the report (Glucker et al., 2013). Importantly, studies have shown that projects with comprehensive and genuine public participation result in enhanced social and environmental outcomes, less conflict and more transparent decision making (Rega & Baldizzone, 2015). Finally, the means of engagement must be appropriate to the target audience and be two-way, thereby enabling review and critique by all interested individuals and groups, and the project proponent should respond to each point raised during the public exhibition.

Box 8

Stakeholder engagement in Kenya's Standard Gauge Railway Phase 2A (Nairobi City – Naivasha Town Industrial Park – Narok Town)

Key lesson: Without proper enforcement mechanisms, project proponents may ignore calls from stakeholders to modify or halt construction.

The Standard Gauge Railway (SGR) Phase 2A was commissioned by the Kenya Railways Corporation as the project proponent and contracted to the China Road and Bridge Corporation to link Kenya's capital city of Nairobi to the towns of Naivasha and Narok. The SGR is a small portion of an ambitious East Africa Railway Master Plan that envisions a rail system linking eight countries.

The East Africa Railway Master Plan is highly important to the economic development of countries in the region. However, it is equally imperative that environmental laws and regulations are adhered to during implementation of such large infrastructure projects. Kenya's laws require that an independent EIA be conducted, which must include public participation as a key legal component. The resulting EIA report is then submitted to the National Environment Management Authority (NEMA) for approval and licensing. Once NEMA receives an EIA report, it is evaluated, public comment is invited, and additional public hearings may be held.
However, a number of irregularities were noted during the Kenya Standard Gauge Railway EIA reporting and approval process. These irregularities should have been addressed during the process, or invalidated the EIA. Some of the irregularities include:

- A predetermined decision to route the SGR through Nairobi National Park despite opposition expressed by different stakeholders during public participation and suggested alternative routes that had a lower impact on Nairobi National Park;
- Publication of an unsigned and undated EIA report by the project proponent;
- Omitting written comments made by stakeholders during public participation;
- Not providing full access to relevant information collected concerning the project during the EIA process;
- Continuation of construction despite the issuance of a stop order by the National Environment Tribunal for all project activities; and
- Failure to meet the required time frame for public notice prior to holding some public hearings and thus preventing some stakeholders from attending and contributing to the public hearings.

The project went ahead and was completed despite the noted irregularities and a stop order. The effects of the SGR on the park include vibration and noise pollution; landscape/aesthetic degradation; and additional fragmentation of the park ecosystem which already faces severe pressures from urbanisation and a road bypass that had been previously

Box 8 (continued)

Construction activity of the Standard Gauge Railway Phase 2A in Kenya, bisecting Nairobi National Park between the port city of Mombossa and the capital city of Nairobi © Eliud Ndung'u

constructed on land carved off from the park (Nyumba et al. 2021; Okita-Ouma, et al. 2020). In this case, even with regulatory mechanisms in place, NEMA allowed the proponent to bypass laws and commit irregularities. This is a concerning example of the government endorsing requirements for public participation, but failing to heed public concern, and ultimately, to comply with its own regulatory requirements.

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Box 9

Coalition of women assist Costa Rica to build wildlife-friendly roads

Key lesson: An initiative to create a landmark best practices document for wildlife-friendly roads was organised by volunteers with minimal funding and full support and participation of the public.

In 2012, several members of the public asked the Costa Rican Ministry of Transportation to implement a range of measures to reduce the environmental impacts of roads on wildlife. The Ministry agreed that the sustainability of transportation infrastructure in Costa Rica needed to be improved, but they required guidance and assistance to achieve that goal.

Between 2013 and 2014, a group of six women from academia, conservation NGOs and government prepared technical guidelines to reduce the ecological impacts of roads and traffic. The guidelines focused on environmentally sensitive areas and wildlife, and also included a legislation section to support the implementation of measures on roads for wildlife. To ensure that the guidelines were both comprehensive and achievable, a series of workshops with scientists, academics, government, practitioners, financial agencies and environmental consultants were held in 2014. In 2015, a draft was circulated to national and international reviewers. Subsequently, the recommendations were incorporated into the final document titled *Guía Ambiental: Vías Amigables con la Vida Silvestre,* which was officially adopted by the Ministry of Environment in 2015 (Pomareda et al., 2015).

This initiative was developed without a specific budget and made possible by the voluntary collaboration of its authors and their organizations. In another demonstration of the role and value of public participation, a group of elementary schoolchildren raised funds to print the guidelines, enabling the distribution of the document to key entities and stakeholders. While the guidelines remain recommendations, rather than formal policy, the Costa Rican Ministry of Transportation has been using them since 2016 to identify and implement mitigation measures on new roads across the country.

Reference

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The Comité Científico de la Comisión Vías y Vida Silvestre, a group of six women from academia, conservation NGOs, and government, who prepared technical guidelines to reduce the ecological impacts of roads and traffic across Costa Rica © Comité Científico de la Comisión Vías y Vida Silvestre

Key messages in this chapter

- More holistic and integrated approaches to linear infrastructure development are necessary to better account for the individuals and communities – especially rural, marginalized and Indigenous communities – that may be disrupted through resulting resettlement, economic displacement, and social, cultural, and environmental changes.

- The right to participate, including Free, Prior and Informed Consent (FPIC), in the development of LTI projects, is enshrined in a variety of international and regional covenants and agreements that guarantee full, effective, and genuine public participation in public affairs and governance.

- Public access to timely and relevant information is necessary for FPIC to be realised, and this includes proposed routes, project designs, and anticipated environmental, social, economic and cultural impacts of LTI projects.

- Access to justice is critical for the public to have remedies for challenging decisions, acts, or omissions associated with the right to participate in EIA processes.

Part 6

Financing safeguards for linear transport infrastructure

Bengal tiger (*Panthera tigris tigris*) in Tadoba National Park, India. India's highly populated landscape leaves narrow, yet essential tiger movement pathways through and around towns and infrastructure. © Grégoire Dubois

The creation and management of PCAs is an increasing focus of financial investment for protecting the environment, especially in the form of official development assistance (ODA) that can support nature-based economic development. This is premised on providing jobs and generating revenue through such approaches as nature-based tourism and payments for ecosystem services, while at the same time contributing to biodiversity conservation and climate resilience efforts (Emerton et al., 2006). Yet, the investments made to conserve biodiversity, particularly to increase the extent and management of PCAs and ecological corridors can be undermined by the LTI projects that are often financed with the intent to promote economic prosperity and alleviate poverty.

Many LTI projects fail to achieve these aims and increasingly contribute to the degradation of natural systems that people depend on for their health and livelihoods (Arcus Foundation, 2018). Traditionally, LTI projects, especially in developing countries, have been financed via public resources, namely tax revenues and government borrowing. While the demand for the provision of more LTI and improved transport services is growing – particularly in emerging economies – the public revenues available for transport spending are becoming more uncertain (Woetzel et al., 2016). Overall, levels of public sector debt in developing countries stand at record levels, and many countries have seen their budget deficits increase in recent years.

In response, public and private sector institutions play increasingly important roles in the identification, financing and management of LTI projects. These institutions can be broadly categorised as: (i) international financial institutions (IFIs), including global, regional and sub-regional development banks; (ii) bilateral institutions; and (iii) private or commercial financial institutions. With the launch of China's Belt and Road Initiative in 2013, there has been a significant increase in global financing of LTI across all categories of financial institutions.

This chapter summarises the different types of financial institutions, the polices of major institutions regarding safeguards for biodiversity and addresses recent changes that may impact or affect their biodiversity objectives. It then concludes with emerging trends of new entrants from China and the policies directed towards client countries including investors of the BRI. It is important to note that the specific architecture of entities financing transportation projects in developing countries is more nuanced than reported here and that this chapter offers a necessarily limited review into these organizations.

International financial institutions, multilateral finance and official development assistance

International development finance is the primary source of money to supplement domestic funding (e.g. tax revenues, vehicle licensing fees, fuel levies, etc.), and ODA remains the dominant source of external funding for transport infrastructure. International financial institutions (IFIs), including several multilateral development banks (MDBs) have historically supported the development of LTI projects through the provision of ODA and, recently, new MDBs such as the Asian Infrastructure Investment Bank (AIIB), the New Development Bank (NDB) and the China Development Bank (CDB), have emerged as important actors in supporting LTI in developing countries.

The lending policies of IFIs strive to provide lower than commercial rates to sovereign (public) clients. The rates and terms of lending often depend on the borrowing country's gross national income per capita. Low-income countries can benefit from grants and concessional loans (rates, grace and repayment periods significantly better than at-market rates). Middle and high-income countries receive lending at near market rates. All countries are encouraged to benefit from other IFI services such as capacity-building, institutional strengthening and upstream planning. IFIs utilise a variety of financial instruments (debt, guarantees, grants) to invest in, or fund, both the planning and operation of a range of projects, including LTI. MDBs typically support governments through the financing of sector plans (e.g. transport master plans, SEAs) and project-specific preparatory studies (e.g. pre/feasibility analyses, EIAs, cost benefit analyses) to assist governments in their efforts to realise the need for additional transport infrastructure.

For projects, IFI operations manuals provide the policies, directives and procedures that apply to an IFI's business processes. They can be loosely categorized into (i) project financing, (ii) environmental and social, (iii) procurement, and (iv) institution-specific policies. Environmental and social safeguard policies are relevant to PCAs, biodiversity and natural habitat protection. Approximately half of the MDBs have some form of institutionalized safeguards.

Even though IFIs have their own sets of environmental and social standards, the policies look similar across most MDBs with the policies of the World Bank Group (i.e. International Bank for Reconstruction and Development (IBRD), International Development Association (IDA), International Finance Corporation (IFC), and others) setting a standard (see Annex 1). The World Bank's 2018 Environmental and Social Framework for public clients, and the International Finance Corporation's 2012 Performance Standards (Chapter 3), for private clients are considered good industry international practice for multilateral, bilateral and commercial loans (Losos et al., 2019). In time, other IFIs will likely revise and harmonise their environmental, social and governance (ESG) policies with these in mind.

The World Bank updated its previously numerous ESG policies in 2018 and combined them all under a single Environmental and Social Framework (ESF). This ESF makes it easier for borrowers to comply with and the Bank to respond to, "a growing demand for lending operations to be more efficient, for due diligence to be more flexible, and for greater reliance on host country environmental and social standards" (Losos et al., 2019) which are less likely to be as strict (Dollar, 2018). Other institutions are slowly updating their policies to reflect the World Bank's new ESF.

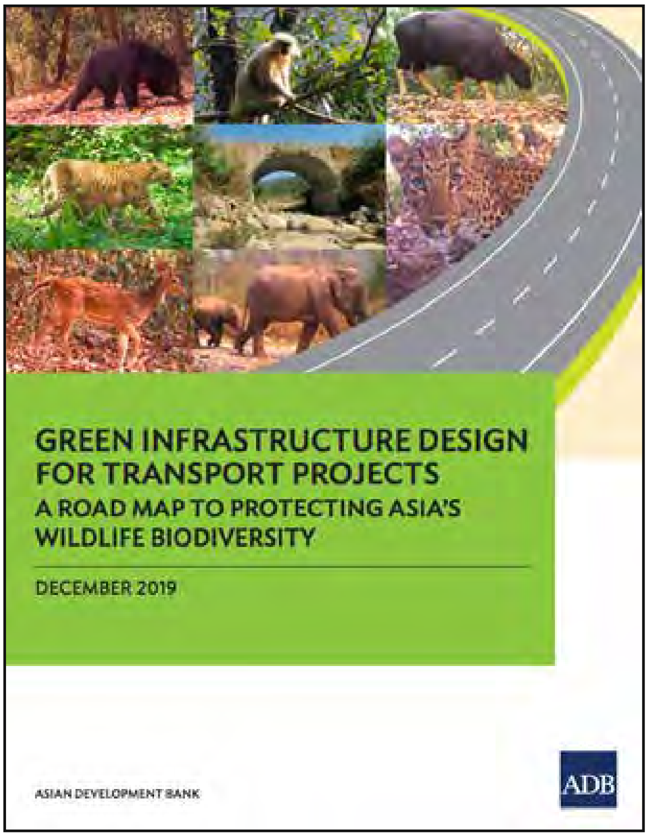
The World Bank ESF comprises 10 Environmental and Social Standards (ESS), with ESS1 (processes and mitigation hierarchy) and ESS6 (biodiversity) of highest relevance to PCAs, biodiversity and natural habitat protection. The IFC provides private sector lending and addresses mitigation of environmental and social impact under their Performance Standards (PS). Performance Standard 6 is analogous to ESS6 and aims for a net gain of Critical Habitat and no net loss of Natural Habitat. Application of PS6 is site-specific and is a significant undertaking that requires an early start with project planning and integration with an EIA (Biodiversity Consultancy, 2020). The IFC monitors the implementation of the Performance Standards based on a client's observed ability to achieve them. Clients with robust and effective systems receive an annual audit, whereas clients requiring corrective actions can receive up to quarterly audits.

Bilateral finance

While the traditional sources of bilateral aid (direct government to government) are well known and widely used, multiple new and expanding sources of bilateral funding, in particular from China, are less known and increasingly exploited. The European Union provides funding to transport infrastructure projects through its European Development Fund to African, Caribbean and Pacific countries. The US Government, through its development finance mechanisms (e.g. the US Agency for International Development, the Millennium Challenge Corporation and the Development Finance Corporation) support emerging market transport infrastructure projects. Unlike the MDBs, bilateral donors do not *necessarily* adhere to a common set of policies associated with their approvals process and may set specific requirements related to funding approvals.

Private and commercial bank finance

Among the potential expanded opportunities for financing LTI in developing countries are those provided by the private sector. As demands for investment in transport are increasing, the MDBs and other financial institutions are finding ways to leverage private finance. The leveraging strategy has been moderately successful for bankable' transport projects (e.g. toll roads and rail), and typically only in countries with stable, investor-friendly enabling environments. Private finance may be defined as term-limited (specific duration of investment) or open-ended (sustained ownership or management of an asset) and is more frequently used to finance existing assets as opposed to new or greenfield development projects.



The Asian Development Bank's 2019 guidance outlining the awareness, commitments and opportunities to protect Asia's biodiversity during the design and implementation of transport infrastructure projects © Asian Development Bank

The World Bank's Environmental and Social Framework defines its commitment to sustainable development, with the aim of ending extreme poverty and promoting shared prosperity, and makes it easier for borrowers to comply with standards, including the mitigation hierarchy and biodiversity protection. © The World Bank

Construction of a toll road through a rural area, intended to replace an existing road © Alex Traveler / Adobe Stock

In developing countries, private investors are known to cut construction costs for profit, building deficient infrastructure that over time can require much more maintenance that countries may have to assume. © Adobe Stock

While private or commercial lending institutions adhere to their own lending and safeguard policies, their ESG considerations are increasingly prevalent and feature as important decision-making and planning criteria. Generally, ESG factors in infrastructure investing create a unique set of challenges for investors. With best practices and industry guidelines such as the Equator Principles (Figure 16) set by the MDBs, many investors feel that the environmental element of ESG can be managed effectively under the appropriate ESG management system. The social aspect of ESG, specifically stakeholder engagement and consultation, land acquisition and resettlement are much more dynamic and unpredictable elements. As stewards of investors' capital, it is critical that an investor maintains its social licence to operate from the community, otherwise the financial and reputational ramifications can be catastrophic.

Public-private partnerships

Most direct private finance in transport infrastructure comes via public-private partnerships (PPPs). Though commonly assumed that the private sector provides the majority of financing for PPPs, analyses indicate that PPP financing in developing countries actually comes from a diverse mix of sources, with strong roles played by both the public sector and development financing institutions (UNECE, 2017). MDBs and bilateral institutions are the most active in International Development Association (IDA) countries, playing a key role to mobilize private sources of financing in countries where private lenders may not otherwise be comfortable taking country risk.

Figure 16: The Equator Principles are best practices and industry guidelines set by the MDBs that can help project teams more effectively manage the environmental elements of projects. © Mary Collins / CLLC

Support for the adoption of PPP programs to deliver investment in transport infrastructure is by no means universal, although it can be a condition of finance being made available. An advantage of a PPP in the transport sector is that infrastructure is developed and services delivered according to objective standards, or private providers suffer financial and operational penalties that can lead to contract termination. The disadvantages generally result from contracts that are not well specified or executed. This can include a lack of flexibility or inappropriate transfer of risk, leading to high costs or poor value for money.

Chinese investment in infrastructure development and the Belt and Road Initiative

Among other massive infrastructure development plans around the world, China's Belt and Road Initiative (BRI) is deserving of particular attention for its size and scope (Hughes et al., 2020; Narain et al., 2020; Ng et al., 2020). In 2016, China launched the Asian Infrastructure Investment Bank (AIIB) and the New Development Bank (NDB) which is a reformation of the BRICS Development Bank, originally constituted by Brazil, Russia, India, China and South Africa in 2013. AIIB published their Environmental and Social Framework in 2016 (AIIB, 2019) which lists "Conserving Biodiversity" as Objective 17 with further elaboration in its Environment and Social Standard 1 (ESS1). In contrast, the NDB uses the national systems of the member countries, which typically have lower standards, instead of commonly agreed safeguards to address environmental, social and procurement risks. China's policy banks, the China-Exim and the China Development Bank provide most of the lending but not at the expense of other regions (Dollar, 2018). A listing of Chinese bank environmental policies and further discussion of their relative strengths can be found in Annex 1.

Additional financing considerations: operations and maintenance funding

Studies of road systems in developing countries over the past few decades have consistently shown that road maintenance is underfunded and often inefficient (Obeng & Tuffour, 2020). Many countries have addressed underfunding by earmarking specific tax revenues to road funds. Over 20 countries have introduced a new model of road funding. This includes governments setting the level of general revenue taxes, and (in theory) road boards — with significant stakeholder

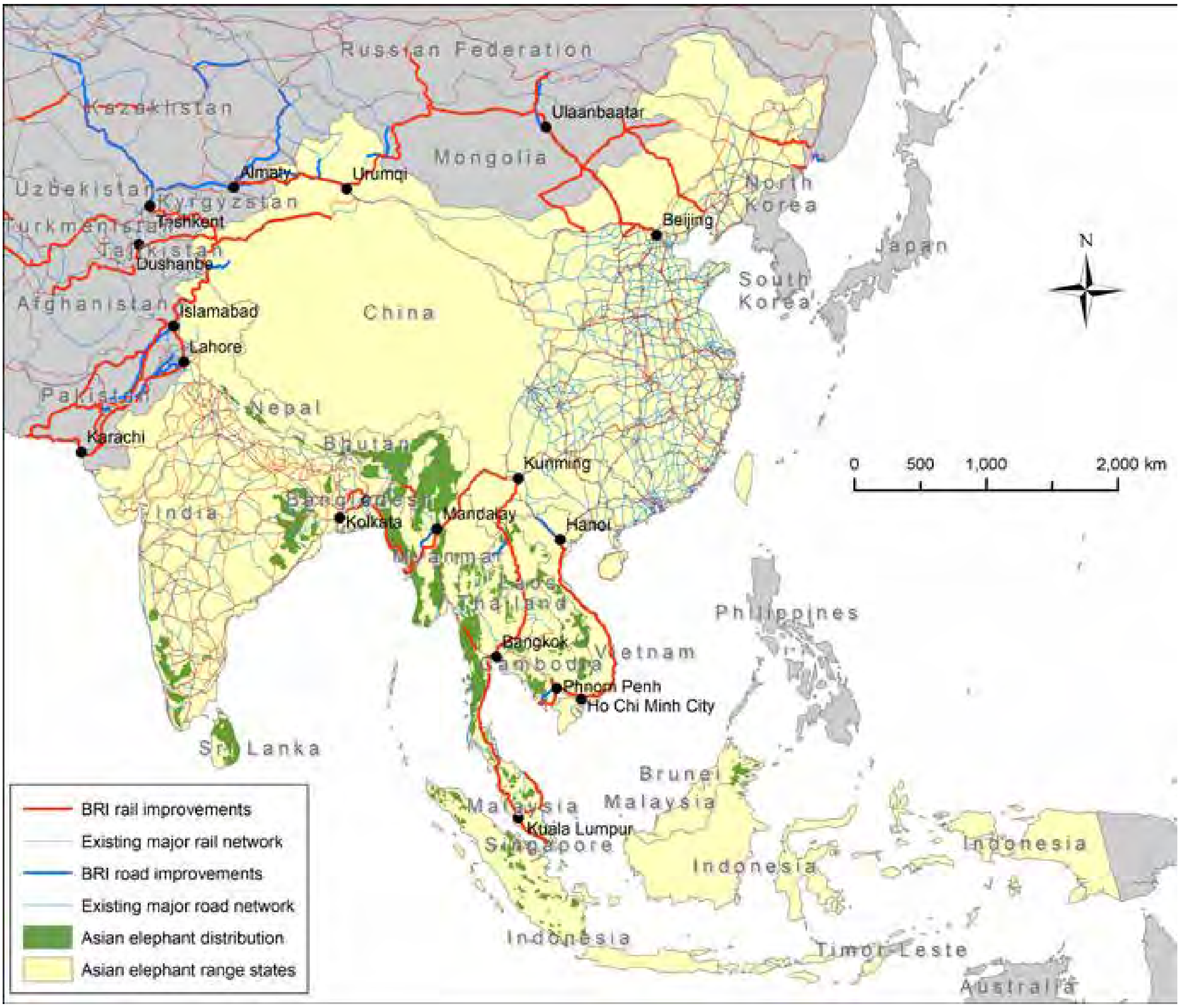


Figure 17: Map of Asian elephant distribution and the larger regional context of China's Belt and Road Initiative based on best available data in 2021 © Tyler Creech / CLLC

representation — determining the road user charges and controlling the revenue from them (Heggie, 1995). Separate agencies are then responsible for actual road maintenance. This approach is supposed to reduce rent seeking and make resource allocation more efficient by creating an explicit link between what users pay for roads and the quality of the roads available to them. Under these second-generation road funds, fuel taxes include both general revenue taxes and road user charges. Funding of adequate operations, and specifically maintenance is often a major factor when considering the viability of transport infrastructure.

Environmental and social due diligence

Most lenders will conduct some degree of environmental and social due diligence of projects proposed for support prior to financing approval. The purpose of the environmental and social due diligence is to assist the lender in deciding whether to provide support for the proposed project and, if so, the way in which environmental and social risks and impacts will be addressed in the assessment, development and implementation of the project. The due diligence will assess whether the project is capable of being developed and implemented in accordance with defined safeguards. The World Bank's safeguard policies present a useful lens through which best practices related to environmental and social due diligence and lending requirements may be viewed and Annex 1 summarises the different policies of the major IFIs which largely align with those developed by the World Bank.

Improving financing and environmental outcomes

Choosing sources of financing: The choice of funding for transport infrastructure is not intrinsically linked to the model employed to deliver the project. However, the instrument for financing will have a profound impact on how

Construction of the 414 km Laos - China high speed railway brings infrastructure prominently in view of a rural home in Laos. The rail cuts through 167 Laos villages, and research has shown that many people in the affected villages were unclear about plans, timelines, land compensation processes and the ability to comment on construction. © Jessica DiCarlo

each funding model functions. Thus, choosing which mix of taxes and user charges (or public and private capital) to employ is a fundamental sovereign risk and must be undertaken by governments in advance of designing the model by which the transport infrastructure and transport services will be delivered.

Availability and delivery of data will drive development: New patterns of service needs and delivery will only be discernible if we have the data to identify them. The accessibility and accuracy of this data varies considerably, and governments must take a systematic and holistic approach towards data governance which balances data availability with privacy concerns.

Addressing sustainability through operations and maintenance: In addition to justifying a project based on sector planning, engineering designs and EIAs, funders generally also assess the sustainability of the proposed investment over time. For example, the asset lifetime of roads is considerable (20+ years) if appropriately maintained. However, maintenance is typically a lower priority in many developing countries and funders will take the availability and execution of maintenance into consideration.

Box 10

Hanoi Forum on Sustainable Infrastructure: Integrating climate resilience and natural capital into transport infrastructure planning and design

Key lesson: A forum organised for the first time to unite government, industry, financial institutions and NGOs has addressed new ways of financing ecologically sustainable infrastructure.

This unique and first-of-its-kind forum was co-organised in 2017 by the Asian Development Bank, the World Wildlife Fund, the Viet Nam Institute of Strategy and Policy on Natural Resources and Environment, and the Greater Mekong Subregion Environment Operations Center. The event convened planners, ecologists, engineers and climate specialists alongside government ministries, multilateral banks, bilateral aid agencies, infrastructure finance investment firms, NGOs and academia. The forum challenged participants to design infrastructure without eroding the ecological integrity or natural capital of the lands they pass through.

Box 10 (continued)

These forums normally bring together experts to talk about finance, or climate change, or ecology, but rarely at the same forum and usually speaking different languages. The Hanoi Forum aimed to bring these streams together in one place, for all to begin speaking the same language and work together on integrated solutions. Organisers used interactive approaches including a "Trade-Off Infrastructure" game developed by The Natural Capital Project (Stanford University) to get experts talking to each other about solutions for infrastructure challenges. On the finance side, participants discussed principles for incorporating environmental, social, and governance risks into infrastructure designs.

The forum developed key principles for making infrastructure more sustainable. While a range of topics were covered – including policy, planning, design, and finance – the overwhelming consensus was that planning for infrastructure should start early, at national and landscape scales, well before a specific project is initiated to allow for integrated, multi-sectoral priority setting. This involves diverse stakeholders and should be informed by strategic environmental and climate assessments. These are called the *Hanoi Principles for Sustainable Infrastructure.* Under the theme of Facilitating Finance for Sustainable Infrastructure', three financing principles were developed:

- *Principle 1:* Develop financing systems and national policy to channel government funding and also attract international and private funding to ensure sustainability and resilience aspects of infrastructure projects.
- *Principle 2:* Consider the full scope of impacts of infrastructure projects including comprehensive risk analysis (climate, disaster, and other finance related risks) using the widest range of tools and methods (EIA, SEA, etc.).
- *Principle 3:* Promote mechanism to monetise environmental risks and bring out the full environmental cost of new infrastructure projects and "build metal bridges" between green and finance worlds.

The forum was the first of its kind, bringing together biologists, engineers, planners, multilateral banks, aid agencies and economists. Currently the principles are being refined, while case studies and guidance materials are being created to put into practice in Asia, Africa and Latin America where global infrastructure development is accelerating dramatically.

Reference

Asian Development Bank (ADB) (2017). Forum on sustainable infrastructure: Integrating climate resilience and natural capital into transport infrastructure planning and design – Event briefer (17-18 May 2017), Hanoi, Viet Nam. Available at: http://www.gms-eoc.org/uploads/resources/1192/attachment/Sustainable%20Infrastructure%20-%20Forum%20Briefer.pdf (Accessed 16 March 2022).

Participants at the Hanoi Forum play "Trade-off Infrastructure," a game designed to spark discussion about infrastructure challenges and solutions.

Box 11

USAID review enforces environmental safeguards on the Narayanghat – Butwal (NB) Road, Nepal

Key lesson: Deficient EIAs can result in inadequate safeguard recommendations and trigger a suspension of financial assistance for LTI projects. This project was temporarily halted based on Asian Development Bank (ADB) and client commitments to environmental safeguards.

The ADB-financed Narayanghat to Butwal (NB) road improvement project traverses the Terai Arc lowlands in Nepal. This 115 km-long project involves the expansion from two to four paved lanes, and contains 24 km of road adjacent to the buffer zone of Chitwan National Park. Eight forest patches 47 km in length are crossed by the NB road. These forest patches serve as important biological corridors for animal movement between the National Park and the Terai Arc Landscape. The road project will result in increased number of wildlife road kills; increased poaching due to improved access; and limits to animal movement due to habitat alteration and increased vehicle and human activity.

Roadside grading with revegetation after construction, part of a revised mitigation strategy for the Narayanghat – Butwal (NB) Road, Nepal © Pramod Neupane

The USAID review (Dear et al., 2019) found numerous project deficiencies related to insufficient use of guidelines; flawed pre-construction wildlife analyses; mitigation recommendations not meeting international standards; failure to consult subject experts; and budgets inadequate to support necessary safeguards.

Wildlife data were re-analysed in a baseline biodiversity assessment. This work resulted in a mitigation strategy consisting of 112 wildlife underpasses and two wildlife overpasses (50 m wide) along the 115 km section of NB road. The revised safeguards strategy reflects a joint commitment by the Nepalese government and ADB to develop a more comprehensive approach to preserving biodiversity.

One of 112 wildlife underpasses installed along the 115 km road as part of a revised mitigation strategy for the Narayanghat – Butwal (NB) Road, Nepal
© Pramod Neupane

Reference

Dear, C., Melnyk, M., Sharma, N., Berg, K., Ament, R., Shrestha, M., and Pariwakam, M. (2019). *Post-approval field review report, SASEC Roads Improvement Project, Asian Development Bank, Nepal.* Washington, DC: USAID.

Key messages in this chapter

- Unless environmental and social due diligence is addressed across the identification, financing, assessment, development and implementation of projects, investments in LTI will contribute to the degradation of natural systems and undermine other investments in biodiversity objectives, including PCAs, ecological corridors and ecological networks.

- Although projects, especially in developing countries, have traditionally been financed via public resources, there is now a greater diversity of mechanisms, including international financial institutions (IFIs) – such as global, regional and subregional development banks, other bilateral institutions and private or commercial institutions – that are providing vast amounts of funding that have varying policies toward financing projects and requiring and fulfilling environmental and social due diligence.

- Approximately half of all MDBs have some form of institutionalized environmental and social safeguards, and many are similar and aligned with leading World Bank Group standards, such as the Environmental and Social Framework (ESF) for public sector lending and the International Finance Corporation's (IFC) Performance Standards for private sector lending.

- China's Belt and Road Initiative (BRI) and involvement in LTI projects around the world is financed through a diversity of mechanisms that are evolving to meet international environmental norms, including the Asian Infrastructure Investment Bank (AIIB), New Development Bank (NDB), China-Exim Bank and China Development Bank.

- The ongoing development, improvement and adoption of environmental and social safeguards by financial institutions is a key step towards sustainable infrastructure projects. However, there remains considerable room for improvement in the details of each safeguard and the outcomes of their implementation.

Part 7

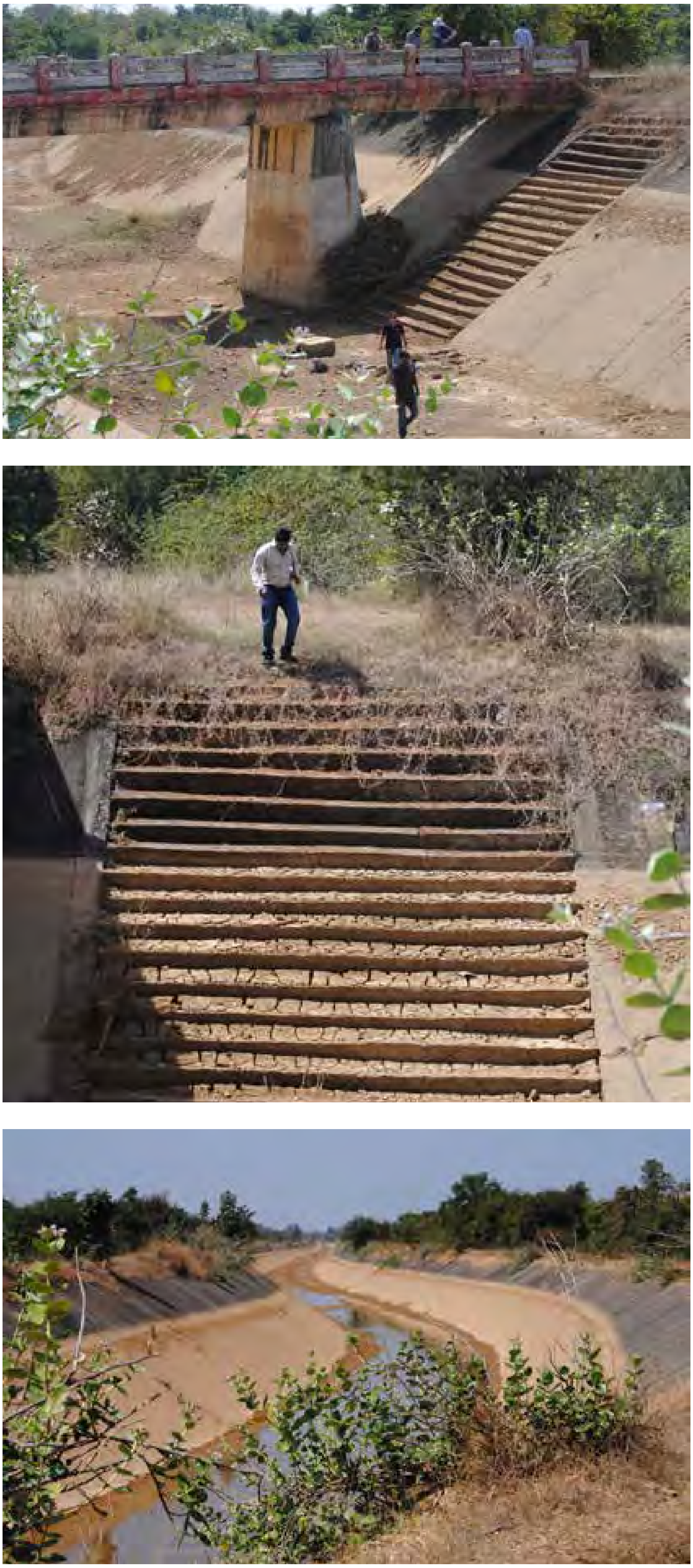
Mitigation measures to reduce wildlife mortality and maintain ecological connectivity across roads, railways and canals

Malaysian sun bears (*Helarctos malayanus*) are vitally important to seed dispersal, pest control and nutrient cycling across their historical range. However, their vulnerable populations are increasingly fragmented due to human infrastructure and development. © Gary Tabor

The effective management of PCAs, the conservation of ecological connectivity and the needs of wildlife should be considered at the beginning of the planning phase of LTI projects. This can most efficiently and effectively avoid, minimise, mitigate, restore, and compensate (or offset) for ecological impacts. By genuinely following the mitigation hierarchy (Chapter 4), projects achieve improved environmental, social and economic outcomes. Where impacts are unavoidable, significant effort should be made to minimise negative effects and, when necessary, apply appropriate mitigation measures. These measures should be aimed at maintaining, enhancing, and restoring ecological connectivity, preventing or reducing wildlife mortality and lessening other impacts.

Specially designed wildlife crossing structures such as underpasses or overpasses with accompanying directional fencing are effective mitigation strategies for decreasing WVCs and for increasing wildlife movement (van der Ree, 2007; Rytwinski et al., 2016). In the case of canals, ramps, stairs and other structures can enable wildlife to escape and reduce rates of drowning. Non-structural mitigation techniques such as signage, vegetation management, lighting, movement detection or other strategies may also be employed. However, these are either completely ineffective or often significantly less effective at safeguarding connectivity and reducing rates of mortality compared to wildlife crossing structures and fencing (Huijser, et al., 2022).

To accomplish successful and cost-effective conservation outcomes, LTI projects require close cooperation of infrastructure planning institutions and natural resource conservation experts. Furthermore, national and local policies that support and incentivise interagency and interdisciplinary collaboration are needed to avoid or reduce the loss of ecological connectivity due to LTI (see Chapter 4). Where present, such policies also contribute to the protection of overall biodiversity in an efficient manner. It is almost always more cost-effective to install wildlife crossing structures and other mitigation strategies during the initial construction of projects, rather than to retrofit them into existing infrastructure later. However, upgrades and improvements to existing roads, railways and canals provide important opportunities to restore connectivity and reduce mortality. Targeted mitigation on existing transport networks should also be considered where high priority species,



Top: Egress steps next to a wildlife crossing structure over a canal in central India. Middle: Sediment from canal water has partially filled many of the lower steps. Bottom: An unmitigated portion of the same canal © Robert Ament habitats or ecological corridors are impacted, independent of any planned upgrade works.

Defining mitigation objectives

An important step in implementing effective mitigation measures is to define the objectives, such as to improve motorist safety or increase connectivity for wildlife. Ideally, the objectives are specific enough to enable a rigorous assessment of success (see Chapter 8). Identification of the target species or group of species for mitigation is critical because wildlife perceive the landscape and potential threats in varying ways, and accordingly, often require different solutions (Brennan et al., 2022).

One or more target species are typically selected as a focus for planning and design, with the idea that, for example, a wildlife crossing structure designed for the target species or group can also serve as a passageway for other species. However, some species have very specific needs, such that effective mitigation measures may not encompass the needs of other species. Target species vary widely and may be rare or endangered species. They can also include large-bodied species commonly involved in WVCs that may cause injury and death to motorists (such as elephants, deer, moose or kangaroo). Large carnivores are also ideal target species whose extensive territories render them likely to encounter LTI. In other cases, amphibians and reptiles are frequently subject to mortality where their territories are bisected by roads. Fish and other aquatic wildlife can also serve as focal species in certain cases, as can birds and bats. While mitigation strategies for some species are well-understood, for many others, much less is known. This is especially the case in Asia, Africa and South America, where transport ecology is still an incipient field. In these circumstances, a generalised approach using species guilds based on physical characteristics and anti-risk adaptations may be helpful (Kintsch et al., 2015). In situations where there is high uncertainty about the occurrence of a species, the likely impacts of a project or the effectiveness of mitigation, field surveys, adaptive management and experimental trials should be undertaken.

Large herbivores

Ungulates (hoofed mammals) occur naturally across all continents except Australia and include deer, moose and buffalo, which tend to gather in groups and move long distances. Consequently, they need to frequently cross LTI to access seasonally available resources (Cramer et al., 2015). Many species of ungulates are large-bodied, occur in high abundances and tend to move in herds, leading to their frequent involvement in WVCs. In North America and western Europe, concern for motorist safety means these species are often the focus of mitigation projects (Sawyer et al., 2016). An equivalent large herbivore in Australia are kangaroos, which also occur in large numbers in some localities and are frequently involved in collisions with vehicles and trains (Visintin et al., 2016; 2018). Collisions between other large herbivores (e.g. elephants, zebra, giraffe, etc.) and vehicles or trains may be relatively less frequent than ungulates and kangaroos but can result in equally serious consequences for both people and wildlife involved in collisions, especially for small and declining populations of wildlife. Mitigation for these groups is therefore a high priority (Okita-Ouma et al., 2021).

Large carnivores

Large carnivores such as bears, wolves, tigers, wild dogs and lynx are examples of species whose populations are vulnerable to the impacts of vehicles and LTI (Grilo et al., 2015). Habitat fragmentation is also a major threat to many large carnivores due to their large territorial requirements to find prey, mates and to meet other life history needs. If a transportation route leads to a decrease in prey populations or hampers their ability to hunt, a carnivore population may have reduced survival rates and reproductive success.

African elephant (*Loxodonta africana*) using a railway underpass in Balule Nature Reserve, South Africa. © Hannah de Villiers

A mountain lion (*Puma concolor*) walks through an underpass located on the lands of the Confederated Salish and Kootenai Tribes (CSKT) of the Flathead Reservation in Montana, USA. © MDT & WTI-MSU

Direct mortality due to WVCs or drowning in canals would then further impact an already vulnerable population. Large carnivores are keystone species that play critical roles in controlling prey populations and regulating ecosystem functions. Due to their overarching ecological significance, and the dynamics between predator and prey, wildlife crossing structures and conservation efforts should be designed to conserve both groups (Smith et al., 2019).

Arboreal species

Arboreal species spend all or most of their lives in trees and primarily include possums, gliders, and primates, as well as some frogs and reptiles (Soanes & van der Ree, 2015). Mitigation strategies for this group depends on their degree of arboreality and their willingness and ability to travel along the ground, their gliding capability and degree to which they avoid roads, railways and canals. A common approach around the world are canopy bridges that connect tree canopies, made of ropes, cables, poles or other materials (Soanes et al., 2017; see also Box 15). The installation of glider poles' that act as artificial trees for gliders to launch from and land on have been widely deployed in Australia. Solutions for arboreal frogs and reptiles are yet to be widely tested and deployed, but crossings with continuous tree cover may be effective for these species. Mitigation strategies for primates are similarly being tested and developed (Donaldson & Cunneyworth 2015; Linden et al., 2020; Gregory, et al., 2022). Effective fencing is also a challenge for arboreal species because many are excellent climbers and can easily scale standard fencing.

Amphibians and reptiles

A greater percentage of amphibian and reptile species are at risk of extinction globally than any other animal group (IUCN, 2010), with LTI and traffic posing a major threat. For example, amphibians and reptiles are affected by roads and traffic through the loss, degradation and fragmentation of their habitats as well as direct mortality (Jackson et al., 2015).

Amphibian populations near developments tend to have lower species richness and smaller population sizes than populations further from LTI, particularly where they must migrate across to access wetland breeding sites. Some species of snakes are at increased risk because they immobilise in response to passing vehicles or may bask on roadways for thermoregulation (Gunson et al., 2016). Turtles are especially vulnerable because some species take more than 20 years to reach sexual maturity and, thus, even relatively low rates of mortality reduce the number of breeding adults and can lead to population decline (Gunson et al., 2016).

A variety of strategies have been used to protect ecological connectivity and reduce related mortality for amphibians and reptiles, including specialised wildlife crossing structures, along with fencing, signage and human intervention or road closures during migration seasons (Hamer et al., 2015; Langen, 2015). In general, effective wildlife crossing structures for these species must consider their limited mobility, habitat and physiological constraints, and, for some, their mass migrations (Kintsch et al., 2015).

A gravid (pregnant) female Eastern box turtle (*Terrapene carolina carolina*) crosses the road in Patuxent Research Refuge, Maryland, USA. © Nicholas Tait

White-faced capuchin (*Cebus imitator*) cross Route 257 using a canopy bridge, Costa Rica. © Daniela Araya-Gamboa / Panthera

Female iguana (*Iguana iguana*) roadkill on Route 4, Costa Rica © Panthera

Aquatic species

Aquatic species are totally, or mostly, restricted to waterways and many drainage structures can be easily adapted to accommodate their requirements (Wagner, 2015; Ottburg & Blank, 2015). However, poorly designed and maintained bridges, culverts and pipes can disrupt the continuity of stream channels and create barriers for fish and other aquatic species (Normann et al., 2005). Fortunately, many terrestrial wildlife species also move along waterways, offering the potential for cost-effective opportunities to integrate terrestrial and aquatic wildlife crossing structures at the same location. To do so effectively, the differing needs of terrestrial and aquatic wildlife must be accommodated. Structures that replicate natural stream conditions within them may serve fish and other aquatic or semi-aquatic species. Yet, if the bridge or culvert does not include dry banks on both sides of a waterway, they may not allow the movement of terrestrial wildlife. Similarly, terrestrial wildlife crossings that do not provide sufficient depth of flow, control water velocities, or minimise outlet drops may create barriers to the movement of aquatic species.

Fish ladder on the Roubion River near Lyon, France. This structure was built in 2011 to provide passage for fish around a weir in place since 1964, originally built to protect downstream infrastructure from flood damage. The ladder and ledges were designed for eels, numerous fish and beaver. © Rodney van der Ree

A technician stands in a highway underpass incorporating design for free stream flow and ledges for dry passage by wildlife. © Daniela Araya-Gamboa/ Panthera

Birds and bats

It is often assumed that because birds and bats can fly that they are immune to the negative impacts of roads, railways and canals (Abbott et al., 2015; Kociolek et al., 2015). However, some species avoid gaps in habitat created by linear infrastructure, or avoid the disturbance caused by vehicle traffic and trains. Others are subject to high rates of mortality due to WVCs. There is increasing evidence that open span bridges or vegetated overpasses which provide a (near-) continuous strip of habitat are effective options for many of these gap-sensitive species (e.g. Pell & Jones, 2015; McGregor, et al., 2017). Solutions that minimise collisions and mortality are more challenging but include fencing or walls of poles to force individuals to fly up and over the road or railway (Kociolek et al., 2015). The severity of impacts from traffic or train noise and light can be minimised with panelled fencing, soil berms, vegetation screening and other aspects of landscape design that that block or reduce traffic or train noise and artificial light.

An owl struck by a passing vehicle. Many species of birds and bats are subject to high rates of mortality due to WVCs. © Axel Redder / Adobe Stock

Key information – Main considerations for successful mitigation

- Identification of target species and priority locations based on data from WVCs, habitat conditions and wildlife movement patterns
- Attention to opportunities and constraints of terrain and land use
- Prioritisation of region-wide approaches over site-by-site or project-by-project needs
- Identification of strategically important solutions and direction of limited fund to areas of greatest need and/or greatest potential success
- Consideration of existing culverts and bridges that can be cost-effectively enhanced to improve ecological connectivity and reduced WVC
- Installation of specifically designed wildlife crossing structures and associated directional fencing to funnel animals to underpasses, overpasses, culverts, bridges, etc. and exclusionary fencing to reduce entry onto roads and railways, and into canals
- Including addition of dry ledges, pathways and shelves to existing culverts and bridges for smaller species
- Replacing culverts or bridges with larger and more open structures

Selecting the proper site location for mitigation measures

The locations of wildlife crossing structures, fences and other mitigation measures can be determined via the analysis of a variety of data that identify areas with high rates of wildlife mortality, important habitats, and where best to support or restore wildlife movement across LTI. The availability and quality of data sources can vary greatly, from spatially precise wildlife presence and movement to observational information provided by wildlife managers or local community members. Habitat and movement models and hotspot analyses of WVCs can all be used to identify potential areas to install mitigation measures (Gunson & Teixeira, 2015). Once priority areas are identified, a mitigation strategy needs to consider opportunities and constraints of terrain and land use. Ideally, region-wide approaches rather than site-by-site or project-by-project needs are adopted to identify strategically important mitigation solutions and direct limited funds to areas of greatest need.

While new projects are excellent opportunities to integrate mitigation into LTI, many existing roads, railways and canals already affect areas with high levels of biodiversity. Most infrastructure around the globe was constructed without consideration of the needs of wildlife and often present barriers to movement or ongoing causes of wildlife mortality. Fortunately, many existing culverts and bridges are potentially suitable for use by at least some wildlife with quick and cost-effective enhancements possible to improve movement and reduce mortality. For example, adding fencing to funnel animals to existing culverts and bridges can keep them off roads and railways and reduce rates of collision by 95% (Gagnon et al., 2015; Gagnon et al., 2018). Other simple retrofits include the addition of dry ledges, pathways or shelves to culverts or bridges (Forseman, 2004; Andrews et al., 2015).

Where modification of existing LTI is not feasible, culverts or bridges can be replaced with larger or more open structures designed to also allow movement of wildlife. For example, the installation of seven large box culverts and wildlife directional and exclusion fencing on an existing road in Wyoming, USA, resulted in over 49,000 mule deer passages in the first three years and an 81% reduction in the rate of WVCs (Sawyer et al., 2012). Stand-alone projects in the United States that focused on resolving WVCs have realized a breakeven point where benefits exceed project costs in as little as three to five years (Sawyer et al., 2012; Gagnon et al., 2015; Gagnon et al., 2018).

The most effective approach for reducing rates of wildlife mortality and maintaining, enhancing and restoring animal movement involves the installation of wildlife crossing structures and associated directional fencing. This approach is not always feasible or cost-effective due to terrain or other constraints. Many other approaches have been employed with varying levels of success (van der Ree et al., 2015). Strategies with some success that require significant maintenance include:

- Vegetation management to improve driver sightlines, wildlife visibility and reduce attractiveness of road and railway verges to wildlife;
- Reduction in the use of de-icing salts that attract some herbivores;

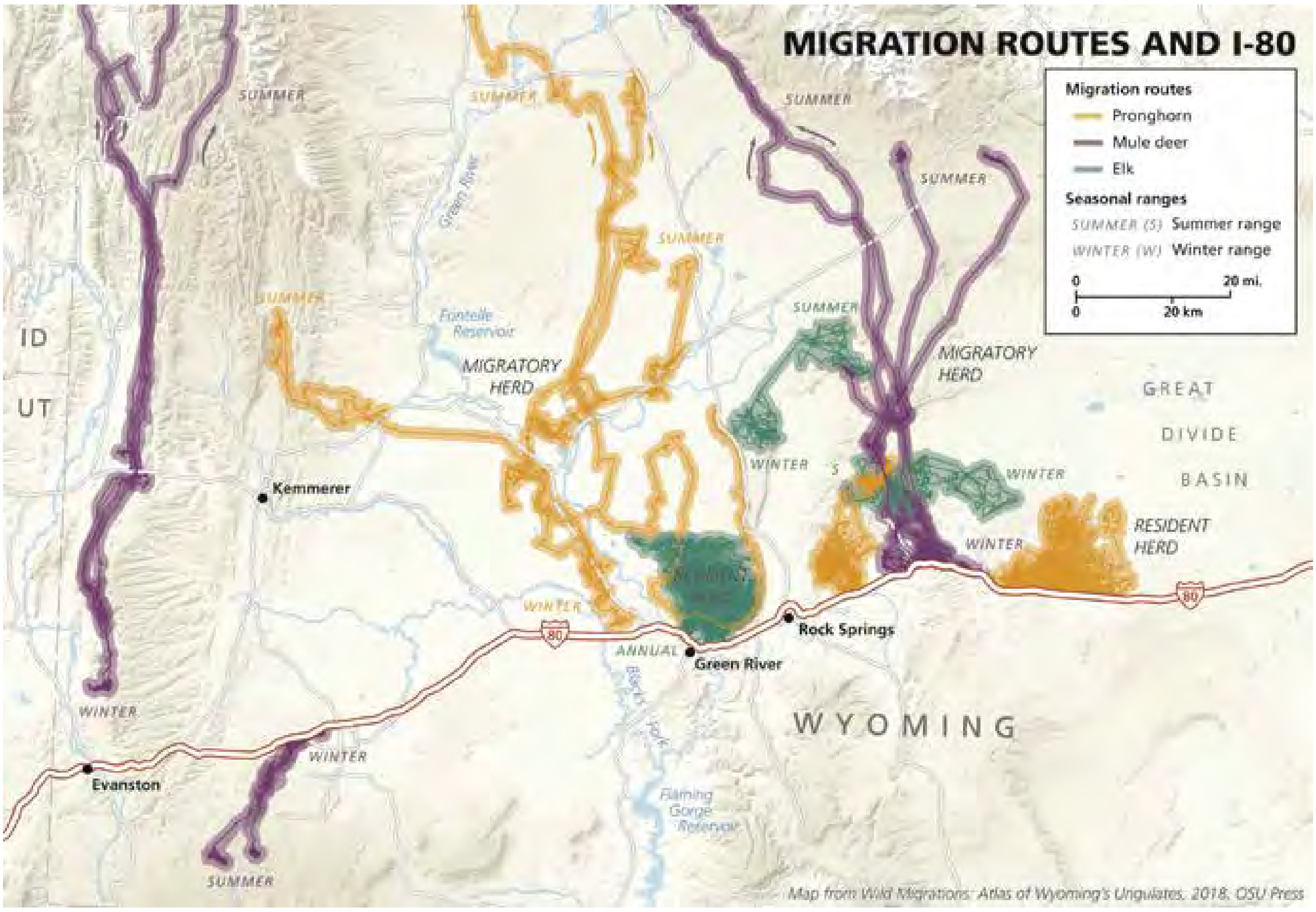


Figure 18: Map of migration paths of pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), and elk (*Cervus canadensis*) near Interstate 80 in Wyoming, USA. The road creates a barrier effect to movement and a corridor effect when wildlife paths are diverted along the road. Reproduced with permission from *Wild Migrations: Atlas of Wyoming's Ungulates,* Oregon State University Press. © 2018 University of Wyoming and University of Oregon

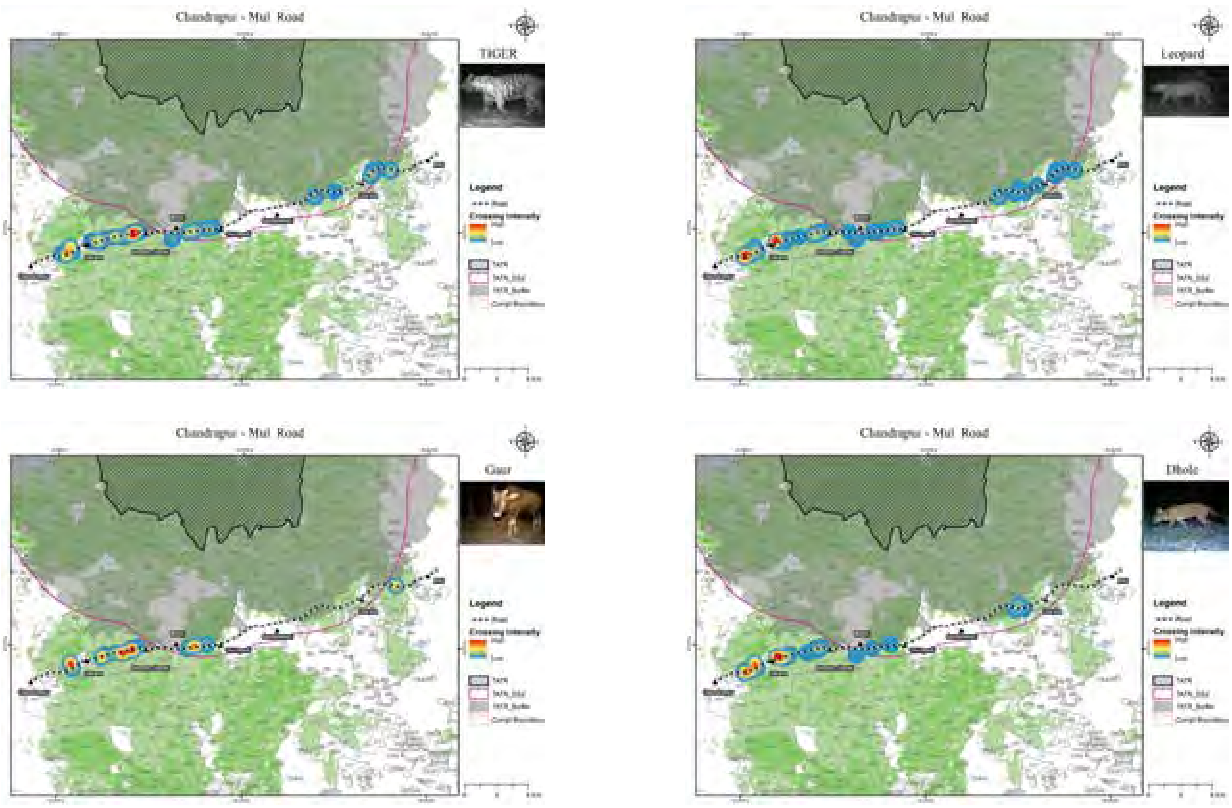


Figure 19: Crossing intensity of tiger (*Panthera tigris tigris*), leopard (*Panthera pardus fusca*), gaur (*Bos gaurus*) and wild dog (dhole; *Cuon alpinus*) in India. Using data collected by Wildlife Conservation Trust scientists, roadkill hotspots were located, and suitable locations identified for mitigation structures. © Wildlife Conservation Trust

- Carcass removal to prevent secondary mortality by scavengers;
- Road and railway closures at certain times of the day or year in wildlife crossing zones;
- Animal detection systems with driver warning signs, speed limit reductions and other traffic calming measures to reduce road and rail collisions; and
- Inclusion of ramps and ropes in canals to allow trapped wildlife to climb out.

Approaches with little evidence of success include whistles, sonic devices and reflectors, or lights to deter animals from roadsides and railways, along with standard signage to warn motorists (van der Ree et al., 2015). However, recent trials with sonic devices on trains to deter bears shows promise (Backs et al., 2020).

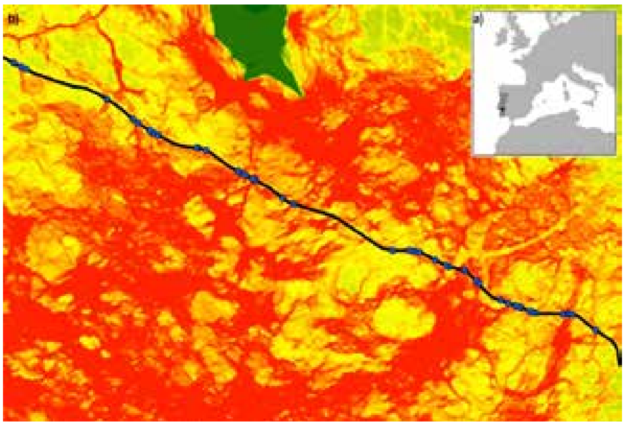
The potential for unintended consequences of different mitigation options should be carefully considered during planning to optimise outcomes. For example, exclusionary fencing alone will reduce WVCs but reduces or eliminates any connectivity for some species. Fencing alone should therefore only be adopted in situations with high rates of wildlife mortality and where connectivity at that specific location is not immediately required. Similarly, pruning trees to improve sightlines may increase attractiveness of the roadside to herbivores through increased growth of desirable shrubs, forbs and grasses. Removing trees also reduces connected habitat for arboreal species and increases the barrier effect for gap-sensitive birds, reptiles and small mammals.

Box 12

Functional connectivity as a tool to help plan where to mitigate road impacts on movement and mortality in Portugal's Montado landscape

Key lesson: Connectivity models built from species occurrence data can be used to prioritize locations for mitigation measures along roads. This approach can be widely replicated across large landscapes to inform road agencies and land conservation organizations.

Mitigation measures can reduce the barrier effect of roads and wildlife mortality by retrofitting existing structures (e.g. culverts). Often, funding is limited and a prioritization process is needed to identify the most critical road or rail segments for implementing measures. Ideally, crossing structures are placed where animal movement is highest, such as at wildlife corridors.



The study area location. (a) Location within Portugal. (b) The road sector (black line) on a connectivity map (high connectivity in red; low connectivity in yellow), also showing genet roadkill locations (blue dots). The model is from Valerio et al. (2019) and under CC BY licence (Creative Commons Attribution 4.0 International licence).

Portugal's Montado is a biodiverse agro-silvo-pastoral ecosystem crossed by roads and railways. Researchers here built connectivity models for genets (Genetta genetta), a small carnivore particularly affected by roads (Valerio et al., 2019). Functional connectivity models were informed by species occurrence data to identify movement corridors and road sections most critical for mitigation. Independent roadkill data were used to evaluate how well the models predicted genet roadkill locations and dispersal. The study showed that connectivity models built from occurrence data accurately predicted roadkills. They also performed well at predicting daily and dispersal movements.

Some lessons learned from this exercise that may aid transportation agencies who must fund wildlife crossing structures are that:

- Crossing structures are costly and require a process of identification and prioritization;
- Connectivity models built with species occurrence data can accurately predict roadkill locations; and
- Models can be a useful tool to help identify locations and prioritise mitigation investments, and can be easily replicated at other study areas.

Reference

Valerio, F., Carvalho, F., Barbosa, A. M., Mira, A., and Santos, S. M. (2019). Accounting for connectivity uncertainties in predicting roadkills: a comparative approach between path selection functions and habitat suitability models. *Environmental Management* 64(3):329–343. https://doi.org/10.1007/s00267-019-01191-6.

Box 13

Mitigating the impacts of the Q-T Railway on long-distance migrating Tibetan antelope

Key lesson: With adequate data, mitigation measures can preserve near-optimal migration routes for wide-ranging animal populations.

Reliable pre-construction information on the fine-scale travel patterns of migratory species is necessary if mitigation measures are to be effective. In rural western China, the highest-elevation railway on Earth transports visitors from Qinghai to Tibet (QTR). The QTR bisects the migration route of antelope approximately 40 km from their summer calving area. A detailed study of the estimated impacts of the QTR on Tibetan antelope (*Pantholops hodgsonii*) migration was not conducted prior to design. Most information was based on anecdotal field observations. Four major wildlife crossing structures eventually were constructed (Wubei underpass, Chumaer Bridge I and II, Wudaoliang Bridge), all designed for connectivity of migratory Tibetan antelope to their wintering and calving areas. Crossing structures offer the only means for antelope to cross the railway.

The Wubei underpass was evaluated to determine how placement affected migration routes and movement efficiency. The study utilized a Tibetan antelope tracking (GPS) dataset to compare actual migrations with optimal' migration (i.e. the route with least energy expenditure according to topography). While the underpass did facilitate antelope migration, animals deviated from their optimal migration route (Xu et al., 2019). This deviation led to longer travel distances and greater energy expenditure. Animal migration is closely associated with reproduction and migration disruptions are especially detrimental on the return trip when lactating females must migrate to meet energy demands and feed their offspring. Despite two other underpasses being closer to the optimal migration routes, few antelope used them.

We learn here that animal movement and behavioural studies should be conducted before and after the construction of underpasses to reveal the true impacts and the effectiveness of crossing structures aimed to facilitate connectivity. This is especially important for migratory ungulate species that connect calving grounds with over-wintering areas.

The Qinghai-Tibet Railway (QTR) travels over China's Wubei Underpass, constructed to facilitate Tibetan antelope (*Pantholops hodgsonii*) migration between key habitats on either side of the rail. © Wenjing Xu

Box 13 (continued)

Tibetan antelope (*Pantholops hodgsonii*), an iconic species in Tibet © Nyanpo Yurtse / Environment Protection Association

Reference

Xu, W., Huang, Q., Stabach, J., Buho, H., and Leimgruber, P. (2019). Railway underpass location affects migration distance in Tibetan antelope (*Pantholops hodgsonii*). *PLoS One* 14(2):e0211798. https://doi.org/10.1371/journal.pone.0211798.

Box 14

Simple, low-cost mitigation measures reduce Zanzibar red colobus mortality by 80%

Key lesson: In some cases, low-cost interventions like speed bumps and signage can lead to significant protections for wildlife.

Zanzibar red colobus (*Procolobus kirkii*) runs across a road. Crossing signs and speed bumps were placed by park managers attempting to reduce collisions that are now the leading cause of mortality for the species across Unguja (also known as Zanzibar Island), Tanzania. © Alexander Georgiev

Box 14 (continued)

Proposed and constructed development corridors in Africa have the potential to affect nearly one-third of Africa's protected areas (Sloan et al., 2017). Simple measures such as speed limits, speed bumps and signage offer affordable options for protected area managers looking to mitigate the effects of LTI. Unguja (also known as Zanzibar Island) is home to 6,000 endangered Zanzibar red colobus (*Piliocolobus kirkii*), a species endemic to the island. Half of these individuals are in Jozani-Chwaka Bay National Park. With no large predators located within the island's only national park, road mortality has become the leading cause of red colobus mortality. The road which intersects the national park was resurfaced in 1996 and this improvement allowed for faster travel speeds and increased traffic. Historical estimates suggest that annual average road mortality comprised 14.5% of the local population living near the road.

In response, park managers began planning how best to mitigate road impacts on these primates. Their solution was to install four speed bumps and wildlife crossing signs close to the park entrance. After installation, they found that the annual average road fatalities of red colobus was reduced to 3.2% of the location population (Olgun et al., 2021). While further mitigation measures are being explored, this example highlights the efficacy of relatively low-cost mitigation options that can be viable for protected area managers.

References

Olgun, H., Mohammed, M. K., Mzee, A. J., Green, M. E. L., Davenport, T. R. B., and Georgiev, A. V. (2021). The implications of vehicle collisions for the Endangered endemic Zanzibar red colobus *Piliocolobus kirkii*. *Oryx* 56(2):268-276. https://doi.org/10.1017/S0030605320000605.

Sloan, S., Bertzky, B., and Laurance, W. F. (2017). African development corridors intersect key protected areas. *African Journal of Ecology* 55(4):731–737. https://doi.org/10.1111/aje.12377.

Zanzibar red colobus (*Piliocolobus kirkii*) on Unguja (also known as Zanzibar Island), Tanzania © Alexander Georgiev

Key messages in this chapter

- The effective management of PCAs, the conservation of ecological connectivity and the needs of wildlife should be considered at the beginning of the planning phase of LTI projects.
- Where impacts from projects are unavoidable and significant minimisation options are exhausted, appropriate mitigation measures should be applied through careful planning.
- Specially designed wildlife crossing structures, such as underpasses and overpasses with accompanying fencing, are effective mitigation strategies that far outperform other non-structural strategies.
- It is more cost-effective to install wildlife crossing structures during initial construction but retrofitting and replacement should also be considered during upgrades of existing infrastructure or as stand-alone projects.
- Successful planning and construction of mitigation measures requires the identification of specific objectives and target species as well as identification of priority locations for implementing mitigation solutions.

Part 8

Monitoring and evaluation

Technicians monitor the effectiveness of a wildlife underpass on Route 4, Costa Rica. © Daniela Araya-Gamboa / Panthera

Research, monitoring and evaluation is an integral component of landscape management and conservation (Nichols & Williams, 2006). A systematic and comprehensive monitoring program is important when evaluating the effectiveness of management of PCAs (Margules & Pressey, 2000). The impacts of existing and new linear infrastructure, especially within and around PCAs, wilderness areas and ecological corridors and networks, should also be evaluated and the effectiveness of mitigation measures assessed.

Why evaluate performance?

Assessing whether actions taken in all approaches of the mitigation hierarchy are functional and meet their intended objectives is an important best management practice. Such evaluation allows for: (i) appraisal of whether the resources invested achieved the intended outcome; (ii) identification of necessary modifications or adaptive management of actions to achieve better performance; and (iii) the generation of knowledge to maximise the success of future projects. Considerable research has been conducted on the performance of various measures to reduce collisions with large wildlife over the past 20 years (Rytwinski et al., 2016), especially in temperate climates and developed countries. In many parts of the developing world, however, where the application of more sustainable LTI is now growing, the relative effectiveness of different measures is unknown even for some common species.

Technicians install a wildlife camera onto a tree trunk in Malaysia. © Rosli Hasan

Assessment of mitigation effectiveness can help to improve the planning and design of future mitigation measures using an adaptive management approach (CMP, 2020). As measures are evaluated for a variety of taxa in different ecosystems and cultural contexts, increasingly reliable information and insights will support the development of robust best practice techniques. While research and monitoring have provided excellent guidance on effectiveness of various measures in parts of Australia, Europe and North America (van der Ree et al., 2015; IENE, 2021; Huijser et al., 2021), there is an urgent need for parallel research in developing countries with high levels of biodiversity, complex ecosystems and unique fauna.

Mitigation measures need to be effective

Mitigation measures are primarily designed to reduce wildlife mortality and promote ecological connectivity by allowing safe movement of animals across LTI. The criteria to measure whether goals are achieved depend on whether the purpose of the measures is to reduce wildlife mortality or to restore functional population connectivity, or to achieve both aims. Some guidance has been developed to evaluate the performance and conservation value of mitigation measures (van der Grift et al., 2015; van der Grift & van der Ree, 2015). Goals range from measures geared to benefit a single species to entire populations, to those that seek to address ecological processes and functions (Clevenger, 2005). The use of crossing structures by wildlife does not guarantee that they are effective (Clements, 2013). Rather, assessing effectiveness is complex, and interpretations of functional mitigation and impact reduction can vary (van der Grift et al., 2013).

Ideally, performance objectives for each mitigation measure should be developed a priori, be agreed upon by all stake-holders, be scientifically defensible and be measurable. Further, adequate funding must be in place to ensure that:

A hippo (*Hippopotamus amphibius*) using a railway underpass in Balule Nature Reserve, South Africa. This photograph was taken using a camera trap, which is a key monitoring tool that informs managers about the effectiveness of wildlife crossing structures, including species diversity and numbers utilizing them. © Hannah de Villiers

(i) the evaluation of the effectiveness of mitigation measures is conducted in a sound manner, and (ii) that applicable laws and policies are enforced to minimise adverse LTI impacts on threatened species and other statutory natural resource requirements (e.g. those that protect tiger corridors, wetlands, community forests, water quality).

Performance assessments can be complex

LTI affects wildlife at all levels of biological organization, from genes to species and populations, to communities and ecosystems (Noss, 1990). Measures of performance can therefore vary across a gradient of complexity from the individual animal level (e.g. use of structures, dispersal) to the meta-community or ecosystem levels (e.g. community structure, population dynamics). Each of these suggests different sets of mitigation measures and requires specific approaches to research and monitoring. Biological diversity should be monitored at multiple levels of organization and at various spatial and temporal scales (Noss, 1990). For example, evaluations of small culverts for small- and medium-sized mammals will likely need different monitoring techniques and evaluation processes to those applied to overpasses or other types of wildlife crossing structures, or for rare or wide-ranging species of wildlife. To frame objectives and determine performance indicators, it is also important to consider specific spatial and temporal scales. These factors influence how ecological connectivity is measured within populations and ecosystems, and the cost and duration of research that is required to address performance adequately (Table 1).

Study design and methods

After formulating mitigation objectives, a critical next step is the design of a monitoring program that applies a robust study design, appropriate methods of data collection and analysis. The design of the research framework requires thinking through the duration of data collection to sufficiently answer both management questions and applied research questions. Sampling should be adequately resourced and account for seasonal variations, inter-annual variability and necessary sample size for robust analysis.

Study designs should be able to test for anticipated changes before and after mitigation measures are installed. Impacts of concern may include mortality rates, movement patterns and complex ecosystem processes such as changes in predator-prey relationships. Effective measures should result in positive changes, such as reduced mortality, or increased movement and ecological connectivity after mitigation. Several study designs to test for these changes using control and treatment (mitigation) sections have been published (Roedenbeck et al., 2007; Rytwinski et al., 2015; van der Grift et al., 2013). Options include: (i) collecting data before and after mitigation at sites with mitigation and sites without; the latter known as control sites. This design is commonly called Before-After-Control-Impact (BACI) and is typically a robust design and should always be implemented if feasible (Rytwinski et al., 2015), while some LTI projects may benefit from other

Wildlife cameras and passive integrated transponder (PIT) tags mounted at the end of a canopy bridge in Australia. PIT tag readers are technologies used to track the movement of individual animals that carry internal microchips. © Rodney van der Ree

Glider poles are installed on the verges of linear infrastructure or in the centre median at locations where the size of the gap in tree cover exceeds the glide distance of gliding animals. This close-up shows the cross-arm or launch platform at the top of a glider pole, along with cameras and solar panels to evaluate use. The metal shield on top of the pole and the pipe under the cross arm provides shelter from aerial predators. The cross-arm points towards the trees on the opposite side of the infrastructure, thereby decreasing the size of the gap to be crossed. © Rodney van der Ree

Table 1: Mitigation objectives for wildlife crossings (simple to complex), target level of biological organization, and required study duration and cost to evaluate effectiveness

Level	Mitigation objectives	Level of biological organization	Cost & duration of monitoring effort
1	Movement within populations and genetic interchange	Genetic	Low-cost / Short-term
2	Ensure that the biological requirements of finding food, cover and mates are satisfied	Species-population	Moderate-to-High cost / Long-term
3	Dispersal from maternal ranges and recolonisation after long absences	Species-population	Moderate-to-High cost / Long-term
4	Population movement in response to environmental changes or natural disasters	Ecosystem-community	High-cost / Long-term
5	Long-term maintenance of metapopulations, community stability, and ecosystem processes	Ecosystem-community	High-cost / Long-term

designs (Thiault et al., 2017); (ii) data collection before and after mitigation with no control areas; and (iii) data collection post-mitigation with control areas (Clements, 2013).

In evaluation, it is also important to determine whether unrelated factors might be affecting monitoring results and, ultimately, performance. These types of factors can include illegal hunting and human disturbance, damaged fencing that allows wildlife to enter the right-of-way, and passages blocked by debris or occupied by people (Clements, 2013). These factors must be monitored and managed to avoid negative effects on wildlife movement that can confound results.

The duration of monitoring will vary depending on the objectives of mitigation and the likely response time of the target species. Simple power analysis can be used to determine data requirements needed to detect significant changes in species mortality rates (Guillera-Arroita & Lahoz-Monfort, 2012). Monitoring strategies also need to allow enough time and data to allow for strong inferences about wildlife crossing performance. Importantly, it can take several years for wildlife to adapt and learn to use wildlife crossing structures (Reed et al., 1975; Gagnon et al., 2011), so most monitoring should be conducted for at least 4–5 years. More well-designed studies that quantify the effectiveness of mitigation measures are still needed (Rytwinski et al., 2016), especially in Africa, Asia and South America.

A variety of methods can be used to assess the performance of mitigation measures (Table 2) and it is important to choose a method that provides data that is most closely aligned to the objective. For example, roadkill surveys indicate changes in mortality rates; tracking methods provide information on individual behaviours and movements; genetic sampling and camera traps (for species with unique markings) identify individuals and functional genetic connectivity; and mark-recapture can be used for population responses.

Arboreal species crossing structures are being deployed around the world. Here, a technician in Costa Rica places cameras to monitor their effectiveness and use. © Panthera

Table 2: Methods of measuring effectiveness of mitigating impacts of LTI

Metric	Methods	Selected references
Roadkill rates	• Surveys • Encounter surveys • Citizen science • Review of existing databases	Gerow, et al., 2010 Guinard, et al., 2012 Lee et al., 2006
Wildlife use of crossing structures	• Sign surveys • Tracking beds (e.g. sand, snow, sooted track plates) • Camera traps (with or without individual identification) • Video cameras • Passive integrated transponder (PIT) tags and automated readers	Gonzales-Gallina, 2018 Clevenger & Waltho, 2005 Clements, 2013 Soanes et al., 2013 Mateus et al., 2011 Wang et al., 2017
Animal movements and dispersal	• Animal tracking (e.g. radio, satellite, GPS, etc.) • Species encounter rates (camera-trapping without individual identification) • Camera-trapping with individual identification (dispersal) • Movement/behavioural observation	Shephard et al., 2008 Colchero et al., 2011 Bautista et al., 2004
Genetic and demographic connectivity	• Non-invasive sampling (hair snaring') • Invasive sampling to collect DNA	Sawaya et al., 2014 Balkenhol & Waits, 2009 Soanes et al., 2018
Species occurrence and distribution (plants, animals)	• Camera trapping, trapping, active searches • Vegetation plots	Goosem, 2002 Herrmann et al., 2016
Animal population demographic parameters	• Capture-mark-recapture	Garland & Bradley, 1984 McCall et al., 2010

Adaptive mitigation in transportation planning

The rapid expansion of LTI across the globe emphasises the importance of monitoring and evaluation as a vital part of informed decision making. It will serve to shape the deployment of future mitigation measures and the development of better policies (Walters, 1986). Monitoring results should be used in a deliberate, adaptive management' approach to make informed decisions with the information available (CMP, 2020). For example, the design of wildlife crossing structures and associated measures like fencing should be improved if monitoring results show they are not effective. Similarly, pre-construction data gathered on the occurrence of local species and wildlife movements should be used to determine the locations and types of mitigation measures. Adaptive management of the project design from pre-construction monitoring results will require regular communication between the wildlife research coordinator and the environmental manager of the construction project. Subsequently, close coordination between research and management will allow for timely changes to project design plans that reflect the most current results from monitoring activities. In addition to using monitoring and evaluation results to inform individual projects, adaptive mitigation allows for meta-analysis by increasing experimental replications (Rytwinski et al., 2016) of similar measures, similar habitats and/or of the same species in different locations.

Post-construction monitoring of two honey badgers (*Mellivora capensis*) using a railway underpass in Balule Nature Reserve, South Africa © Hannah de Villiers

Box 15

Using a Before-After-Control-Impact (BACI) study design to evaluate canopy bridges and glider poles for arboreal mammals in Australia

Key lesson: Programs that evaluate the use and effectiveness of wildlife crossing structures and other mitigation must be scientifically robust to ensure the information they provide is reliable.

One of the first studies to use a replicated Before-After-Control-Impact (BACI) experimental design to assess the effectiveness of crossing structures was conducted in southeastern Australia for arboreal mammals. The primary focus was the squirrel glider, a small (~300 gm) marsupial that can glide up to 40 m, limiting its ability to safely cross wide roads.

A collaborative project between the state transportation agency and two universities established the baseline, or before', conditions for arboreal mammals through detailed field studies, including estimating population size and rates of crossing (van der Ree et al., 2010), survival (McCall et al., 2010) and gene flow at multiple sites along the Hume Freeway in northern Victoria. After installing two canopy bridges and three arrays of glider poles, the same parameters were re-measured and compared at sites with and without crossing structures, as well as before and after mitigation. Similar measurements were taken at another five bridges and 12 pole arrays in New South Wales.

Arboreal crossing over Hume Freeway, Australia © Rodney van der Ree

Extensive after' studies showed a wide range of species and multiple individuals used the structures over time. Use varied by species and population density, and for glider poles use was related to glide length and number of poles in the array (Soanes et al., 2013; Soanes & van der Ree, 2015). Gene flow before the installation of the crossing structures was significantly increased after mitigation, demonstrating a successful reduction in the barrier effect. Only one (unsuccessful) predation event was observed from >13,000 detections of arboreal mammals on the structures (Soanes et al., 2018).

The main strengths of this work were the use of unmitigated control sites to provide a robust comparison and a suite of measures (e.g. use, rate of crossing, survival, and gene flow) used to evaluate success. Transportation agencies and researchers should collaborate more to undertake these experiments to better understand the effectiveness of mitigation, not just whether or not animals use a crossing structure and how often they use them.

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Box 15 (continued)

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A squirrel glider (*Petaurus norfolcensis*) captured on camera using a glider pole over Warrenbayne road, Australia

Ringtail possum (*Pseudocheirus peregrinus*) with young on its back using a canopy bridge in Australia

Box 16

Asian elephant crossing structures on the Sixiao Expressway, Xishuangbanna, China

Key lesson: Monitoring and performance evaluation is critical for understanding the effectiveness of bridges and tunnels built for Asian elephants.

Mengyang is the largest nature reserve in Xishuangbanna and is home to more than half of China's Asian elephants (*Elaphus maximus*) – approximately 150–180 individuals. Forests provide important habitats, natural food sources and

Asian elephant (*Elephas maximus*) underpass across the Sixiao Expressway, Xishuangbanna, China © Yun Wang

Signage alerts travellers to the presence of wild elephants and asks them to refrain from honking their car horns, Sixiao Expressway, Xishuangbanna, China. © Yun Wang

Box 16 (continued)

minerals for the elephants. These animals use both sides of the reserve and cross Sixiao Expressway and the 213 National Road frequently. Crops outside the reserve further attract elephants to approach villages scattered along the road.

Constructed in 2006, Sixiao Expressway is 97 km long with 18 km bisecting the Mengyang Nature Reserve. The EIA for the project indicated the highway would fragment habitat and act as a barrier to movement of elephants. Mitigation measures were suggested consisting of wildlife crossing structures including viaducts or flyovers as many parts of the expressway were crossing large valleys. As a result, 23 bridges and two tunnels were built. Crossings had funnel fencing (1.9 m in height) on both sides of the expressway to keep animals off the road and direct them to use the crossings.

The bridges and tunnels were monitored from April 2006 to May 2008. Many of the crossings were not used by elephants, presumably because they were outside elephant habitat. However, use of the crossings increased slightly from 76 total crossings (at eight crossing structures) in 2006 to 86 detected crossings (at 10 crossing structures) in 2008. Elephants seemed to prefer crossing structures placed along their original corridors. However, elephants also walked across the expressway surface at grade; most of these crossings occurred in the evening, causing several vehicle-elephant collisions.

Key lessons learned from this project were that human activities that cause deforestation near the crossings – such as quarrying – should be prohibited; crossings should be sited at the original migration routes and movement corridors of Asian elephants; and lastly, careful planning is needed prior to road construction which involves collaboration among politicians, scientists, conservation practitioners and land use planners.

Reference

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An overpass used by Asian elephants (*Elephas maximus*) in China © Yun Wang

Key messages in this chapter

- Research and monitoring that evaluates the performance of mitigation measures is a critical component of infrastructure projects to ensure they function and meet their intended objectives.
- Such assessments can evaluate if resources were well-allocated, whether modifications are necessary to increase performance, and inform the planning and design of future projects.
- Although assessing effectiveness can be complex, there are exemplary study designs and methods available.
- There is an urgent need in developing countries for research and monitoring to quantify the impacts of linear infrastructure and evaluate the effectiveness of mitigation measures.
- Study designs should test for anticipated changes before and after (commonly called Before-After-Control-Impact (BACI)) mitigation measures are installed, such as mortality rates, movement and complex ecosystem processes like changes in predator-prey relationships.
- The results of monitoring should be applied by overseeing authorities toward adaptive management that consistently improves the project and its performance.

Part 9

Construction, operation and maintenance of roads, railways and canals

Saiga antelope (*Saiga tatarica*), a critically endangered species in central Asia, migrate up to 1,000 km each year in a north-south orientation. In 2015, Kazakhstan, Mongolia, Russian and Uzbekistan agreed on joint conservation measures to facilitate the species' free movement and survival under the UN Convention on Migratory Species (CMS). © Nikolay Denisov / Adobe Stock

The construction, operation and maintenance of LTI projects are critical to ensuring that long-term ecological impacts are limited in accordance with aims and objectives detailed during the planning, design and approval phases. Roads, railways and canals that are poorly built, badly operated or inadequately maintained can have significant impacts on PCAs, ecological connectivity, and biodiversity. These longer-term impacts typically remain unaddressed because the focus of regulators and the community has moved on or shifted to other projects or issues. This is particularly apparent on highly contentious projects when opponents who campaigned for many years to stop or change the alignment or design can feel that the struggle is over once construction begins. However, project construction is a high-risk stage for not achieving the ecological goals of a project. This is because many unexpected changes can occur, sequential interpretations of detailed designs can result in the construction of sub-standard mitigation measures, or they can be dropped from the project entirely due to time and cost over-runs or lack of contingency funding. In addition, costs involved in building mitigation measures can be wasted if they are poorly or incorrectly maintained and become ineffective. After a project has been planned and designed, there are three phases related to successful and efficient transportation systems: construction, operation and maintenance. These phases have different objectives and can affect biodiversity and ecological connectivity in different ways (McGuire & Morrall, 2000).

Minimising and mitigating the environmental impacts of construction

While only temporary, construction impacts can still be significant and affect the presence, survival and movement of wildlife due to noise, operation of heavy equipment, excavation and blasting and increased human presence. Even the construction of mitigation measures, such as underpasses, overpasses and fencing, can cause significant ecological impacts that need to be considered. For example, fencing and approach ramps to wildlife crossing structures may require the clearing of large areas of high-quality habitat adjacent to the road, railway or canal. Simple steps to minimise or mitigate these impacts include:

- Ensure the bidding documents and contracts clearly specify all mandatory environmental requirements and restrictions, with non-compliance consequences described;
- Locate construction camps, offices, storage areas, parking areas and related construction facilities offsite and avoid natural vegetation, ecological corridors and other sensitive areas;
- Physically demarcate areas of special concern and sensitivity as no-go' zones with fencing or bunting, and ensure they are maintained and enforced during construction;
- Ensure strict hygiene and waste management protocols are developed and followed, and that waste materials are appropriately re-used, recycled or disposed;
- Undertake strict supervision and formal performance audits once construction commences, with non-compliance consequences enforced;
- Establish an environmental and social code of conduct for all workers and visitors to the construction site, including ensuring all workers and visitors are inducted prior to commencement, with periodic refreshers as required, explaining the environmental and social conditions and expectations and encouraging workers and visitors to report breaches of the code and any observations of significant wildlife;
- Provide incentives to encourage exceptional environmental outcomes, such as clearing less wildlife habitat than approved;
- Prohibit hunting, fishing, timber cutting and plant collection within and adjacent to the project area, while restricting firearm permits to security personnel only; and

Key information – Three phases of a project on the ground

Construction is the physical process of building the infrastructure. While relatively short in duration, construction activity has the potential to cause significant interruption and disturbance to habitats and wildlife and their movement due to noise, movement of equipment, disturbance, establishment of work camps, and the sourcing and delivery of raw materials.

Operation commences after construction and represents the use of infrastructure creating noise, light, chemical and other disturbance and impacts to the surrounding environment, as well as causing deterioration of the asset itself. Operational activities include salting to de-ice surfaces, sweeping, line painting, and mowing and pruning of adjacent vegetation.

Maintenance is the routine and periodic activity required to maintain or extend the effective life of the infrastructure, and includes pothole patching, re-sealing, repair and replacement of guard-rails and fencing. Maintenance is also done on mitigation measures such as repair to fencing, cleaning of underpasses and other work to strengthen wildlife crossing structures (van der Ree and Tonjes, 2015).

- Incorporate seasonal scheduling, suspension or reduction of construction activities to address sensitive times of the year such as annual migrations, hibernation periods or breeding seasons of species.

Sourcing and storing construction materials

The construction of LTI usually requires vast quantities of raw construction materials, much of which often needs to be sourced from quarries. Material sourced locally can reduce construction costs and carbon dioxide emissions and decrease construction time. However, extracting and processing material within sensitive ecological areas can have significant impacts and should be avoided. It is also important that the sourcing of raw materials for construction is included in the EIA to ensure all impacts of the project are fully considered. For example, all quarries and other source areas should have plans for their development and remediation, such as converting quarries into wetland habitats. A further best practice is for raw materials stored during construction to be placed outside sensitive areas and contained to prevent run-off and erosion into waterways and other habitats.

Construction of an overpass over Interstate 90 on Snoqualmie Pass, Washington, USA. Spanning six lanes of traffic, this large overpass is just one piece of a multi-phase, multi-decade effort to restore connectivity in the Cascade Range. Other elements include a 330 m elevated stretch where wetlands and creeks flow beneath the highway, and numerous expanded culverts. Monitoring has documented around 4,000 successful wildlife crossings per year. © Terry McGuire

Blasting and clearing

While the construction of roads, railways and canals is noisy, dirty and disruptive, there are numerous strategies to minimise these effects in sensitive environments, including:

- Avoid bulk-earthworks during high-rainfall periods when the risk of seasonal flooding, flash flooding and erosion is highest;
- Ensure dust-suppression measures are adopted during hot, dry and windy conditions to avoid the spread of dust into adjacent habitat;
- Do not undertake blasting and tree clearing during sensitive periods for wildlife, such as during breeding seasons, hibernation periods or other times when wildlife are near the construction zone and likely to be significantly impacted;
- Always use environmentally sensitive construction techniques, such as avoiding ammonia nitrate explosives in favour of more environmentally friendly excavation methods;
- Minimise the extent of vegetation clearing, and where feasible maintain vegetation structure and tree canopies over the right of way as a natural bridge for arboreal species and sensitive species of birds and bats; and
- Minimise disruption to important vegetation along stream banks (riparian zone) that is used by many species and creates shade for fish.

Fencing, wildlife crossing structures and other mitigation

All infrastructure projects through environmentally sensitive areas should have a suite of mitigation measures, such as

Overpass construction in progress that includes natural surfaces, vegetation variations and design elements to reduce noise and light disturbances to provide favourable conditions for a diversity of species to cross the Trans-Canada Highway, Banff National Park, Alberta, Canada. © Terry McGuire

The diversity of canals built around the world have different ecological impacts at different spatial scales and intensities. Large canals can be almost total barriers to species movement, but any canal may alter landscape and species connectivity. Top: An excavator digs a new irrigation canal. © Dusan Kostic / Adobe Stock. Bottom: Heavy machinery building a canal to connect lakes created as part of large-scale strip-mining restoration efforts in Germany. © Getty Images fencing and wildlife crossing structures to protect biodiversity and maintain ecological connectivity. There are typically three types of fencing that may be used on infrastructure projects, each with different designs and potential impacts: (i) temporary fencing to exclude people or wildlife from the construction site or sensitive exclusion zones; (ii) permanent fencing along the right of way to delineate property ownership; and (iii) permanent fencing to exclude wildlife from the road, railway or canal and direct wildlife to crossing structures (van der Ree et al., 2015). It is important to consider the following:

- Ensure the fencing, crossing structures and other types of mitigation are constructed as planned and designed by conducting regular audits of construction activities and consulting the ecological and wildlife specialists when design changes are proposed, such as changing the size or location of the structure;
- Always assess the timing and frequency (i.e. daily, seasonal, annual) with which wildlife are crossing the construction site before erecting any fencing. Some species may have very set migration pathways and are unable to easily adjust their routes, such as elephants;
- When fencing is installed to reduce WVCs, always construct the associated crossing structures first;
- Install fencing progressively on both sides of the transportation corridor to avoid trapping wildlife on the wrong side of the fence;
- Include escape mechanisms, such as jump-outs, to allow trapped animals to escape the fenced right of way (Huijser et al., 2015); and
- Ensure the fencing is appropriately designed for target species, is of sufficient length and attention is given to the design of the fence ends (Huijser et al., 2016).

Operating and maintaining roads, railways and canals

The operation and maintenance of LTI will likely continue for decades or centuries, and can therefore significantly influence PCAs, ecological connectivity and ecosystem integrity. It is critical that the mitigation measures identified during the planning and design stages and built during construction are maintained appropriately to ensure their long-term effectiveness. Standard maintenance programs consist of four key elements which should also be applied to maintaining mitigation measures: 1) inventory of the asset; 2) inspection schedule; 3) routine upkeep and repairs; and 4) adaptive response to new information about maintenance techniques.

Unfortunately, maintenance can be expensive and is typically underfunded and done poorly, resulting in poor ecological outcomes. The cost-effectiveness of maintenance can be improved by engaging with maintenance engineers and ecologists during the design stage and incorporating features to improve maintainability, despite the potentially slightly higher initial construction cost. In addition, registering the mitigation measure on the transportation department database as an asset' will help ensure sufficient funding and resources are allocated to maintenance.

Maintenance programs for LTI are often developed without consideration of the objectives of PCAs and the wildlife within and outside of them, and many standard practices are incompatible with these needs. For example, the cleaning of culverts and clearing of vegetation at underpass entrances may discourage use by some wildlife. Well-meaning maintenance crews can render crossing structures temporarily or permanently ineffective through simple mistakes and it is critical that they know the specific requirements of each mitigation measure. The program should also provide information on the ecological goal of the mitigation measure, the target species and some relevant ecological information (van der Ree & Tonjes, 2015).

Wildlife crossing structures can be even more effective when integrating directional fencing to funnel animals to the safest passage and reduce rates of collisions with vehicles. Left: The 100 m wide Dedin green bridge' with directional fencing in the foreground was constructed along with 43 viaducts and tunnels on the highway stretching 68.5 km from Zagreb to Rijeka in Gorski kotar (Croatia). © Djuro Huber; Right: Underpass on US Highway 93 with directional fencing on the lands of the Confederated Salish and Kootenai Tribes (CSKT) of the Flathead Reservation in Montana, USA © Luca Guadagno

For the first time in over 100 years, an endangered and divided Western hoolock gibbon (*Hoolock hoolock*) population was reunited when technicians at Hoollongapar Gibbon Sanctuary in Jarhat, India, intertwined branches over a rail line. Intact vegetation structure and tree canopies over right of ways serve as natural bridges connecting arboreal species and sensitive bird species. © Dilip Chetry

Effective fencing is critical to the success of crossing structures and reducing rates of WVC (van der Ree, Gagnon & Smith, 2015) and maintenance is essential to its effectiveness (Huijser et al., 2016). Fencing damaged by falling trees, floods, the build-up of snow or sand and vehicles leaving the roadway must be quickly identified and repaired to maximise effectiveness. Fencing that incorporates easily adjusted bracing and other designs to withstand damage will also increase fence longevity and reduce repair and maintenance costs (Huijser et al., 2015).

Other important operational activities include maintenance of vegetation adjacent to roads, railways and canals, such as regular mowing to reduce attractants for wildlife, improve motorist and wildlife visibility, or control invasive weeds. Recent innovations include the establishment of pollinator-friendly plant species along linear infrastructure to reduce mowing costs and simultaneously provide a biodiversity benefit (Ries et al., 2001, Hopwood et al., 2015).

Some species of wildlife have adapted to these linear intrusions in their habitat and use structures such as bridges and culverts for roosting and denning. For example, many bridges and culverts are used as roosts by bats, birds of prey can nest on bridge structures and many mammals will use culverts as underground dens. Standard approaches to maintenance activities or replacement of failing structures can

A male Western hoolock gibbon (*Hoolock hoolock*) in Assam, India © Gregoire Dubois result in significant impacts to such wildlife, and alternative approaches can be adopted, such as doing work at certain times of year when not in use by wildlife, or by providing alternative structures as substitute roosts.

The relatively short-term duration of the construction phase of a project belies its critical importance in ensuring the infrastructure is built as planned and can be operated and maintained effectively. In addition, the risks associated with inappropriate construction techniques are often significant and can have lasting ecological impacts in environmentally sensitive areas if not managed accordingly. It is not feasible to outline a comprehensive maintenance program to maintain ecological connectivity because maintenance standards and approaches are still being developed for many types of structures and regions. Therefore, a common-sense approach based on objectives of PCAs, the needs of ecological connectivity, and wildlife is needed initially, including with regular review and adaptation over time to refine the program. Above all, the primary guiding goal of maintenance should always be to improve the effectiveness of a mitigation measure.

Wetland restoration of gravel/borrow pits along a major highway in Canada, before (top) and after (bottom) © Terry McGuire

Box 17

Protecting roosting bats under bridges in the southern United States

Key lesson: Maintenance activities can be important to help protect and sustain populations of wildlife that are sometimes forgotten, such as bats.

Bats are an important component of many ecosystems worldwide and many species use road and railway bridges as roosting sites. The construction of roads has the potential to negatively impact bat populations through loss of roosts, foraging habitats, and by fragmenting landscapes used as commuting routes by bats. Increasingly, growing numbers of transportation departments are integrating bat management techniques into maintenance schedules.

Gray bats (*Myotis grisescens*) roosting between beams on the underside of a bridge in Kentucky, USA. The deteriorating bridge was slated for rehabilitation, but when the bats were discovered, transportation planners adjusted their designs to protect the vulnerable species. Repairs were conducted in midwinter when the bats were hibernating elsewhere. New beams were installed with extra space in between to provide safe habitat for the bats to return.
© Kentucky Transportation Cabinet

Transportation departments need information on bat roosts in bridges to protect roosting bats while safely and effectively maintaining bridge functions. As an example, the US Federal Highway Administration initiated a national study of bat use of bridges. They found that just within the southern USA, 3,600 highway structures were being used by approximately 33 million bats. The fact that 43 percent of bridges suitable for night roosting were used indicates that in many areas bat habitat enhancement projects would be successful and could help by providing roosts needed for rearing young.

Transportation departments are ideally positioned to help re-establish globally important wildlife at little or no cost through highly popular proactive measures. Other countries are also beginning to recognise the value of providing roosts in bridges and are initiating their own projects, suggesting that habitat enhancements in highway structures may become a powerful conservation tool worldwide.

If creating roosts on LTI structures for bats, a review of the species susceptibility to collisions with vehicles or trains (Fensome & Matthews, 2016) should be evaluated so that the potential benefits outweigh the costs.

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Box 18

Reconnecting the canopy with arboreal crossings and underpasses on Costa Rican roads

Key lesson: Cross sectoral partnerships can assist in designing, installing, and monitoring mitigation measures like canopy crossings.

Costa Rica is a biodiverse country with 25% of the territory dedicated to the protection of wild places. Development here needs to be in balance with the conservation of its natural resources. Underpasses, arboreal crossings, and road signs are now a frequent part of new roads in Costa Rica. Monitoring of this green infrastructure' is crucial to evaluate whether they ensure connectivity and reduce mortality of Costa Rica's rich wildlife.

Arboreal species need a connected canopy to cross roads safely. Many of them cannot travel across the road on the ground. When building roads, arboreal connectivity is mostly lost, as right-of-ways are widened, trees cleared, and the canopy opened up. Arboreal bridges (canopy crossings) are a useful tool to reconnect canopy-dwelling species. However, installing canopy crossings requires special equipment, as does monitoring with camera traps. Maintenance crews and specialised technicians can assist by using their skills.

A white-faced capuchin (*Cebus imitator*) crosses above Route 257 using a canopy bridge in Costa Rica. © Panthera

In Costa Rica, canopy crossings were installed by local communities, electric utility companies and road administrators. On Route 4, volunteer firefighters helped install camera traps to monitor arboreal bridges. Kinkajous, howler monkeys, porcupines, opossums, and capuchin monkeys use them to cross safely over the road. An NGO monitored these structures with funding from a service agreement from the Ministry of Transportation. This agreement helps support monitoring wildlife use of the structures with camera traps and helps inform new projects (Araya-Jiménez 2019). Mitigation measures are being built throughout Costa Rica. NGOs, academia, and government have been working hand in hand for over 10 years for safer roads for wildlife and motorists. Through this collaborative work, Costa Rica has built nearly 40 underpasses for wildlife and more than 100 arboreal bridges.

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A mantled howler monkey (*Alouatta palliata*) crosses above Route 4 using a canopy bridge in Costa Rica. © Panthera

Key messages in this chapter

- The construction phase of linear infrastructure projects requires careful attention to ensure that plans and designs are followed to achieve the ecological goals of the project.
- Most projects encounter unexpected challenges that require last-minute changes as well as sequential interpretation of detailed designs that result in modifications to the project. The effect of these iterative changes on the ability of the project to achieve its ecological goals must be assessed prior to adoption.
- Ecological mitigation measures may be eliminated or downgraded during construction due to time and cost over-runs elsewhere on the project. This must be avoided because it invariably leads to insufficient mitigation and poor ecological outcomes.
- The construction, operation and maintenance phases of projects have different objectives and can affect biodiversity and ecological connectivity in varying ways.
- It is important to minimise and mitigate the construction phase by limiting impacts that affect the presence, survival and movement of wildlife such as operation of heavy equipment, excavation and blasting, increased human presence, sourcing and storing of construction material, and the fencing, wildlife crossing structures and other impacts associated with the mitigation measure itself.
- Operation and maintenance of LTI lasts for decades, if not centuries, and influence PCAs, ecological connectivity and ecosystem integrity over long time spans. Consequently, the mitigation measures must be similarly maintained for ongoing effectiveness.
- Standard maintenance programs for maintaining mitigation measures consist of four key elements: inventory of the asset, inspection schedule, routine upkeep and repairs and adaptive response to new information and maintenance techniques.

Part 10

Conclusion: The road ahead

One of Russia's first wildlife overpasses, Route M3, Kaluga, Russia © Adobe Stock

Roads, railways and canals are a significant and growing threat to the species, habitats and ecosystem processes within PCAs, ecological corridors and networks and habitats around the world. The boom in LTI development, especially in developing and emerging economies in Africa, Asia, and South America has the potential to wreak havoc on biodiversity and undermine efforts to achieve conservation, sustainable livelihoods and resilient landscapes. A vast body of research and practice globally has identified a suite of effective solutions that can be applied in all contexts around the world. Navigating the road ahead will depend not just on awareness of the issues, but a shared commitment, allocation of sufficient resources, good governance and effective policies. Based on the best available science and research, we conclude this Technical Report with the following recommendations for addressing ecological connectivity in the development of roads, railways and canals:

Impacts: When considering the role of LTI on the landscape, it is important to understand that construction, operation and maintenance of roads, railways and canals exert a range of direct and indirect impacts on the environment. The loss, fragmentation and degradation of habitat is often severe, and the disruption to animal movement and increased wildlife mortality are likely. The ecological impacts of LTI can extend many kilometres beyond the immediate area of the project and affect ecosystems near and far. The most effective way to protect the natural environment from impacts of LTI is to avoid constructing new or expanding existing infrastructure in or near protected areas, ecological corridors and networks, and other intact natural areas. In some situations, the impacts of existing LTI may be serious enough to warrant removal of the road, railway or canal.

Policies and planning: Positive outcomes from LTI projects are much more likely when ecological concerns are incorporated early in the decision-making process. Upstream planning is essential to ensure that projects do no harm to the local environment and communities, which can be better achieved through coordinated and comprehensive planning that includes all relevant stakeholders. Managers of PCAs are encouraged to get involved in the planning of any LTI as early as possible. This includes contributing to the collection of sufficient and rigorous data, while being prepared to apply high quality information to make a strong case in stakeholder meetings and planning processes. The mitigation hierarchy – avoid, minimise, mitigate, restore, compensate (or offset) – should always be genuinely applied to achieve the best possible outcomes. Significant residual impacts may still exist after applying the mitigation hierarchy, and in some cases, proposed projects should not proceed.

In Alto Conte, Costa Rica, Indigenous community members gather to consult with the Ministry of Public Works and Transportation on road improvements slated to include construction of three bridges and paving to provide year-long access to a nearby town. © Andrea Avila Alfaroy

Financing: All countries, regions and municipalities, as well as lending institutions and private contractors, must adhere to minimum performance standards and effective environmental and social safeguards. It is encouraging to see financial institutions develop, improve and adopt these safeguards. However, there is an urgent need to improve many details of the safeguards and their implementation to maximise their benefits.

Environmental assessments: All LTI plans and projects should be guided by master planning that is informed by SEAs and associated EIAs. These processes should evaluate all available scientific information and identify and prioritise PCAs, ecological corridors and networks at regional, national and international scales.

Social consequences and public participation: To avoid disruption to people and their communities – especially rural, marginalized and Indigenous communities – more holistic and integrated approaches are necessary. LTI projects should account for the true costs of resettlement, economic displacement, and the myriad of both negative and positive social, cultural and environmental changes. To assist planning processes, SEA and EIA should adhere to the legal doctrine of Free, Prior, and Informed Consent in the development of LTI projects. Lastly, SEAs and EIAs should be prepared by experts independent of LTI project proponents and adhere to proper quality assurances and controls.

Mitigation measures: While *avoidance* and *minimisation* should always be the first priorities of proposed LTI projects, there are also tools available to *mitigate* impacts. Wildlife crossing structures, such as underpasses and overpasses with accompanying directional fencing, can effectively mitigate roadkill and barrier effects of LTI for many species and should be implemented where those impacts are unable to be avoided or minimised.

Monitoring and evaluation: All approaches in the mitigation hierarchy should be thoroughly studied after implementation to evaluate effectiveness. Robust data sets ensure that resources for mitigation continue to be allocated wisely and enable adaptive management of each project – contributing to improved performance over time.

Construction, operation and maintenance: Construction, operation and maintenance phases of LTI can affect biodiversity and ecological connectivity in varying ways. Operation and maintenance of LTI is a commitment of decades, or centuries, and influences PCAs, ecological connectivity and ecosystem integrity over correspondingly long-time spans. Consequently, mitigation measures must be similarly maintained for ongoing effectiveness.

Red crabs (*Gecarcoidea natalis*) use a specially designed bridge with purpose-built directional fencing to safely cross a road during seasonal migration on Christmas Island, Australia. © Parks Australia

A wildlife crossing over a canal east of Banff National Park, Canada. Top: view from the side; Bottom: view from above © Francesco Del Greco

Postscript

This Technical Report sought to primarily provide practical guidance for managers to address the impacts of LTI projects affecting their PCAs and adjacent landscapes. It is a resource that we hope will also assist transportation and conservation professionals to achieve international ambitions for sustainable development by balancing human development with the needs of nature. Importantly, this resource is also available to inform communities and enable local leaders to achieve improved LTI in their communities.

In the first two decades of the 21st century, critical advances have been made in science and engineering that have allowed LTI ecology to make great strides. Currently, new technologies are being developed to even more effectively address the impact of LTI on the environment, and we can expect more progress in coming years. Ultimately, the goal of this report is to inspire a future where biodiversity conservation is at the forefront of LTI development and the roads, railways and canals that we plan and build today function in harmony with ecological processes.

This is the first IUCN publication to examine LTI in such a context. While not intended to serve as a formal guideline, the report lays the groundwork for subsequent efforts. Along with numerous partners, the Transport Working Group will continue to expand on this initial foray. For example, future work may wish to evaluate and provide guidance on other LTI, including power lines and pipelines. While we hope the reader has found this report helpful, there will always be a need to improve global information sharing about what does and does not work. Collaboration among a network of practitioners will continue to support an open dialogue, share ideas, and spur innovative ideas. As the field matures, accessible information, inter-organisational and interdisciplinary collaboration and partnerships are increasingly important. This publication contributes to that end.

Leopard (*Panthera pardus*) using a culvert underpass below a railway in Balule Nature Reserve, South Africa © Hannah de Villiers

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Annex 1: International financial institution environmental policies (adapted from Losos et al., 2019)

IFI	Key Aspects of Relevant Environmental Policy	Year Produced
International Finance Corporation (IFC) Performance Standards	The IFC Performance Standards on Environmental and Social Sustainability (PS) have gained recognition as the global best practice standard for assessing and mitigating negative environmental and social outcomes related to large infrastructure projects. The standards adhere strictly to the mitigation hierarchy, placing high importance on avoidance of impact if possible. Especially relevant for the environment risks related to transport infrastructure are Resource Efficiency and Pollution Prevention (PS3) and Biodiversity Conservation and Sustainable Management of Living Natural Resources (PS6). Each performance standard has an accompanying guidance note that provides more technical details about how borrowers should adhere to the PS.	Updated 2019
World Bank Environmental and Social Framework	In addition to protecting the poor and the environment and ensuring sustainable development, WB's Environmental and Social Framework (ESF) addresses, among other things, transparency, non-discrimination, social inclusion, public participation, and accountability. The Environmental and Social Standards mirror the IFC's Performance Standards very closely.	Revised 2018
Asian Development Bank (ADB)	ADB's Safeguard Policy Statement (SPS) governing the environmental and social safeguards of ADB's operations are a cornerstone of its support to inclusive economic growth and environmental sustainability in Asia and the Pacific. The objectives of the SPS are to avoid, or when avoidance is not possible, to minimise and mitigate adverse project impacts on the environment and affected people, and to help borrowers strengthen their safeguard systems and develop the capacity to manage environmental and social risks.	Revised 2009
African Development Bank (AfDB)	AfDB's Integrated Safeguards System consists of four interrelated components: Integrated Safeguards Policy Statement (PS), Operational Safeguards (OS), Environmental and Social Assessment Procedures. The PS describes common objectives of the Bank's safeguards and lays out policy principles. The OS are a set of five safeguard requirements that Bank clients are expected to meet when addressing social and environmental impacts and risks. The Impact Assessment Guidance Notes provide technical guidance to the Bank's borrowers or clients on standards of sector issues, such as roads or fisheries, or on methodological approaches clients or borrowers are expected to adopt to meet OS standards. OS3, Biodiversity, Renewable Resources, and Ecosystem Services, is especially relevant to addressing environmental risks from transport infrastructure.	2013
European Bank for Reconstruction and Development (EBRD)	EBRD's Environmental and Social Policy (ESP) puts safeguards in place to prevent or minimise any adverse environmental or social impacts, to improve the project's efficiency, and maximize benefits for the wider community and future generations. ESP outlines how the EBRD will address the environmental and social impacts of its projects by defining the respective roles and responsibilities of both the Bank and its clients in designing, implementing and operating projects; setting a strategic goal to promote projects with high environmental and social benefits; and mainstreaming environmental and social sustainability considerations into all its activities.	2014
Inter-American Development Bank (IDB)	IDB's social and environmental safeguards are in process of modernization to an environmental and social policy framework. The core principles of the new framework will be (i) no dilution of current policies, (ii) outcome oriented (iii), proportionality (iv), transparency and (v) "do good" beyond "do no harm". The draft standards track closely to the World Bank ESF.	2007 draft ESPF 2019
Asian Infrastructure Investment Bank (AIIB)	AIIB's Environmental and Social Framework (ESF) includes an Environmental and Social Exclusion List— a list of project types or activities that the bank refuses to finance on environmental or social grounds. In many ways, the AIIB Environmental and Social Framework aligns with similar standards released by other banks, but it also relies heavily on its partners' standards (Weiss, 2017).	2017
New Development Bank (NDB)	The NDB's ESF includes an environmental and social policy as well as environmental and social standards (ESS). ESS1, the Environmental and Social Assessment, is particularly relevant.	2016
Export-Import Bank of China (Exim Bank)	The 2007 Guidelines for Environmental and Social Impact Assessment of China Export and Import Bank's Loan Projects requires environmental impact assessments, monitoring, and review of project impacts for all projects before a project gains approval. When deemed necessary, environmental and social responsibilities may be included in the loan contact. The Exim Bank also has the right to monitor the client's implementation of the mitigation activities (FOE, 2016; Leung et al., 2013).	2007; 2015
China Development Bank (CDB)	CDB has transparent sustainable development objectives – including an objective on environmental protection for climate, ecology, clean energy, and low carbon living – but specific environmental policies and their content are not available to the public (FOE, 2016). In 2006, CDB pledged to abide by the UN Global Compact 10 principles in human rights, labour standards, environment and anti-corruption. CBD produced a series of non-binding frameworks to promote environmentally-friendly businesses, including an annual Work Plan for Loans to Reduce Pollution and Emissions, Guidelines on Environmental Protection Project Development Review, and Guidelines on Special Loans for Energy Conservation and Emission Reduction (FOE, 2016).	2004

Annex 2: Resources

This Technical Report follows in the footsteps of decades of work to develop and share best practices in ecological connectivity conservation and transport ecology around the world. Below you will find information on selected resources for connectivity conservation (Part 1), linear transport ecology (Part 2), and other sources for further information (Part 3). For ease of use, these resources have been organised by their geographic applicability, and ordered from newest to oldest.

Part 1: Connectivity conservation

Guidelines for conserving connectivity through ecological networks and corridors (2020)
Hilty, J., Worboys, G.L., Keeley, A., Woodley, S., Lausche, B., Locke, H., Carr, M., Pulsford I., Pittock, J., White, J.W., Theobald, D.M., Levine, J., Reuling, M., Watson, J.E.M., Ament, R. and Tabor, G.M. Best Practice Protected Area Guidelines Series No. 30. Gland, Switzerland: IUCN. https://doi.org/10.2305/IUCN.CH.2020.PAG.30.en

“Connectivity conservation management” in **Protected Area Governance and Management** (2015)
Pulsford, I., Lindenmayer, D., Wyborn, C., et al. Worboys, G.L., Lockwood, M., Kothari, A., Feary, S., and Pulsford, I. (eds.). Canberra: ANU Press. https://doi.org/10.22459/PAGM.04.2015

The Legal Aspects of Connectivity Conservation: A Concept Paper (2013)
Lausche, B., Farrier, D., Verschuuren, J., et al. IUCN Environmental Policy and Law Paper, no. 85, volume 1. Gland, Switzerland: IUCN. https://portals.iucn.org/library/node/10421

Part 2: Linear transport infrastructure ecology

Global

A Global Strategy for Ecologically Sustainable Transport and Other Linear Infrastructure (2020)
Georgiadis, L. (Coord). Paris, France: IENE, ICOET, ANET, ACLIE, WWF, IUCN-CCSG.
http://www.iene.info/wp-content/uploads/2020Dec_TheGlobalStrategy90899.pdf

Handbook of Road Ecology (2015)
van der Ree, R., Smith, D.J. and Grilo, C. (eds.). Chichester, UK: John Wiley & Sons.
https://doi.org/10.1002/9781118568170

Railway Ecology (2017)
Borda-de-Água, L., Barrientos, R., Beja, P., and Miguel Pereira, H. (eds.). London, UK: Springer Nature.
https://doi.org/10.1007/978-3-319-57496-7

Roads and Ecological Infrastructure (2015)
Andrews, K.M., Nanjappa, P., and Riley, S.P.D. (eds.). Baltimore, MD: JHU Press
ISBN 9781421416397

Safe Passages: Highways, Wildlife, and Habitat Connectivity (2010)
Beckmann, J.P., Clevenger, A.P., Huijser, M., and Hilty, J.A. Washington, D.C.: Island Press
ISBN 1597269670, 9781597269674

Road Ecology: Science and Solutions (2002)
Forman, R.T.T., Sperling, D., Bissonette, J.A., et al. Washington, D.C.: Island Press
ISBN 1559639334, 9781559639330.

Asia

Protecting Asian Elephants from Linear Transportation Infrastructure: The Asian Elephant Transport Working Group’s Introduction to the Challenges and Solutions (2021)
Ament, R., Tiwari, S.K., Butynski, M., et al. IUCN WCPA and SSC Asian Elephant Transport Working Group.
https://doi.org/10.53847/VYWN4174

Green Infrastructure Design for Transport Projects: A Road Map to Protecting Asia's Wildlife Biodiversity (2019)
Asian Development Bank http://dx.doi.org/10.22617/TCS189222

Central Asian Mammals Migration and Linear Infrastructure Atlas (2019)
UNEP/CMS, eds. CMS Technical Series No. 41. Bonn, Germany.
https://www.cms.int/cami/sites/default/files/publication/cami_atlas_3_complete.pdf

Eco-Friendly Measures to Mitigate Impacts of Linear Infrastructure on Wildlife (2016)
Wildlife Institute of India
https://wii.gov.in/images/images/documents/eia/EIA_BPG_Report_2017.pdf

Guidelines on Mitigating the Impact of Linear Infrastructure and Related Disturbance on Mammals in Central Asia (2014)
Convention on Migratory Species. UNEP/CMS/COP11/Doc.23.3.2.
http://www.cms.int/sites/default/files/document/COP11_Doc_23_3_2_Infrastructure_Guidelines_Mammals_in_Central_Asia_E.pdf

Smart Green Infrastructure in Tiger Range Countries: A Multi-Level Approach (2010)
Quintero J., Roca, R., Morgan, A.J., and Mathur, A. Global Tiger Initiative, The World Bank, Washington, D.C.
http://www.globaltigerinitiative.org/download/GTI-Smart-Green-Infrastructure-Technical-Paper.pdf

Australia

Roads in Rainforest: Best Practice Guidelines for Planning, Design and Management (2010)
Goosem, M., Harding, E.K., Chester, G., et al. Cairns, Queensland: Reef and Rainforest Research Centre Limited. Australia.
http://researchonline.jcu.edu.au/12113/1/goosem_guidelines.pdf

Review of Mitigation Measures Used to Deal with the Issue of Habitat Fragmentation by Major Linear Infrastructure (2008)
Van der Ree, R., Clarkson, D.T., Holland, K., et al. Report for Department of Environment, Water, Heritage and the Arts (DEWHA), Contract No. 025/2006.
https://www.environment.gov.au/system/files/resources/dbcf5e19-a1bc-4405-b497-fdcc7c05ab12/files/habitat-fragmentation.pdf

Europe

Wildlife and Traffic in the Carpathians: Guidelines how to minimize the impact of transport infrastructure development on nature in the Carpathian countries (2019)
Hlaváč, V., Andel, P., Matoušová, J., et al. TRANSGREEN project Integrated Transport and Green Infrastructure Planning in the Danube-Carpathian Region for the Benefit of People and Nature.
https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/35/02caaafe3c1c1365f76574e754ddbdc4e1af4a7a.pdf

Ecology Guidelines for Transmission Projects: A Standard Approach to Ecological Assessment of High Voltage Transmission Projects (2012)
EirGrid and Natura Environmental Consultants, Dublin, Ireland.
http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Ecology-Guidelines-for-Electricity-Transmission-Projects.pdf

Guidelines for Assessment of Ecological Impacts of National Roads Schemes (2009)
National Roads Authority, Ireland.
http://www.tii.ie/technical-services/environment/planning/Guidelines-for-Assessment-of-Ecological-Impacts-of-National-Road-Schemes.pdf

Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions (2021)
Infrastructure and Ecology Network Europe
https://handbookwildlifetraffic.info/

North America

Cost Effective Solutions: Best Practices Manual to Reduce Animal-Vehicle Collisions and Provide Habitat Connectivity for Wildlife (2023)
Huijser, M.P., Fairbank, E.R., Paul, K.S., (eds). Transportation Pooled Fund Study, TPF-5(358). Nevada Department of Transportation, Carson City, NV. 10.15788/ndot2022.2.
https://westerntransportationinstitute.org/wp-content/uploads/2023/01/Report_TPF-5-358_AVC_Best-Practices-Manual.pdf

Highway Crossing Structures for Wildlife: Opportunities for Improving Driver and Animal Safety (2021)
Ament, R., Jacobson, S., Callahan, R., and Brocki, M. (eds.). US Department of Agriculture, Forest Service – Pacific Southwest Research Station, Albany, CA. General Technical Report PSW-GTR-271.
https://www.fs.fed.us/psw/publications/documents/psw_gtr271/psw_gtr271.pdf

Innovative Strategies to Reduce the Costs of Effective Wildlife Overpasses (2021)
McGuire, T.M., Clevenger, A.P., Ament, R., et al. US Department of Agriculture, Forest Service – Pacific Southwest Research Station, Albany, CA. General Technical Report PSW-GTR-267.
https://www.fs.fed.us/psw/publications/documents/psw_gtr267/psw_gtr267.pdf

Measures to Reduce Road Impacts on Amphibians and Reptiles in California: Best Management Practices and Technical Guidance (2021)
Langton, T.E.S. and Clevenger, A.P. Western Transportation Institute for CA Department of Transportation, Division of Research, Innovation and System Information.
https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca20-2700-finalreport-a11y.pdf

Manual de Diseño de Pasos Para Fauna Silvestre en Carreteras [México] (2020)
Secretaría de Comunicaciones y Transportes. Subsecretaría de Infraestructura. Dirección General de Servicios Técnicos.
https://www.sct.gob.mx/fileadmin/DireccionesGrales/DGST/Manuales/Manual_de_Fauna/ManualPasosparaFauna.pdf

Road Passages & Barriers for Small Terrestrial Wildlife: Project Summary Report (2019)
Gunson, K.E. and Huijser, M.P. Eco-Kare International and Western Transportation Institute in association with Louis Berger US, Inc. Contractor's Final Report Prepared for AASHTO Committee on Environment and Sustainability.
http://onlinepubs.trb.org/Onlinepubs/NCHRP/docs/NCHRP25-25Task113ProjectSummaryReport.pdf

Design of Terrestrial Wildlife Crossing System: Nature Conservation Practice Note
Agriculture, Fisheries and Conservation Department, US, Ref. AF GR CON 21/2. (2014) https://www.afcd.gov.hk/english/conservation/con_tech/files/NCPN_No.04_Wildlife_Underpass_Structures_v2006.pdf

Trans-Canada Highway Wildlife Monitoring and Research: Final Report 2014 (Part B: Research) (2014)
Clevenger, A.P. and Barrueto, M. (eds.). Prepared for Parks Canada Agency by the Western Transportation Institute and the Miistakis Institute.
https://arc-solutions.org/wp-content/uploads/2015/12/Banff-TCH-Wildlife-Monitoring-Research-Final-Report-2014_withappendices1.pdf

Wildlife Crossing Structure Handbook: Design and Evaluation in North America (2011)
Clevenger, A.P. and Huijser, M.P. US DOT, FWA - Central Federal Lands Highway Division.
https://roadecology.ucdavis.edu/files/content/projects/DOT-FHWA_Wildlife_Crossing_Structures_Handbook.pdf

Wildlife Vehicle Collision Reduction Study: Best Practices Manual (2008)
Huijser, M.P., McGowen, P., Fuller, J., et al. Report No.FHWA-HRT-08-034. U.S. Department of Transportation.
https://www.fhwa.dot.gov/publications/research/safety/08034/08034.pdf

Central and South America

Atropellamiento de fauna silvestre en Colombia: Guía para entender y diagnosticar este impacto (2021)
Jaramillo-Fayad, J.C., Velázquez, M.M., Premauer, J.M., González, J.L., and González Vélez, J.C. Gobierno Nacional de Colombia – Institución Universitaria ITM.
https://www.mintransporte.gov.co/publicaciones/10217/gobierno-nacional-lanza-guia-para-entender-y-diagnosticar-el-impacto-del-atropellamiento-de-fauna-silvestre-en-colombia/

Lineamientos de Infraestructura Verde Vial para Colombia (LIVV) (2020)
Ministerio de Ambiente y Desarrollo Sostenible-Minambiente, Fundación para la Conservación y el Desarrollo Sostenible-FCDS, y WWF-Colombia
https://wwflac.awsassets.panda.org/downloads/infraestructura_verde_b23_c9_safe_oct2020.pdf

Guía Ambiental "Vías Amigables con la Vida Silvestre" (2014)
Pomareda, E. Araya-Gamboa D., Ríos Y., et al. Comité Científico de la Comisión Vías y Vida Silvestre, Costa Rica.
https://www.researchgate.net/publication/307946704_Guia_Ambiental_Vias_Amigables_con_la_Vida_Silvestre_Environmental_Guide_Wildlife_Friendly_Roads

Principles, Practices and Challenges for Green Infrastructure Projects in Latin America (2012)
Quintero, J. D. Discussion paper no. IDB-DP-250. Inter-American Development Bank (Available in English and Spanish).
http://www19.iadb.org/intal/intalcdi/PE/2013/11428.pdf

Guía de Manejo Ambiental de Proyectos de Infraestructura Subsector Vial (2011)
INVIAS (Instituto Nacional de Vias) y Ministerio de Ambiente, Vivienda y Desarrollo Territorial, República de Colombia.
https://www.invias.gov.co/index.php/archivo-y-documentos/documentos-tecnicos/guia-de-manejo-ambiental-de-proyectos/971-guia-de-manejo-ambiental/file

Part 3: Additional resources

IUCN WCPA-CCSG Transport Working Group (TWG)
(https://conservationcorridor.org/ccsg/working-groups/twg/)

IUCN SSC-AsESG and WCPA-CCSG Asian Elephant Transport Working Group (AsETWG)
(https://conservationcorridor.org/ccsg/working-groups/asetwg/)

IUCN WCPA-CCSG Latin American and Caribbean Transport Working Group (LACTWG)
(https://conservationcorridor.org/ccsg/working-groups/lactwg/; https://latinamericatransportationecology.org)

Transportecology.info (https://transportecology.info/)

Conservation Evidence (https://www.conservationevidence.com/)

African Conference for Linear Infrastructure and Ecology (ACLIE) (https://aclie.org)

Australasian Network for Ecology and Transportation (ANET) (http://www.ecologyandtransport.com)

Infrastructure and Ecology Network Europe (IENE) (https://www.iene.info/)

Biodiversity and Infrastructure Synergies and Opportunities for European Transport Networks (BISON)
(https://bison-transport.eu)

International Conference on Ecology and Transportation (ICOET) (https://www.icoet.net/)

Global Conference for Linear Infrastructure and Environment (GCLIE) (https://gclie.org/)

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