



# GREEN INFRASTRUCTURE DESIGN FOR TRANSPORT PROJECTS

## A ROAD MAP TO PROTECTING ASIA'S WILDLIFE BIODIVERSITY

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DECEMBER 2019



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On the cover: Wildlife species captured on camera while carrying out a baseline biodiversity assessment in Phibsoo Wildlife Sanctuary, Bhutan. Center photo shows one of Asia’s first wildlife underpasses constructed on a new highway in southern Bhutan (photos by ADB).

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# ACKNOWLEDGMENTS

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**T**his report reflects the rapid evolution of the awareness and commitment of development agencies, national governments, think tank organizations and nongovernmental organizations to protecting Asia's biodiversity during the design and implementation of transport infrastructure projects, an evolution that has accelerated over the last 5 years. Vital to continuing the application of green infrastructure principles in transport projects in Asia are comprehensive guidelines based on the best available science and project experiences. These guidelines serve as a road map to balancing economic development with conserving Asia's biodiversity in transport infrastructure projects, and as a tool and resource for engineers, transport planners, and ecologists in the pursuit of green transport infrastructure.

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Marie Kristine Estrella, project analyst of the South Asia Department, and April Marie D. Gallega, associate communications coordinator, and Noren M. Jose, associate communications officer, of the Department of Communications in ADB made significant contributions in editing and bringing the report to its final shape.



# ABBREVIATIONS

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AADT	average annual daily traffic
ADB	Asian Development Bank
BBA	biodiversity baseline assessment
CEPF	Critical Ecosystem Partnership Fund
EIA	environmental impact assessment
ESV	ecosystem service values
GIS	geographic information system
GPS	global positioning satellite
ha	hectare
IBAT	integrated biodiversity assessment tool
IFC	International Finance Corporation
IUCN	International Union for the Conservation of Nature
km	kilometer
km <sup>2</sup>	square kilometer
LPI	Living Planet Index
m	meter
NCHRP	National Cooperative Highway Research Program
NDVI	normalized difference vegetation index
PRC	People's Republic of China
SDI	Shannon–Weaver diversity index
SPS	<i>Safeguard Policy Statement</i> (ADB)
US	United States
WVC	wildlife–vehicle collisions
WWF	World Wide Fund for Nature

# ANIMAL SPECIES REFERENCED IN THIS REPORT

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African (savannah) elephant	<i>Loxodonta africana</i>
African forest elephant	<i>Loxodonta cyclotis</i>
Asian elephant	<i>Elephas maximus</i>
Asian tapir	<i>Acrocodia indica</i>
Asian wild ass	<i>Equus hemionus</i>
Asiatic golden cat	<i>Catopuma temminckii</i>
Asiatic lion	<i>Panthera leo persica</i>
Asiatic water buffalo	<i>Bubalus bubalis</i>
Barking deer	<i>Muntiacus muntjak</i>
Bighorn sheep	<i>Ovis canadensis</i>
American black bear	<i>Ursus americanus</i>
Asiatic black bear	<i>Ursus thibetanus</i>
Black-necked crane	<i>Grus nigricollis</i>
Bobcat	<i>Lynx rufus</i>
Caribou	<i>Rangifer tarandus</i>
Civet family	<i>Viverridae</i>
Coyote	<i>Canis latrans</i>
Deer	<i>Odocoileus spp.</i>
Dhole (Asiatic wild dog)	<i>Cuon alpinus</i>
Eastern quolls	<i>Dasyurus viverrinus</i>
Elk	<i>Cervus canadensis</i>
Gaur	<i>Bos gaurus</i>
Giant panda	<i>Ailuropoda melanoleuca</i>
Great barbet	<i>Megalaima virens</i>
Grizzly bear	<i>Ursus arctos</i>
Langur subfamily	<i>Colobinae</i>
Leopard cat	<i>Prionailurus bengalensis</i>
Leopard	<i>Panthera pardus</i>
Marten	<i>Martes spp.</i>
Mongolian gazelle	<i>Procapra gutturosa</i>
Moose	<i>Alces alces</i>
Mountain lion	<i>Puma concolor</i>
Mule deer	<i>Odocoileus hemionus</i>
Plateau pika	<i>Ochotona curzoniae</i>
Pronghorn	<i>Antilocapra americana</i>
Przewalski's horse	<i>Equus ferus przewalskii</i>

Red-breasted parakeet  
Sambar  
Siberian weasel  
Spotted (Chital) deer  
Tasmanian devil  
Tibetan antelope  
Tiger  
White-tailed deer  
Wolf  
Wolverine

*Psittacula alexandri*  
*Rusa unicolor*  
*Mustela sibirica*  
*Axis axis*  
*Sarcophilus lanarius*  
*Pantholops hodgsonii*  
*Panthera tigris*  
*Odocoileus virginianus*  
*Canis lupus*  
*Gulo gulo*

# EXECUTIVE SUMMARY

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Asia harbors immense biodiversity that is increasingly threatened by expanding road and rail networks across the region. Much of the world's terrestrial biodiversity is concentrated within the rainforest landscapes of Asia, which hosts half of the eight global biodiversity "hotspots." Biodiversity is of tremendous importance to the region's teeming population that depends on natural and diverse ecosystems for livelihood and well-being.

Roads and railways are widely regarded as a primary driver—gateway and catalyst—for the loss of natural ecosystems even if they are considered essential for economic development and support to vital human activities. Transport development projects must consider the habitats and wildlife species present in project areas if they are to properly address and conserve biodiversity values. This report centers on this key theme.

The main goal of the report is to provide an overview of considerations for the proactive integration of ecological protection measures. These measures include management, planning, and design activities in road and railway projects to balance construction with the conservation of Asia's remaining biodiversity. The considerations are applicable to both new and existing transport projects, and even standalone "retrofit" applications to address existing impacts on biodiversity.

The report underscores the importance of an "overarching" policy to guide transport project impact assessment, planning, and design.

This includes systematically evaluating the economic and social need for projects and pursuing alternative alignments within areas of high biodiversity containing threatened and endangered animal and plant populations. The Asian Development Bank's *Safeguard Policy Statement* (2009) and *Environment Safeguards: A Good Practice Sourcebook* (2012) and the International Finance Corporation's *Performance Standard 6 Guidance Note* (2012, updated in 2019) provide a policy framework applicable to transport infrastructure projects.

This report details the variety of green infrastructure and protective measures available to minimize road impacts on wildlife and biodiversity. It also provides compelling examples of green infrastructure benefits, demonstrating that components of any comprehensive road and conservation strategy are most effective if planned and implemented as integrated systems.

The protective measures may include wildlife passage structures (overpasses and underpasses), motorist alert signage, reduced design speeds, traffic calming treatments, wildlife fencing and alternative applications, arboreal mammal canopy bridges, at-grade crossings, and wildlife "crosswalks."

To effectively address specific wildlife conservation needs, design variations for wildlife passage or crossing structures and fencing options are discussed, together with the recommended metrics for passage and fence structure and size, spacing, and

placement; different structural approaches to ensure unimpeded line-of-sight visibility for wildlife; criteria for underpass openness and overpass dimensions; the advantages of earthen substrate for flooring; and whether the underpass or overpass may be better for certain specific species.

Overarching road design principles and standards are essential to transport project design and management considerations to reduce a project's impact on biodiversity and wildlife species. The principles and standards are to (i) fully construct roadbed formations once, to accommodate anticipated future upgrading; (ii) build to the minimum width necessary; (iii) limit lateral road access; (iv) focus infrastructure investment where land tenure or control is secure; and (v) design infrastructure that could minimize maintenance requirements.

To further mitigate road impacts and complement the benefits of green infrastructure, key actors should actively manage and enforce activities, such as

dusk-to-dawn road closures, management of roads as a resource protection asset with observation towers and anti-poaching outposts, post-construction monitoring and adaptive management, and reconstruction and retrofitting opportunities employing “drop-in” applications of prefabricated underpasses to secure safe wildlife passage that can be accomplished with minimal disruption to traffic flow.

The report also examines the importance of conducting scientifically creditable baseline assessments and evaluations of road and highway impacts associated with proposed road alignments (Appendix). Some general guidelines and considerations that pertain to desktop analyses—essential to sound field study design—and field studies are provided.

A list of various resource materials further supplements the overall discussion on and recommendations for the development of environmentally sound transport infrastructure projects that minimize impacts and ultimately safeguard and conserve Asia's remaining biodiversity.



# CHAPTER 1

## INTRODUCTION

---

**H**ome to a vast variety of living species and ecosystems, Asia is nestled in an immense geographical land mass. The region's land mass is formed by the convergence of two of the world's eight biogeographic realms, Palearctic and Indomalayan, and their many biogeographic provinces (Udvardy 1975), and accentuated by the greatest elevational relief on Earth—sea level soaring above 8,000 meters (m). Asia's biodiversity and species richness rival that of South America as the most biologically diverse on Earth (Squires 2013).

Asia hosts a significant percentage of the world's recognized biodiversity hotspots. These hotspots are biogeographic regions tied to the loss of species endemism—species found only in a particular region. The region also faces threats from further habitat loss beyond the 70% already lost (Myers et al. 2000). Of the 25 hotspots that have been identified in the world, 6 are in Asia.

Roads are widely regarded as a “gateway” to the loss of biodiversity within roadless areas. Poorly planned and implemented roads have been characterized as the “enemy” of rainforests (Laurance et al. 2009). Tropical forests, including those prevalent in Asia, are especially susceptible to the impacts of linear infrastructure since they have evolved as stable, complex ecosystems exhibiting minimal forest edge effect. Associated species are often quite specialized in their use of contiguous forest habitats and are not well adapted to the presence of narrow, linear openings in the forest canopy.

In particular, roads within Asia's tropical forests are regarded as the primary driver of habitat destruction and the catalyst for the spread of

major threats, including modification of forest habitats, intensification of forest destruction, and illegal hunting and trade in animal parts (Clements et al. 2014). New roads that permeate pristine, biodiversity-rich areas have been identified as the potentially most dangerous, with paved roadways exhibiting much greater impact than unpaved roads due to enhanced access (Laurance 2015). The most rapid rates of deforestation occur within 10 kilometers (km) of roads, especially if they are paved (Selva et al. 2015). In East Asia's developing countries, the percentage of paved roads increased dramatically from 16% to 51% during 2005–2010, which correlates within the region's high rate of tropical forest destruction and fragmentation (Clements et al. 2014).

While poorly planned roads are characterized as the “enemy” of rainforest biodiversity, roads are still recognized as essential for economic development and support to vital human activities in developing nations (Laurance et al. 2009). The developing nations of Asia are flooded with new road proposals and plans to support economic development initiatives. In 2001, 13,000 km of new roads were planned in India alone (Rajvanshi et al. 2001) to address the anticipated quadrupling of vehicles on its roads (Seshadri and Ganesh 2015). The proposed Asian Highway, crossing 32 countries and linking Asia to Europe, spans approximately 143,000 km (Rajvanshi and Mathus 2015).

This report aims to provide an overview of considerations for proactive integration of road ecology measures, including management, planning, and design activities in road and other transportation projects, to help balance

construction with the preservation of Asia's wildlife biodiversity. It should be emphasized that, to address existing impacts on biodiversity, these considerations apply to both new road and transportation project construction and existing road reconstruction and upgrading (e.g., widening), and even standalone "retrofit" applications. The report provides a comprehensive overview of

- the scope of Asia's biodiversity hotspots and the varied ecological impact, both direct and indirect, associated with roads, highways, and other transportation infrastructure (Chapter 2 and 3);
- green infrastructure and other measures available to minimize the effects of highways and roads to wildlife and biodiversity, with examples of the benefits they can yield (Chapter 4);
- road design and management guidelines for incorporating effective green infrastructure and other measures in strategies to reduce road impact to wildlife and biodiversity (Chapter 5); and
- approaches and considerations to conducting baseline biodiversity assessments and evaluations of road and highway impact associated with proposed road alignments.

This report, while comprehensive in nature, is by no means all-encompassing in its incorporation of the vast amount of information and resources available on road ecology, green infrastructure, and other measures, as well as their application across the tremendous range of conditions in the diverse Asian continent. The references in this report are also meant to encourage governments and communities, engineers, biologists, environmentalists, and other consultants to seek additional information as needed.



# TERRESTRIAL BIODIVERSITY OF ASIA

**R**egardless of the classification scheme employed, particularly the identification of nine templates for global biodiversity prioritization by Turner et al. (2007), Asia supports a significant proportion of the world's recognized biodiversity hotspots. The landmark biodiversity classification of Myers et al. (2000) recognizes 25 hotspots that affect 1.4% of the earth's land surface, 44% of all vascular plant species, and 35% of all vertebrate species. Myers et al. further identifies eight of the world's

“hottest hotspots,” half of which are in Asia: (i) Indo-Myanmar, (ii) Sundaland, (iii) the Philippines, and (iv) Western Ghats/Sri Lanka (Map 1 and Table 1).

Conservation organizations such as Conservation International and World Wide Fund for Nature (WWF) now recognize 34 to 36 global hotspots. Most organizations ascribe to the identification by the Critical Ecosystem Partnership Fund (CEPF) of 36 hotspots, which cover 2.3% of

## Map 1: Global Biodiversity Hotspots



Note: The map includes the ninth hotspot—the mountains of Central Asia.

Source: Adapted from Conservation International.

the earth's land area, and harbor 42% of all vertebrate species and 75% of all threatened mammals, birds, and amphibians (WWF 2014). The CEPF's hotspot classification is predicated on areas that support at least 1,500 vascular plant species and have already lost 70% of their original natural vegetated habitats. Eight of the 36 CEPF global hotspots occur in Asia, though some classifications include the ninth—the mountains of Central Asia (Map 1 and Table 1).

The Sundaland hotspot of Asia alone harbors 15,000 vascular plant species and 162 endemic and threatened bird, mammal, and amphibian species, the highest recorded for Asia. This tremendous diversity occurs on just the remaining 6.7% of naturally vegetated area.

The eight Asian biodiversity hotspots support an average of 5,156 species of plants and 89 threatened endemic bird, mammal, and amphibian species (Table 1).

Much of the world's terrestrial biodiversity is concentrated within tropical rainforest-dominated landscapes, including a large percentage remaining in Asia (Myers et al. 2000, Ceballos and Ehrlich 2006, Laurance et al. 2009, Squires 2013). This has been the case for the distribution of threatened birds, mammals, amphibians, and other animals (Ceballos and Ehrlich 2006) as shown in Table 1. In particular, the Hengduan mountain region within the hotspot in the southwest of the People's Republic of China (PRC) constitutes the most

**Table 1: Scope of Asia's Biodiversity Hotspots**

Biodiversity Hotspot	Countries Included within Hotspot	Vegetated Area (km <sup>2</sup> )		Endemic Species (Threatened)				Protected Area (km <sup>2</sup> ) (% Original)
		Original	Remaining (%)	Plants	Birds	Mammals	Amphibians	
Himalaya	Bhutan, India, Nepal, Pakistan	741,706	185,427 (25.0%)	3,160	8	4	4	112,578 (15.2%)
Indo-Myanmar	Bangladesh, Cambodia, Lao PDR, Malaysia Myanmar, PRC, Viet Nam	2,373,057	118,653 (5.0%)	7,000	18	25	35	235,758 (9.9%)
Japan	Japan	373,490	74,698 (20.0%)	1,950	10	21	19	62,025 (16.6%)
Mountains of southwest PRC	PRC	262,446	20,996 (8.0%)	3,500	2	3	3	14,034 (5.3%)
Philippines	Philippines	297,179	20,803 (7.0%)	6,091	56	47	48	32,404 (10.9%)
Sundaland	Indo-Malayan archipelago, including Borneo and Sumatra	1,501,063	100,571 (6.7%)	15,000	43	60	59	179,723 (12.0%)
Wallacea	Bali, Borneo, Java, Timor-Leste, west of New Guinea	338,494	50,774 (15.0%)	1,500	49	44	7	24,387 (7.2%)
Western Ghats/Sri Lanka	India, Sri Lanka	189,611	43,611 (23.0%)	3,049	10	14	87	26,130 (13.8%)
<b>Total</b>		<b>6,077,046</b>	<b>615,533</b>	<b>41,250</b>	<b>196</b>	<b>218</b>	<b>262</b>	<b>687,039</b>
<b>Mean</b>			<b>13.7%</b>	<b>5,156</b>	<b>24.5</b>	<b>27.3</b>	<b>32.75</b>	<b>11.3%</b>

km<sup>2</sup> = square kilometer, Lao PDR = Lao People's Democratic Republic, PRC = People's Republic of China.

Source: Critical Ecosystem Partnership Fund. Explore the Biodiversity Hotspots. <https://www.cepf.net/our-work/biodiversity-hotspots>.

species-rich *temperate* forest ecosystem not only within Asia (CEPF) but also in the entire world (MacKinnon 2002, Squires 2013).

While the vegetation across Asia's hotspots is dominated by tropical and subtropical rainforests, it is tremendously diverse—contributing to the region's terrestrial biodiversity. This vegetation includes the dry lowland scrub forests in Sri Lanka; the savannah woodlands in Wallacea; the montane and boreal forests in the Himalayas and Japan; and the mountains in southwest PRC, the Philippines, and the Wallacea hotspots; as well as the high-elevation subalpine and alpine areas in the Himalayas and Japan, and CEPF hotspots in the Philippines.

As another metric to biodiversity, Juffe-Bignoli et al. (2014) reported that 2,035 key biodiversity areas occur within Asia, including 1,937 significant bird and biodiversity areas named by Birdlife International ([www.birdlife.org](http://www.birdlife.org)) and the 98 Alliance for Zero Extinction ([www.zeroextinction.org](http://www.zeroextinction.org)) focused on safeguarding sites critical to preventing species extinctions (Map 2). Together, these key biodiversity areas in Asia account for 95% of all globally threatened species in the International Union for the Conservation of Nature (IUCN) Red List (Juffe-Bignoli et al. 2014). These key biodiversity areas complement the recognized biodiversity hotspots and better reflect areas that have not yet sustained high habitat losses.

**Map 2: Biodiversity Areas of Asia with High Diversity of Bird Species**



Source: Adapted from Birdlife International. 2019. Data Zone. Cambridge. <http://datazone.birdlife.org/site/mapsearch>.



Just 16% of Asia's key biodiversity areas are completely encompassed within protected areas and most remain vulnerable. Proposed development projects within these areas, including roads, must consider the habitats and wildlife species present to properly address and protect biodiversity.

According to Juffe-Bignoli et al. (2014), there are currently about 10,900 protected areas in 24 countries in Asia. These areas often represent the last remaining strongholds for biodiversity and the preservation of Asia's valuable natural capital and ecosystem services that are very important to its human population (ADB and WWF 2012). Within eight of Asia's biodiversity hotspots identified by CEPF (Table 1), only 11.3% of the land area falls within protected areas.

Even with eight (or nine, depending on the classification used) of the world's designated biodiversity hotspots (2,035 key biodiversity areas and 10,900 protected areas), tremendous

biodiversity exists outside these areas across Asia, spanning a vast range of habitat types and supporting unique assemblages of wildlife. The biodiversity associated with such areas, though perhaps not formally protected, nonetheless is important and merits attention and preservation, especially in the context of providing connectivity among formally designated areas.

### A. Biodiversity's Importance to the People of Asia

Asia's land area represents just 14% of the earth's total land surface, yet supports 3.8 billion people (Juffe-Bignoli et al. 2014) or nearly half the world's population. Asia's average human population density is eight times greater than the global average (MacKinnon 2002, Squires 2013), though much of its population is concentrated in cities.

The diverse ecosystem services derived from areas high in biodiversity support over a billion people worldwide, most living in extreme poverty



► **Dual purpose.** Harvested rice field in Bhutan within a protected wildlife sanctuary yields both biodiversity preservation and ecosystem services (photo by ADB).

(World Bank 2006, Turner et al. 2007). A sixth of the population is dependent on the natural capital and ecosystem services associated with protected areas and functioning ecosystems for their livelihood and well-being. A billion people in Asia depend on the freshwater flowing from streams and rivers originating from the Himalayas; and the intact ecosystems provide valuable flood protection (ADB and WWF 2012). Natural capital associated with food production, timber, firewood, mineral deposits, and other natural resources constitutes 26% of the total wealth in low-income countries, including most countries in Asia (World Bank 2006). This proportion of wealth exceeds those from produced capital (16%) associated with infrastructure, equipment, and machinery (ADB and WWF 2012). The full value and potential benefits to people associated with biodiversity are not yet fully understood and quantified, such as the potential pharmaceutical uses of yet undiscovered species in Asia.

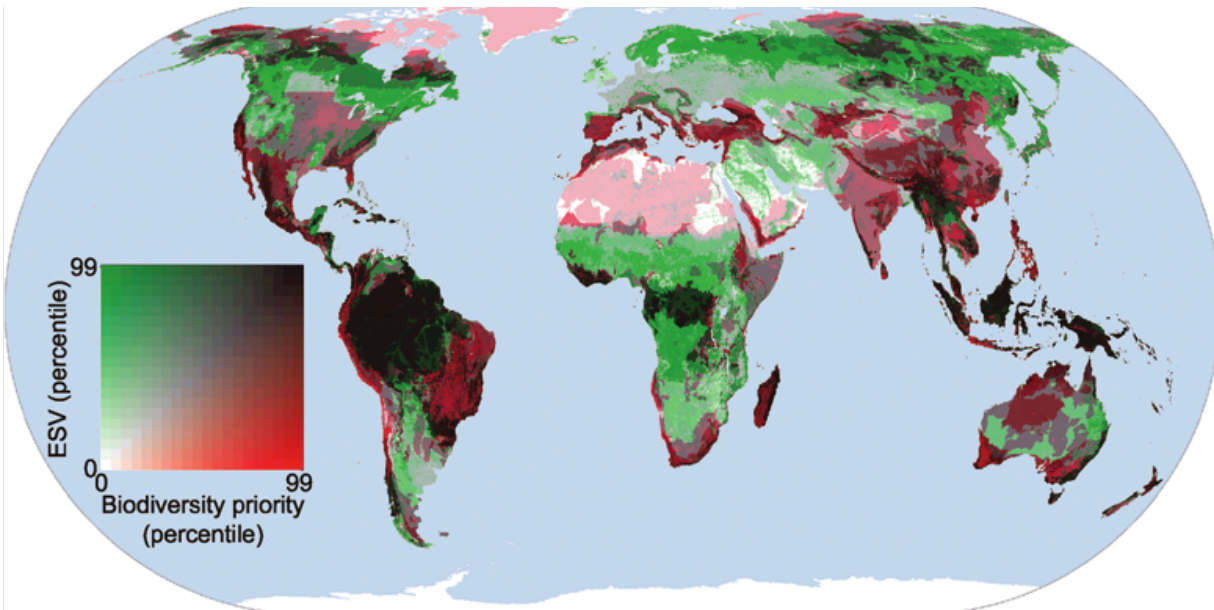
The ecosystem services derived from fully functioning ecosystems in high-biodiversity areas are essential to the rural populations dependent upon them for their direct survival and well-being. These ecosystem services also have tremendous economic value at the local and regional scales. Turner et al. (2007) summarized the economic value of ecosystem services for nine global biodiversity approaches to setting conservation priorities, measured as ecosystem service values or ESV (Sutton and Costanza 2002). Their average ESV in high biodiversity areas ranged from \$46,308 to \$200,720 per square kilometer ( $\text{km}^2$ ) per year. The conservation approaches that were most proactive and focused on preventing habitat and species loss and vulnerability, and thus were indicative of more functional ecosystems, yielded the highest ESV (\$217,356/ $\text{km}^2$ /year). The most reactive approaches associated with areas having already lost much of their biodiversity and ecosystem function yielded an ESV of \$76,057/ $\text{km}^2$ /year, or one-third that of the proactive approaches. The ESV for random areas not located within high biodiversity areas averaged \$60,813/ $\text{km}^2$ /year, or just 20% less than high

biodiversity areas under reactive conservation. This points to the much higher economic benefit to be derived from the pursuit of proactive conservation strategies. The highest priority biodiversity areas that encompass 7% of the earth's surface are estimated to generate ESV in excess of \$1.1 trillion/year (Turner et al. 2007).

Turner et al. (2007) investigated the degree of overlap or concordance in high biodiversity areas and areas yielding high ESV (Map 3), employing the global mapping of ESV by Sutton and Costanza (2002). For eight of the nine global biodiversity approaches they assessed, the global biodiversity templates accounted for a significantly higher mean ESV of 72% than random sites. Thus, concordance was confirmed between biodiversity and ESV at the global scale, especially within tropical forest regions (including Asia) and the high ecosystem services they provide (Map 3). These are areas where the greatest opportunities exist for preserving both biodiversity and ecosystem services. In fact, the preservation of ecosystem services and the benefits they provide can prove to be a strong motivator for the conservation of biodiversity hotspots (Squires 2013).

Another benefit associated with Asia's biodiversity-rich areas is the considerable economic impact that these areas play in the region's rapidly growing and expanding ecotourism industry. The World Trade Organization (WTO 2014) estimated that East Asia and the Pacific region experienced over 248 million international tourism arrivals in 2013 (23% share of the global tourism)—generating \$359 billion in receipts (31% global share). Ceballos-Lascurin (1996) reported that nature-based ecotourism accounted for 7% of all international travel expenditures within Asia, and ecotourism is anticipated to grow faster than other tourism sectors. Lew (1997) projected that Asia's ecotourism sector would experience an annual growth of 10%–25% each year. The WTO (2014) projected Asia to be the fastest growing tourist market in the world through 2030, with 535 million total arrivals and 30% of the global

**Map 3: Concordance between Global Biodiversity Conservation Priorities and Ecosystem Services Value**



ESV = ecosystem services value.

Note: The darkest areas on the map correspond to regions—which include a substantial portion of Asia—with the highest degree of concordance between high biodiversity and high ecosystem services value.

Source: W. R. Turner et al. 2007. Global Conservation of Biodiversity and Ecosystem Services. *Bioscience* 57:868–873.

share in 2030. When managed, ecotourism can provide a sustainable, lower-impact economic benefit compared to logging or mining, while creating opportunity to heighten public awareness and funding support for the conservation of Asia's high biodiversity areas.

## B. Impacts on Asia's Biodiversity

Asia's biodiversity has suffered tremendous losses and impacts from anthropogenic pressures in the past, primarily from (i) biological resource use (e.g., hunting, gathering, and poaching); (ii) deforestation; (iii) human–wildlife conflict; (iv) invasive species; and (v) energy production (Juffe-Bignoli et al. 2014). Asia has lost two-thirds of its original tropical forest vegetation (MacKinnon 2002), with a third of that loss occurring between 1980 and 2000 (Bryant et al. 1997). Within Asia's eight recognized biodiversity hotspots, the losses have

been even higher—an average of just 13.7% of the original vegetated habitat remains (Table 1). According to the Secretariat of the Convention on Biological Diversity (2010), these pressures will likely continue to impact global biodiversity in the future and may even increase in intensity.

Today, Asia's tropical forests continue to experience some of the highest annual deforestation rates of any reported in the world (Brooks et al. 2002)—as high as 3.6% per year in the Philippines and more than 1.75% per year in the Sundaland and Indo-Myanmar hotspots (Sodhi 2010). The Western Ghats/Sri Lanka hotspot, the smallest of hotspots in Asia, has already recorded 20 species extinctions due to tropical forest habitat loss and fragmentation—more than the other seven CEPF-designated Asian hotspots combined (17 total species extinctions, average of 2.4 per hotspot) (Table 1). Together, these four



Asian hotspots were identified among the world's 11 “hyper-hot” hotspots due to past habitat losses and continued threats (Brooks et al. 2002). Asia and the Pacific registered the highest number of threatened species in the world (United Nations Environmental Programme 2010). Based on historic trends in tropical forest destruction and fragmentation, Brook and Sodhi (2003) estimated that of all mammal species native to Southeast Asia, 21%–48% are on trajectories toward extinction by the year 2100.

The Living Planet Index (LPI) is a widely used indicator of global biodiversity health tied to global vertebrate species population trends. The terrestrial LPI tracks population trends for 1,562 species of amphibians, birds, mammals, and reptiles. The trends (and populations) for these species have declined at an average of 39% since 1970. The highest LPI declines were recorded for South America, then by the Asia and Pacific region. The Indo-Pacific Biogeographic Realm's LPI encompassing Asia's tropical forested region had an especially large decline of 67%, second only to the Neotropical Realm's LPI decline of 83% for South America. Illustrating the benefit of protected areas, the LPI in terrestrial protected areas declined by less than half of the overall terrestrial LPI, or 18% (WWF 2014).

## C. Road Development Policy

The key to building new roads and other transportation infrastructure (e.g., railways) is to (i) systematically evaluate the true economic and social need while taking into account the value of biodiversity and ecosystem services;

(ii) pursue alternative alignments that altogether avoid high-biodiversity areas where technically feasible and economically viable; and (iii) strive for “no-net loss” of habitat values when alternatives to impacting high-biodiversity areas do not exist and roads are deemed necessary (Selva et al. 2015). Such overarching policy for all development projects is embodied in the Asian Development Bank's *Safeguard Policy Statement* and *Environment Safeguards: A Good Practice Sourcebook*, and the International Finance Corporation's (IFC) *Performance Standard 6 Guidance Notes*.<sup>1</sup> These documents collectively provide policy and framework for all development projects and are applicable to road and other infrastructure projects, including those within areas of Asia exhibiting high biodiversity, and/or protected areas, and with threatened and endangered animal and plant populations. This policy is critical to the development of sound road and other linear infrastructure projects that minimize impacts and unintended consequences, and ultimately safeguard and preserve Asia's remaining biodiversity. The IFC's environmental, health, and safety guidelines ([www.ifc.org/ehsguidelines](http://www.ifc.org/ehsguidelines)) provide for more specific guidance for the development of roads and other infrastructure.

As will be demonstrated in this report, when roads, highways, and railways are properly designed and pursued to incorporate green infrastructure features and other measures, it enhances the potential to indeed achieve no-net loss of habitat value for wildlife, especially when proactively used in concert with conservation offset programs, best management practices, and other mitigation measures.

<sup>1</sup> ADB. 2009. *Safeguard Policy Statement*. Manila. [www.adb.org/documents/safeguard-policy-statement](http://www.adb.org/documents/safeguard-policy-statement); ADB. 2012. *Environment Safeguards: A Good Practice Sourcebook*. Manila. <https://www.adb.org/documents/environment-safeguards-good-practice-sourcebook>; International Finance Corporation. 2019. *Performance Standard 6 Guidance Notes*. Washington, D.C. [www.ifc.org/wps/wcm/connect/5e0f3c0c-0aa4-4290-a0f8-4490b61de245/GN6\\_English\\_June-27-2019.pdf?MOD=AJPERES&CVID=mKqG85z](http://www.ifc.org/wps/wcm/connect/5e0f3c0c-0aa4-4290-a0f8-4490b61de245/GN6_English_June-27-2019.pdf?MOD=AJPERES&CVID=mKqG85z).

# CHAPTER 3

## ECOLOGICAL IMPACT OF ROADS AND OTHER TRANSPORTATION PROJECTS

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**H**ighways constitute one of the most significant forces altering natural ecosystems and impacting biodiversity in the world (Forman and Alexander 1998, Trombulak and Frissell 2000, Forman et al. 2003). Roads are associated with many other landscape-scale impacts on global biodiversity such as forest fragmentation. The impacts associated with highways are complex, yet are generally characterized as either direct or indirect in nature. While many factors contribute to highway impacts, both impacts to wildlife can be tied, to a large degree, to the volume of traffic that travels upon a given highway (Fahrig and Rytwinski 2009). Moreover, the influence of roads may extend farther than the actual physical footprint of the roadway due to traffic-associated noise and other impacts. Forman and Alexander (1998) estimated that such “road-effect zones” affect more than 20% of the land area within the United States (US). Raman (2011) reported that for each kilometer of road within India’s Bandipur National Park, direct road-related habitat loss and degradation affect at least 10 hectares (ha) of habitat.

New roads can lead to “induced” impact associated with human development and habitation along roadways, as Asian settlement associated with new roads often occurs in a ribbon-like (linear adjacent to road) pattern versus clustered pattern. Such induced impact may be both direct (e.g., habitat loss) and indirect (e.g., access into adjacent habitats for legal and illegal activities, exacerbated wildlife barrier effect) in nature.

### A. Direct Highway Impacts

Direct impacts associated with highways relate primarily to the loss or degradation of habitats from highway construction activities and the mortality associated with wildlife–vehicle collisions (WVC). Road construction leads to a direct and immediate loss of wildlife habitat and impact to ecosystem integrity associated with clearing the roadway footprint. Clearing forest vegetation impacts forest canopy integrity for canopy-dependent species such as birds and arboreal mammals (Rajvanshi et al. 2001). Such disruption to forest canopy integrity and induced edge effect (Laurance et al. 2009) may result in increased predation on vulnerable tree-dwelling species, which are relegated to spending increased time on the ground.

#### 1. Loss or Degradation of Habitats

Road construction, both temporarily and permanently, affects soils and hydrology adjacent to the roadway, potentially altering stream sedimentation and flow levels (Trombulak and Frissell 2000), and even causing flooding that kills vegetation (Laurance et al 2009). Road construction disrupts vegetative community processes and composition with the removal of forest and other habitats (Kalwij et al. 2008). Roads constitute an important vector for the establishment and proliferation of invasive plant species (Forman and Deblinger 2000, Trombulak and Frissell 2000, Gellbard and Belnap 2003, Raman 2011). The impact on water quality, hydrology, and vegetative community processes vary in proportion to the length, width, and area



associated with road alignments. Construction traffic and activities contribute to noise, contaminated surface runoff and pollution (Murnane et al. 2006), and exhaust emissions—all of which can degrade aquatic habitat and sensitive vegetative communities.

The minimum width of cleared roadbeds is largely a function of the terrain and slope upon which they are built. Generally, the steeper the slope, the wider the roadbed needed to clear vegetation and stabilize slopes to prevent future slope failure (FAO Conservation Guide 13/5, United Nations 1998). Roadbed width is also influenced by the type and stability of the soils and geology. Constructions on steeper slopes may require full bench construction of wider radius turns to prevent shoulders from eroding due to off-tracking traffic.

For comparison among hypothetical 25-kilometer road alignments, an alignment on gentle terrain would eliminate or severely impact (e.g., excavation spoil disposal) 25 ha of habitat,

compared to 50 ha for a road on moderate terrain. A road on steep terrain would impact 75 ha of habitat, or a threefold increase over the roadbed on gentle terrain. Table 2 shows the comparative impact on direct loss of habitats associated with three road alignments, with the impact tied to comparative roadbed formation construction width requirements and slope steepness. Thus, a longer alternative alignment on gentle terrain that altogether avoids steep terrain and the generally associated higher biodiversity and intact forests could be three times as long (and still have comparable habitat loss), but yet could potentially pose less impact on biodiversity, soil erosion, and water quality.

Temporary construction and labor camps necessary to house workers can be a source of significant temporary and even permanent impact on wildlife and other resources within high-biodiversity areas. Poaching of wildlife, illegal fishing, harvest of trees for fuelwood, and other illegal activities may take place in these areas. This aspect of road construction must be



➤ **Direct environmental impact.** Wide road bed cuts into a steep slope in Bhutan (photo by ADB).



➤ **Mass slope failure.** New roads constructed on steep, unstable slopes can trigger erosion (photo by ADB).

**Table 2: Comparative Impact of Three Road Alignments on Habitat Loss**

Proposed Alignment	Slope (%)	Road Length (km)	Roadbed Width (m)	Impact Area Length × Width (ha)	Percentage Increase over Gentle Terrain
Gentle terrain	0–15	25	10	25	–
Moderate terrain	10–30	25	20	50	100%
Steep terrain	25–60	25	30	75	300%

ha = hectare, km = kilometer, m = meter.

Source: Asian Development Bank consultant's estimates.

proactively addressed to minimize temporary impacts and avoid permanent impacts. Labor camps should be precluded from protected and high-biodiversity areas (Rajvanshi et al. 2001). Temporary construction material sites, rock quarries, borrow pits, and storage areas can also have an effect on habitat loss and degradation. Such sites should be rehabilitated as appropriate, following their use but before construction is completed.

## 2. Wildlife–Vehicle Collisions

Direct mortality from wildlife–vehicle collisions (WVC) has been recognized as a serious and growing threat to wildlife populations across the globe, and contributing to human injuries, deaths, and property loss (Schwabe and Schuhmann 2002, Huijser et al. 2007, Bissonette and Cramer 2008). In the US, WVC cause 200 human deaths and 30,000 injuries, and economic impact exceeds \$8 billion a year (Huijser et al. 2007). In Europe, an estimated 300 people are killed and 30,000 injured as a result of more than 500,000 WVC taking place each year (Groot- Bruinderink and Hazebroek 1996).

It is estimated that 1 million vertebrates are killed each day in the US (Foreman and Deblinger 2000), and as many as 340 million birds die in WVC each year (Loss et al. 2014). WVC generally do not occur randomly, either spatially or temporally (Bashore et al. 1985, Clevenger et al. 2001, Gunson and Clevenger 2003, Dodd et al. 2012). Many spatial factors contribute to

the distribution of WVC (Farrell et al. 2002), including topography, wildlife concentrations and density (Hubbard et al. 2000), and highway proximity to preferred and seasonal habitats (Farrell et al. 2002, Romin and Bissonette 1996, Gordon and Anderson 2003). In addition to posing risks for motorists, WVC-associated mortality impacts and threatens wildlife population viability and persistence, especially for rare and imperiled species (Foster and Humphrey 1995, Trombulak and Frissell 2000, Garriga et al. 2012, Snow et al. 2012). All taxa of wildlife are affected by WVC-related mortality. Amphibians and reptiles are most vulnerable to road mortality, even at low traffic volumes (Fahrig and Rytwinski 2009).

In Asia, substantial WVC-related mortality rates in reptile and amphibian populations have been reported across India (Baskaran and Boominathan 2010, Selvan et al. 2012,



➤ **Roadkill.** A great barbet killed in a vehicle collision in Bhutan (photo by ADB).



► **Hit-and-run victim.** Leopard killed by a speeding vehicle in northern India (photo by Akanksha Saxena).

Seshadri et al. 2009), and in Sri Lanka (Karunaratna et al. 2013). Karthikeyan et al. (1999) reported 20 species of reptiles and amphibians killed by vehicles in the Western Ghats of India, and Das et al. (2007) reported 21 species of reptiles killed in Assam. Karthikeyan et al. reported that most mortality occurred at night and in areas with natural vegetation near the roadway. While 75% of the Indian species documented in WVC by Baskaran and Boominathan (2010) were reptiles and amphibians, there were also 7% birds and 18% mammals, including leopard, sambar, and spotted or Chital deer. Rajvanshi et al. (2001) reported 11 species of birds killed in WVC in Punjab state, India.

In the PRC, Kong et al. (2013) documented 63 species involved in 3,475 WVCs that occurred in 2009–2012 along the Ring Changbai Mountain Scenic Highway. The WVC incidence with amphibians accounted for the highest occurrence (86.2%), followed by mammals (5.7%), birds (5.2%), and reptiles (2.9%). Within the PRC's Kalamaili Nature Reserve, five endangered Przewalski's horses were killed in WVC in just a 3-month

period of 2007; horses regularly crossed the highway for watering (Zhang et al. 2008, Kong et al. 2013).

Asia's large predators (and other taxa), of which many are imperiled, are quite susceptible to WVC. Along a highway through India's Pench Tiger Reserve, Areendran and Pasha (2000) reported two tigers killed in 4 years, along with 37 langurs. Traffic using a road through the Corbett Tiger Reserve in India has killed five tigers, four leopards, and 37 langurs in 1 year (Rajvanshi et al. 2001). Traffic on roads through the Gir National Park, which harbors the last remaining endangered Asiatic lions in India, killed two lions in 1 year as well as tigers and leopards (Rajvanshi et al. 2001). As many as 12 lions were further killed crossing a railway corridor through the park between 1984 and 1995 (Singh and Kamboj 1996).

While there is a considerably better understanding of the direct impact of highway infrastructure on wildlife, there is a growing body of knowledge regarding the similar (Cserkés and Farkas 2015), if not greater impact (Waller and Serhveen 2005) attributable to railway mortality on wildlife populations. Sieler and Olsson (2017) reported that the per-kilometer impact of railways on wildlife in Sweden exceeds that of highways, with significant associated economic impact. Santos et al. (2017) reported that the *Sociedad Conservación Vertebrados* had found that 36.5 vertebrates/km/year are killed on Spanish railways. Like highways, all wildlife taxa are subject to mortality from trains (Santos et al. 2017, Wildlife Institute of India 2016).

Much of the knowledge related to railway impacts on wildlife from collisions has been focused on ungulates (e.g., moose) and bears in northern climes (Waller and Serhveen 2005, Seiler and Helldin 2006, van der Grift 1999, Santos et al. 2017, Seiler and Olsson 2017). Dorsey et al. (2015, 2017) found that railway collisions with wildlife were tied to several factors including animal abundance, train



speed, and larger rights-of-way widths and/or additional rights-of-way barriers. Roy and Sukumar (2017) found that the Asian elephant mortality along an Indian railway had increased after upgrading and widening activities. The elephant deaths were attributable to a combination of the widened infrastructure, higher train speeds, and increased train traffic.

## B. Indirect Highway Impacts

Indirect highway impacts have the potential to be even more pervasive than direct highway impacts. For many species, barrier and fragmentation effects contribute to diminished habitat or landscape connectivity and highway permeability, or the ability of animals to cross highways and other transport infrastructure (Noss and Cooperrider 1994, Forman and Alexander 1998, Forman 2000, Forman et al. 2003, Bissonette and Adair 2008). Highways constitute barriers to wildlife movement that fragment populations and habitats, and limit juvenile dispersal (Beier 1995) and genetic interchange (Epps et al. 2005, Riley et al. 2006, Proctor et al. 2012), and ultimately threaten population viability (especially in combination with WVC impact). Long-term fragmentation and isolation increase population susceptibility to stochastic events (Swihart and Slade 1984, Forman and Alexander 1998, Trombulak and Frissell 2000).

The degree of barrier effect caused by highways varies by wildlife species, highway type and standard, and traffic volume (Jaeger et al. 2005). Increasing traffic volume magnifies the impact of roads on wildlife, resulting in altered habitat use (Rost and Bailey 1979), restricted movements and fragmented populations (Epps et al. 2005), and increased mortality through collisions with vehicles (Groot-Bruinderink and Hazebroek 1996, Gunson and Clevenger 2003). The magnitude of these highway impacts rises with increasing traffic volume and highway standard, though traffic volume exerts the greatest impact according to modeling done by Jaeger et al.

(2005). Low traffic on wide four-lane divided highways has less impact than high traffic levels on two-lane roads; for high-traffic four-lane divided roads, separating lanes can lessen the impact.

Highways have been documented across the world as being strong barriers to wildlife passage. In the US, even highways with moderate traffic volume (less than 8,000 vehicles per day) were found to be near-total barriers (passage rates are all less than 0.10) to the passage of white-tailed deer (Dodd and Gagnon 2011), pronghorn (Dodd et al. 2009), and desert bighorn sheep (Gagnon et al. 2012). For elk, a species relatively resilient to traffic, only high-traffic highways (more than 14,000 vehicles per day) presented near-total barriers to passage (Gagnon et al. 2011a). Wolf passage rates in Canada averaged 0.93 along a low-traffic highway but only 0.06 along the high-volume Trans-Canada Highway (Paquet and Callaghan 1996). In Canada, Dyer et al. (2002) found that caribou traversed actual roads in Canada less than 20% as often as computer-simulated road networks. Olsson (2007) documented an 89% decrease in the mean moose crossing rate between before- and after-reconstruction levels along a highway in Sweden. Kong et al. (2013) report that the barrier effect caused by the Qinghai-Tibet highway has impacted plateau pikas, resulting in measurable genetic differentiation between populations on each side of the highway.

In Asia, Singh and Sharma (2001) described highway barrier impacts on Asian elephants in northern India, a particular concern with an expanding road network there. Wang et al. (2014) modeled landscape corridors for giant pandas in the eastern PRC where highways have contributed to habitat fragmentation. Clements et al. (2014) assessed the impact of three roads in Malaysia on Asian tapirs and found that forest conversion had intensified after a road construction cut through highly suitable habitats, resulting in forest fragmentation.

An example of how road construction can lead to near-immediate barrier effects is illustrated by the construction of a new road through a nature preserve in the north-central PRC (Pan et al. 2009). Following construction, use of corridors crossing the new road by Asian elephants—diminished by 82% (Pan et al. 2009). Ito et al. (2013) reported strong barrier effects from the combined influence of the fenced Ulaanbaatar–Beijing railroad corridor and the fenced international border between Mongolia and the PRC for far-ranging Mongolian gazelles and wild asses. Though captured on both sides of the railroad, no gazelles crossed and neither species crossed the international border during their long-term study.

Highway traffic leads to wildlife avoidance zones (Forman and Alexander 1998) adjacent to highways, where traffic may become a “moving fence” that creates an impermeable barrier to wildlife passage and reduces habitat quality (Bellis and Graves 1978). Traffic has been documented as causing shifts in habitat use adjacent to highways, typically temporary in nature, for numerous species including grizzly bears (Northrup et al. 2012), elk (Gagnon et al. 2007a), and bobcats (Lovallo and Anderson 1996), which all exhibited increased use of areas near roads during nighttime when traffic is lowest. African forest elephants (Barnes et al. 1991) and impala (Mtui 2014) were found to exhibit avoidance of areas near roads. Gagnon et al. (2011a) documented a zone of permanent avoidance by elk adjacent to high-traffic highways. In the PRC’s Changbai Mountain region and the Yunnan Protected Areas, Kong et al. (2013) measured the road effect zone for Siberian weasel that extended 50 m, while along the Napahai wetland highway, the road effect zone for 17 bird species was found to be variable. The threatened black-necked crane exhibited the largest zone, extending over 150 m from the road.

Studies have alluded to noise being harmful to wildlife populations (Bowles 1997, Forman et al. 2003). Most information documenting impacts of traffic-related noise is for songbirds—densities next to highways were lower for 60% of species, and species richness was a third lower (Reijnen and Foppen 1995, Reijnen et al. 1996). Arevalo and Newhard (2011) found that the richness and abundance of bird species in the Costa Rican tropical forest decreased with increasing traffic noise. The noise effect zone adjacent to highways varies greatly by vegetative type (Reijnen et al. 1995) and traffic volume (Reijnen and Foppen 1995). These factors relate to the noise impact distance, extending outward 0.15 km at 8,000–15,000 vehicles per day, 0.25 km at 15,001–30,000 vehicles per day, and 0.50 km at more than 30,000 vehicles per day (Forman and Deblinger 2000).

New roads and highways have the potential to allow and even promote increased human development (induced impact), and access and disturbance into adjacent areas and habitats (Forman et al. 2003). This increased lateral access may result in increased disturbance to wildlife associated with traffic and noise, as well as legal and illegal harvest of wildlife and other resources (e.g., timber). Modeling of factors contributing to sharp declines (62%) in African forest elephant populations included proximity to roads, as roads facilitated both legal hunting and poaching (Maisels et al. 2013).

Clements et al. (2014) documented the tremendous impact associated with roads in Southeast Asia that provided improved access for illegal harvest and poaching of wildlife as well as the transport of illegally harvested animals for sale to Asian “black markets.” In Malaysia, Myanmar, and Thailand, they documented 187 illegally harvested and transported bears and 1,158 felids (cats) in 1999–2006, indicative of the magnitude of this impact.

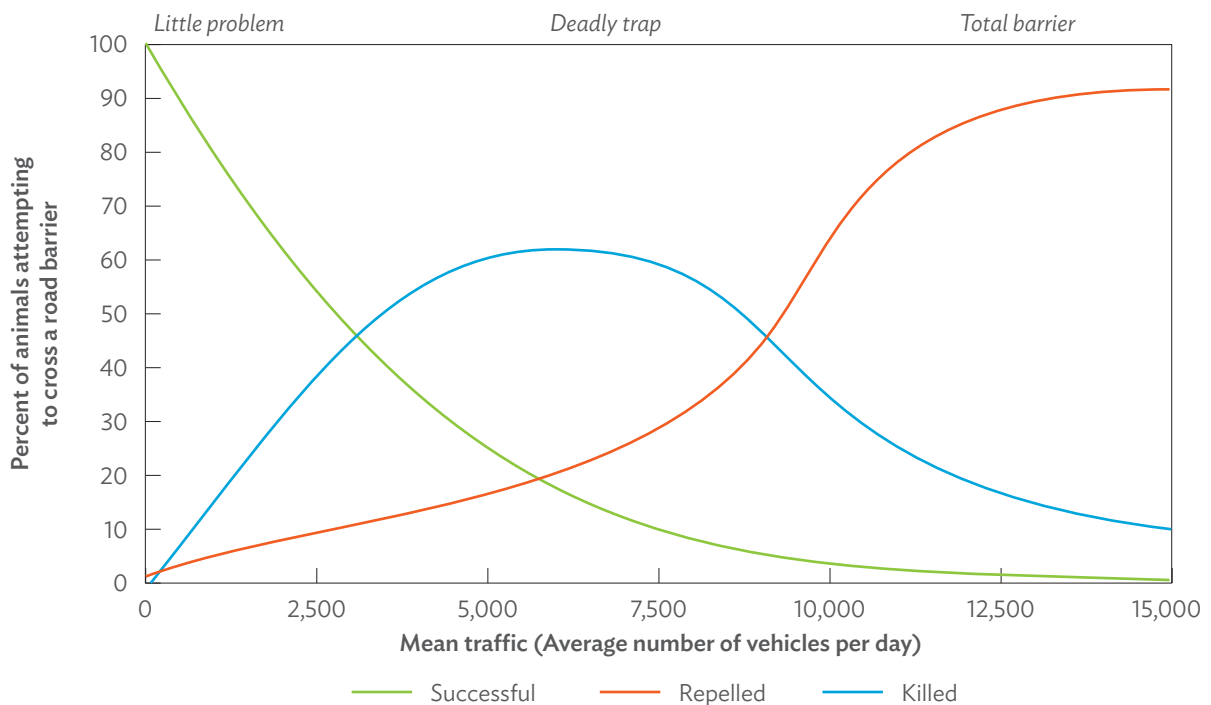
### C. Traffic Relationships to Permeability and Wildlife–Vehicle Collisions

To understand the impact of highways on wildlife and how green infrastructure and road management can lessen impacts, it is useful to understand the important role of traffic. Theoretical models (Seiler 2003, Iuell et al. 2003) infer that highways with 4,000–10,000 average annual daily traffic (AADT) present strong barriers to wildlife passage that repel animals away from highways. Figure 1 illustrates Seiler’s model (2003) of the impact of increasing traffic on highway permeability (percent of attempted crossings) and the proportion of animals killed attempting to cross. Typical rural single-track roads have less

than 1,000 AADT and two-lane roads have 2,500–5,000 AADT.

At 10,000 AADT and above, Seiler (2003) hypothesized that highways become impermeable barriers to many wildlife species. These models have since been empirically validated by ongoing research in Sweden and the US. However, Gagnon et al. (2011a) found that the threshold at which highways become impermeable barriers to ungulate species that otherwise cross highways freely at lower traffic levels was at approximately 8,500 AADT. Highways with AADT of less than 2,500 vehicles per day are theorized to have only limited impact to successful crossing attempts by animals and relatively low incidence of repels. Traffic between 2,500 and 4,000 AADT has moderate impact on wildlife (Figure 1).

**Figure 1: Impact of Increasing Traffic on Animals Crossing Roads**



Source: A. Seiler. 2003. *The Toll of the Automobile: Wildlife and Roads in Sweden*. Dissertation. Uppsala: Swedish University of Agricultural Sciences.

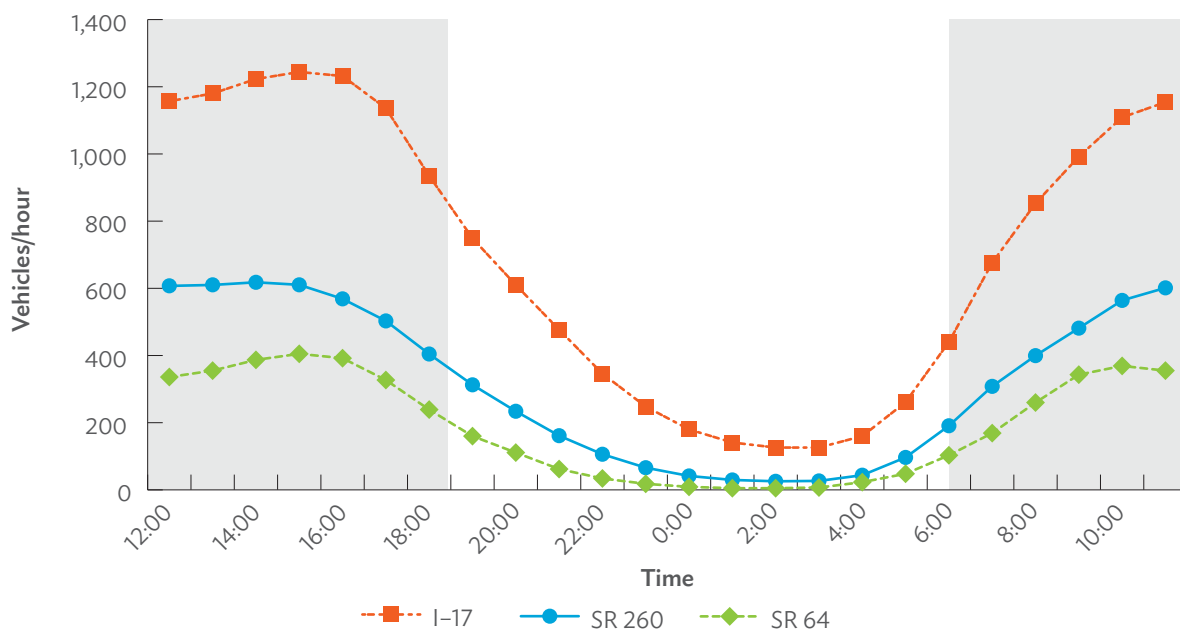
Iuell et al. (2003) and Seiler (2003) also hypothesized that the proportion of animals killed in WVC while attempting to cross highways was related to traffic levels (and thus the degree to which traffic affects permeability). The proportion of animals killed in WVC was relatively low (less than 30%) at low traffic levels (less than 2,000 vehicles per day) where highway permeability was unimpeded. Even at low traffic levels, WVC can be substantial, particularly since some animals may congregate along roadways for feeding (Dodd et al. 2012).

Seiler's model (2003) in Figure 1 predicts that the proportion of crossing animals that are killed peaks at intermediate traffic levels (approximately 7,000 vehicles per day), with 60% of animal crossings resulting in WVC. This peak occurs below a threshold where highways become strong barriers to passage, yet higher traffic levels contribute to increased highway lethality. Waller and Servheen (2005) modeled road mortality,

and reported that highway lethality was related to both traffic volume (interval between passing vehicles) and time spent on the roadway by crossing animals (slower animals like reptiles and amphibians were more susceptible). WVC drop off dramatically on highways with AADT of more than 10,000 vehicles per day due to the barrier effect preventing crossings; and at 15,000 AADT, Seiler theorized that only 10% of the animals that try to cross are killed while the 90% are fended off.

Another behavioral factor that affects the degree to which wildlife species are impacted by traffic levels is whether they are predominately diurnal or nocturnal in their activity patterns (Gagnon et al. 2011a, 2012). Diurnal species are often impacted to a far greater degree by highways and associated traffic volume, as traffic typically is highest during the daytime hours as shown in Figure 2. The graph shows hourly traffic levels (vehicles per hour) for

**Figure 2: Impact of Hourly Traffic Levels on Wildlife Species in Arizona**



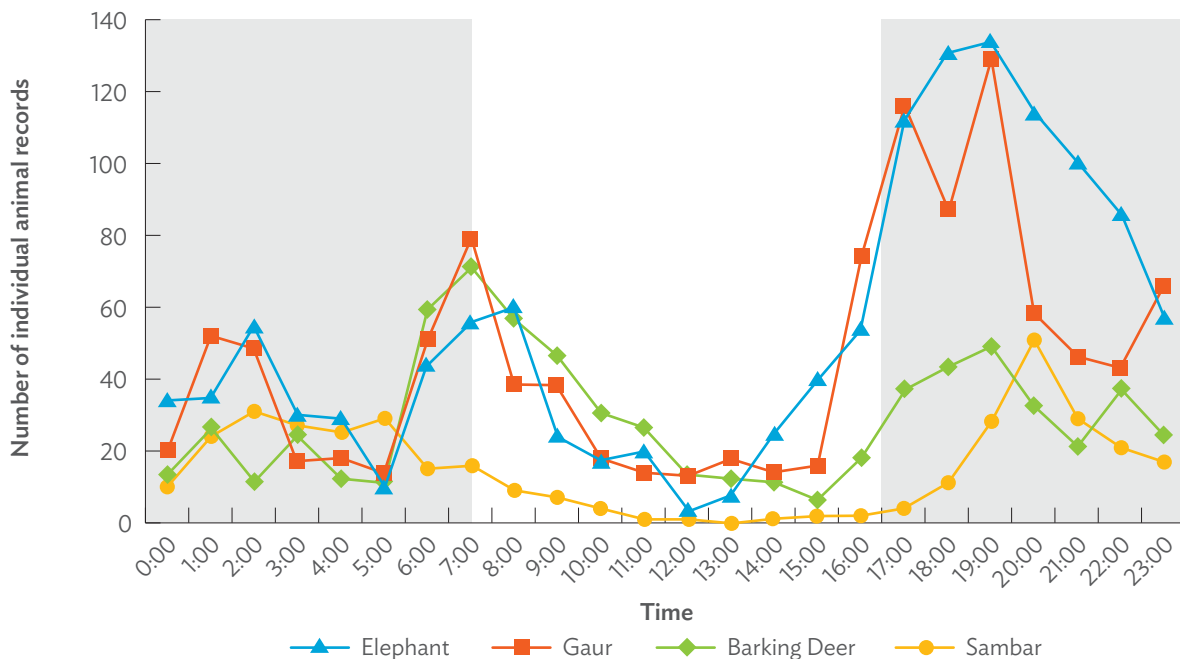
Source: J. W. Gagnon et al. 2011. Elk Movements Associated with a High-Traffic Highway: Interstate 17. Final Project Report 647. Phoenix, Arizona: Transportation Research Center, Arizona Department of Transportation.

three Arizona highways in the US, illustrating the pattern of traffic during daytime versus nighttime (shaded) hours and their impact on wildlife species (Gagnon et al. 2011a).

Such is the case with diurnal langurs that also appear susceptible to WVC in India and other parts of Asia (Areendan and Pasha 2000, Rajvanshi et al. 2001). Conversely, as traffic typically drops substantially during the nighttime hours, predominately nocturnal species generally exhibit greater flexibility in crossing highways when traffic has a lower influence on highway permeability and road lethality (Figure 2). Yet, most WVC occur at nighttime with dawn and dusk peaks, when animals are most active (Laurance et al. 2009, Goosem 2007). For four of the most common mammal species that

were camera trapped at a wildlife sanctuary in southern Bhutan, an average of 60% of the camera images were recorded during nighttime hours, though peaks in activity also spanned the dusk and dawn hours (crepuscular activity). Figure 3 shows the activity patterns (number of individual animals recorded per hour) for Asian elephant, gaur, barking deer, and sambar at the wildlife sanctuary, determined from camera trapping during 2015 (ADB 2018). Shading corresponds to nighttime hours. These crepuscular and nocturnal activity patterns exhibited by many Asian wildlife species present cost-effective road management options (e.g., dusk to dawn closures) to address WVC issues (for animals and motorists alike) and to promote highway permeability.

**Figure 3: Animal Activity Patterns Per Hour Sourced from Camera Trapping in Bhutan**



Source: Asian Development Bank. 2018. Biodiversity Baseline Assessment: *Phipsoo Wildlife Sanctuary in Bhutan*. Manila.



## CHAPTER 4

# GREEN INFRASTRUCTURE AND OTHER MEASURES TO MINIMIZE HIGHWAY IMPACT TO WILDLIFE

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**C**ompared to the significant and onerous challenges posed by large-scale global threats to biodiversity (e.g., climate change, forest health or deforestation), experience and research worldwide over the past 3 decades have demonstrated the technical and economic feasibility of measures and management activities to effectively reduce the impact of highways and railways on the environment, including wildlife (Forman et al. 2003, van der Ree 2015).

Strategies designed to promote wildlife highway passage and landscape connectivity, as well as to minimize WVC, have increased internationally in the past decade (Bissonette and Cramer 2008), including in Asia (Wang et al. 2015, Rajvanshi and Mathur 2015). Such strategies were once pursued as single-species “mitigations” to reduce highway construction impacts (Reed et al. 1975), often as afterthoughts to road design. Increasingly, comprehensive strategies are being proactively implemented to address multiple species and entire ecosystem functions, and are being planned at landscape scale versus project-level scale (Clevenger and Waltho 2000, Clevenger and Barrueto 2014). The ability to implement road projects in high-biodiversity areas may hinge on the commitment to pursuing comprehensive transportation and conservation strategies that employ a range of measures from environmentally sensitive road design to passage structures and management activities.

The components of any comprehensive road and conservation strategy are most effective if planned and implemented as integrated

systems. Such components include but are not limited to wildlife passage structures, associated funnel fencing, wildlife escape measures, and motorist-alert signage. It is critical to properly design and maintain not only the functionality of the individual components, but more importantly, to also maintain the functionality of the entire integrated system. When any one component of the system is not adequately constructed or maintained, it becomes a weak link that can compromise the entire system with potential road safety implications from wildlife–vehicle collisions (WVC) to failure to meet biodiversity objectives.

### A. Motorist Alert Signage

An important function of highway warning signage is to elicit modified motorist behavior (e.g., slowing down) in response to anticipated hazards. With most hazards such as sharp curves, motorists invariably encounter the hazard. However, in the case of wildlife crossing alert or warning signage, motorists often do not encounter animals on the road when passing signs. This contributes to motorists becoming habituated to signage. Hence, signage is generally considered relatively ineffective in helping to lessen WVC (Pojar et al. 1975, Sullivan et al. 2004, Huijser et al. 2015a). However, Found and Boyce (2011) found that WVC incidence in locations where deer warning signs were installed was 58% lower than unsigned locations. Their success was tied to erecting signs at limited, place-specific “hotspot” locations, something stressed as important by Huijser et al. (2015a).



In Asia, signage that alerts motorists to the likelihood of encountering the region's unique and in some instances very large animals (e.g., Asian elephant)—particularly when erected in potential hotspots—can be effective in eliciting motorist response. Warning signs that illustrate the area's unique wildlife species (e.g., tiger) may not only be informative and educational, but also contribute to their increased effectiveness.

Wildlife warning signage with flashing lights and variable message boards have the potential to be more effective than static warning signs (Pojar et al. 1975, Sullivan et al. 2004, Gagnon et al. 2018, Huijser et al. 2015a). However, signs with flashing lights may elicit motorist habituation if they operate continuously (Lehnert and Bissonette 1997). Such signs are most effective if employed only during peak wildlife crossing periods (e.g., migration) or are associated with animal-activated detection systems that trigger flashing and/or message signs only when animals are present (Huijser et al. 2015a). However, detection systems are expensive and maintenance-intensive and may not be well suited for remote applications (see Chapter 4.F). Solar-powered flashing lights (with batteries for nighttime operation) can be attached to static signs for operation during key periods such as elephant migration.

➤ **Animal hotspots.** Brightly colored warnings alert motorists about wildlife crossing (photo from RoadTrafficSigns.com).



➤ **Wildlife warning signs in US roads.** Flashing deer sign (Left), solar-powered flashers for bison (center), and variable message board integrated with animal detection system (Right) alert motorists on crossing animals (photos by the Washington State Department of Transportation and Norris L. Dodd).

## B. Reduced Design Speeds and Traffic Calming Treatments

Kloden et al. (1997) reported that the risk of WVC increases exponentially with increasing vehicular speed. In some instances, especially for lower-volume roadways, reducing vehicular speeds can be effective in decreasing WVC. When speed reductions are achieved either through posted speed limits or with traffic calming devices, and are combined with motorist alert signage to achieve increased motorist alertness, stopping distances can be reduced. For instance, Huijser et al. (2009) reported reduced average vehicle stopping distances of 21 m at 88 km/hour. Such reductions in stopping distance can reduce WVC incidents and severe accidents.

However, achieving reduced vehicular speeds with signage alone is often not effective, and has even resulted in increased collisions. In Jasper National Park in Alberta, Canada, WVC with bighorn sheep and elk increased even after the posted speed limit had been reduced to 20 km/hour (Bertwistle 1999). Gunther et al. (1998) did not find significant reductions in WVC frequency until roadway posted speeds were 88 km/hour or greater (also related to the road design speed). Thus, attempting to achieve reductions in WVC with signage and reduced posted speeds may not be a viable option for most (rural) Asian roads with average speeds below 88 km/hour and where WVC usually takes place or is likely to happen.

To effectively reduce WVC incidence and severity through lowered motorist speeds, two options may be considered. First, if planning a new road (or road reconstruction) where WVCs are a concern, lower design speed (versus posted speed) considerations can be integrated into road design and construction. Specific design speeds are used to engineer various geometric design features into a roadway, with minimum standards applied for different design speeds (American Association of State Highway Transportation Officials 2004).



➤ **Reduce speed warning.** Traffic calming devices and signage alert motorists on crossing wildlife in India (photo by Robert Ament).

Design speed standards to achieve lower vehicular speeds include more aggressive curves (versus straight stretches), narrower lane widths with little or no shoulders, and limited or narrower clear zones closer to roadways.

Second, in situations where roads exhibiting WVC are already in place and integrating design speed standards is not feasible, various traffic calming devices or treatments can be applied to roadways to reduce vehicular speeds. Traffic calming treatments, such as chicanes to create serpentine curves, curb extensions, raised medians, rumble strips in the pavement, speed bumps or humps,



and traffic circles, are generally applicable to low to moderate traffic situations. One example from Tasmania illustrates the potential effectiveness of traffic calming treatments. “Slow points” were created at three high WVC sites with concrete barrier chicanes and signage to constrict and slow traffic. The treatments were successful in achieving 20 km/hour speed reductions (17%–35%) at one site, and more nominal reductions (1%–7%) at two other sites, yet they were collectively effective in reducing WVC and promoting local population recovery for the eastern quolls and Tasmanian devil (Jones 2000).

## C. Wildlife Passage Structures

Wildlife passage (or crossing) structures are typically the most visible and engineering-intensive green infrastructure employed to address wildlife needs along roads and highways, and often are the cornerstone of successful strategies to reduce the effect of roads on wildlife. Passage structures have proven highly effective in promoting passage for a variety of wildlife species (Farrell et al. 2002, Clevenger and Waltho 2003, Bissonette and Cramer 2008). In conjunction with wildlife fencing, these structures have dramatically reduced the incidence of WVC as much as 98% (Clevenger et al. 2001, Dodd et al. 2007a, Olsson et al. 2008, Gagnon et al. 2015), thus enhancing motorist safety and reducing direct impact on wildlife populations.

The integration of wildlife passage structures into transportation infrastructure projects across the world is increasing dramatically. Whereas construction of passage structures over the past 30 years has occurred primarily in North America and Europe (Forman et al. 2003), wildlife passage structure application in the past decade has been accelerating in developing regions of the world (van der Ree et al. 2015), including Asia (Rajvanshi and Mathur 2015,

Wang et al. 2015), which are now accruing a mounting track record of successful applications.

Passage structures are classified as either “underpasses” or “overpasses” (Clevenger and Huijser 2011, Smith et al. 2015), each with their own range of applications, variations in design, and preference in use by various taxa of wildlife (Clevenger et al. 2009, Clevenger and Barrueto 2014). An overview of the considerations for siting and designing passage structures and other green infrastructure is discussed in the next paragraphs.<sup>2</sup>

### 1. Wildlife Underpasses

Underpass structures constructed specifically for wildlife passage have proliferated across the world during the past 20 years. Underpasses refer to structures that facilitate animal passage “below grade” or under a highway. Underpass design (and cost) can range from large bridges and viaducts, to prefabricated arches, and to dual-use drainage structures such as concrete box culverts.

**Viaducts and large bridges.** While large viaducts and multi-span bridges are typically designed and constructed for primary purposes other than wildlife passage, they nonetheless are highly effective in promoting passage due to their large size, high clearance, and the degree of openness they afford for approaching animals. These types of structures often cross sensitive habitats (e.g., wetlands, rivers), and are particularly effective in maintaining the integrity of highly used migration corridors, such as those along the Quinghai–Tibet railway and highway in the PRC, where large bridges span migratory routes for Tibetan antelope (Qisen and Lin 2008). Though expensive, raised highway “flyovers” between 0.25 km to over 1 km in length are used in India to create effective underpasses for Asian elephants, tigers, and other species.

<sup>2</sup> Clevenger and Huijser (2011) provide the most detailed and comprehensive guidelines for planning, designing, and implementing passages for a wide range of species and applications. Other resources include Wildlife Institute of India (2016), Rajvanish et al. (2001), Smith et al. (2015), and Andrews et al. (2015). While other resources are more oriented toward mid- to large-size mammals, Andrews et al. (2015) focus on smaller animals, including reptiles and amphibians.



➤ **Animal-friendly viaduct.** Located on Highway BR-374 in Brazil, the bridge built over an intact drainage promotes passage by wildlife (photo by M. Hiujser).

**Bridges and prefabricated arches.** Most underpasses designed and constructed specifically to promote wildlife passage are either single-span girder bridges (less than 30 m wide) or arch structures made of either concrete or metal plates. Arch structures are typically prefabricated and transported to construction sites. Thus, they present cost-effective and rapid construction options and are especially well suited to retrofit applications on existing highways. Prefabricated metal-plate arch underpasses are highly transportable to remote locations for assembly, requiring limited trucking compared to precast concrete arches where each heavy arch panel is transported separately.

**Culverts and dual-use drainage structures.** Larger concrete box culverts, more than 3 m, have the potential to accommodate wildlife passage for small- and medium-sized terrestrial mammals (Ng et al. 2004, Clevenger and Barrueto 2014), and even large mammals including elephants in some instances with culverts at least 5 m high (Weeks 2015). Successful use of concrete box culverts by larger mammals is often associated with shorter



➤ **Wildlife underpass structure designs.** (From top to bottom) Single-span girder bridge and recast concrete arch in the United States and a prefabricated metal plate arch in Bhutan are examples of wildlife passages (photos by Norris L. Dodd).



culverts which minimize the perceived “tunnel effect” with acceptable openness to approaching animals. Concrete box culverts may either be precast and transported to construction sites, or cast in place. Regardless of the casting method, concrete box culverts, if designed and installed properly, can be a cost-effective means of providing for smaller to medium-sized animal passage. Aside from culvert size, the floor substrate may also influence passage use, with natural, earthen substrates more conducive to passage than concrete floors, such as those associated with slab culverts with spans typically less than 6 m. Concrete floors may contribute to undercutting at downstream outflows leaving floors perched above the approaches, thus creating a barrier to smaller animal passage.

Generally, corrugated metal pipe culverts provide for marginal or limited larger mammal passage but can offer some value for small mammals, reptiles, and amphibians (Clevenger and Huijser 2011), especially if passage ledges or “shelves” are added to normally “wet” culverts

(Forseman 2004, Andrews et al. 2015). It is critical to maintain the corrugated metal pipe (and concrete box culverts with concrete floors) as close to the drainage or as gentle as possible to facilitate wildlife (and fish) use and prevent barriers to movement from undercutting or plunge pools. Corrugated metal pipe grades should be less than 0.01 m drop/m of length up to 25 m, and 0.005 m drop/m for corrugated metal pipe more than 25 m in length (Rajvanshi et al. 2001).

To provide for wildlife passage, one of the most cost-effective means, particularly for reptiles, amphibians, and small- to medium-sized mammals (and even some larger felids and bears), is to integrate both passage and drainage functions into structures. Effective wildlife passages can be achieved with proper design of drainage culverts, providing for dry passage on terraces adjacent to stream and drainage channels, eliminating obstructions to passage, and enhancing openness by increasing the size of structures above normal hydraulic sizing.



► **Slab culvert with natural floor.** Slab culverts with spans less than 6 meters can prevent undercutting of approaches, thus maintaining passage for smaller animals. Southern Bhutan highway (photo by ADB).



➤ **Passage ledge in a culvert.** The shelf design facilitates the movement of small animals (photo by Patricia Cramer).



➤ **Culvert with rock ledge.** The ledge provides a dry crossing for animals and is a better substrate than the corrugated metal pipe (photo by Randall Reeve).

Increasingly frequent and destructive extreme weather events, including heavy precipitation, are occurring around the world (Intergovernmental Panel on Climate Change 2014). Such extreme precipitation events impact transportation infrastructure, damaging and even washing out bridges and culverts that are unable to accommodate infrequent extreme flows. In addition to impacting both road and environmental integrity, damaged infrastructure disrupts commerce and results in repair and maintenance costs (National Cooperative Highway Research Program [NCHRP] 2015).

To address increasing climate unpredictability and infrastructure resilience to extreme precipitation events, and reduce long-term maintenance costs, consideration should be given to increasing culvert sizes, at relatively low to moderate cost (NCHRP 2015). Upgrading culverts to small arch structures, if adequate openness is achieved, can also benefit a wide range of wildlife species.



➤ **Oversized metal plate arch drainage.** Located in southern Bhutan, the prefabricated structure is used in place of a concrete box culvert, through which increased flows both from extreme weather events and of animals may pass (photo by ADB).



## 2. Wildlife Overpasses

Overpasses provide for “above grade” wildlife passage over highways (Clevenger and Huijser 2011). They typically (at least historically) have been more costly than underpasses often due to the amount of fill required to create gentle approach slopes where the terrain is flat. However, structures can be positioned between large cut slopes or tied into terrain features, cutting costs and

providing continuity with preferred animal travel routes (e.g., ridgelines). Some wildlife species exhibit strong preference for overpasses as opposed to underpasses when both are present (Clevenger et al. 2009).

Overpass types include girder bridge and concrete arch designs, and their size may range from relatively small to very large land bridges or “eco-bridges” that have long been integrated into the landscape over highways and railways in Europe.



➤ **Wildlife overpass designs.** (Clockwise from top left) A girder bridge in the United States is integrated into cut slopes and a ridgeline upon which animals travel, and the same principle was applied to a large land bridge with arches in Alberta, Canada, and a small precast concrete arch overpass, which is also in the United States (photos by Norris L. Dodd and Steve Gandomski).



### 3. Wildlife Passage Structure Effectiveness

Wildlife passage structures have proven universally successful, whether in North America, Europe, or Asia. There are various metrics to passage structure success, including numbers of animals crossing via structures, reductions achieved in wildlife–vehicle collision, highway permeability, and genetic diversity. Recent studies have yielded quantitative data pointing to the benefits of well-spaced wildlife passage structures (Bissonette and Adair 2008) in promoting highway permeability, providing insights into the mechanism by which underpasses are effective in reducing the impact of traffic and associated noise on crossing wildlife (Gagnon et al. 2007b, Dodd and Gagnon 2011). In conjunction with fencing, such passage structures have dramatically reduced the incidence of WVC (Clevenger et al. 2001, Dodd et al. 2009, Gagnon et al. 2015). These assessments, along with studies of genetic interchange (Sawaya et al. 2013), help justify the cost of passage structures and other measures to maintain habitat connectivity (Corlatti et al. 2009).

**Wildlife use.** Regardless of location, the numbers of animals that have been documented using passage structures for crossing under or over highways are impressive, as is the wide diversity of species that use them. Some of the more dramatic results include the following:

- Monitoring of the many crossing structures (38 underpasses, 6 overpasses) along the Trans-Canada Highway in Banff National Park, Alberta since 1996 has documented over 152,154 wildlife crossings, including 40,000 elk; 125,000 deer; 4,500 bighorn sheep; 5,000 wolves; 7,200 coyotes; 1,400 mountain lions; 1,100 black bears; and 700 grizzly bears. This represents the most intensively and longest continuous monitoring effort in the world (Clevenger and Barrueto 2014).
- On Arizona State Route 260, US, research on wildlife use of six underpasses over 7 years recorded visits by 15,000 animals accounting for 16 species, with 72% successfully crossing through the underpasses. Elk accounted for 68% of the visits (Dodd et al. 2012).
- Also in Arizona, along US Highway 93 where the overpasses and two underpasses were constructed, 6,531 desert bighorn sheep crossed in the first 4 years (Gagnon et al. 2017).
- In a retrofitting project along US Highway 30 in Wyoming, US, where seven large box culvert underpasses were installed with fencing, over 49,000 mule deer were recorded crossing in the first 3 years (Sawyer et al. 2012).

Another retrofitting project in Wyoming along US Highway 191 entailed installing six small bridged underpass and two overpasses (Sawyer et al. 2016). In the first 4 years, 40,251 mule deer crossed (79% using the underpasses) and 19,900 pronghorn (92% crossing via overpasses).

**Reduction in WVC incidence.** Along with the dramatic number of animals using passage structures is a commensurate decline in WVC incidence, largely due to the fact that passages reduce at-grade crossings and consequently animal exposure to vehicles. Fencing that funnels animals to passage structures is important in limiting at-grade access (Clevenger et al. 2001, Dodd et al. 2007a).

- Along the stretches of the Trans-Canada Highway with passages compared to stretches without, large carnivore mortality was 50%–100% lower, with few mountain lion, grizzly bear, and wolves involved in WVC. Collisions involving ungulates were 2 to 4 times lower on the Trans-Canada Highway with passages. Collisions with elk, which accounted for the highest proportion of all species using wildlife passages, dropped to zero. (Clevenger et al. 2009).

- On Arizona State Route 260 where a retrofit project was implemented to link three existing wildlife passages, a 98% reduction in the incidence of WVC with elk was realized over 9 years since the project completion (Gagnon et al. 2019). On another stretch of highway with seven passages and strategic fencing along half the section, WVC dropped by 87% (Dodd et al. 2007a). Along Interstate 17 in Arizona, the elk-vehicle collision rate was reduced by 97% with cost-effective retrofit fencing that linked existing bridges to serve as passage structures (Gagnon et al. 2015).
- Along US Highway 93 in Arizona, the incidence of bighorn sheep-vehicle collisions after reconstruction declined 97% over the first 4 years.
- Along the stretch of US Highway 30 in Wyoming where seven small underpasses and fencing were installed, an 81% decrease in the incidence of mule deer-vehicle collisions was recorded within 3 years after fencing (Sawyer et al. 2012). Along US Highway 191 in Wyoming with six underpasses and two overpasses, mule deer and pronghorn collisions dropped 79% and 100%, respectively.

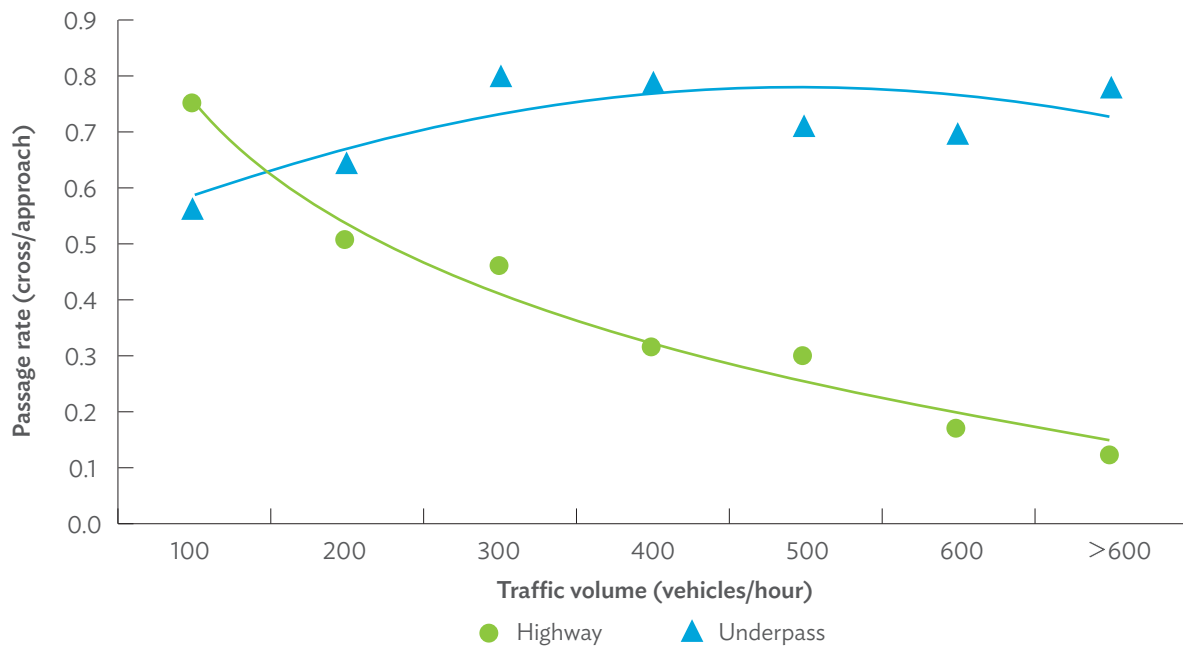
**Enhanced highway permeability and connectivity.** Research along Arizona State Route 260, US, provides some of the best empirical evidence that well-spaced passage structures and fencing can promote highway permeability, and why. Once underpasses were constructed and fencing erected, the highway passage rate for elk increased by 52% (Dodd et al. 2009, 2012). This increase was attributed to the funneling of animals toward passages where elk crossed below-grade. While increasing traffic volumes resulted in diminished elk passage rates when animals crossed the highway at-grade (pavement) without underpasses (Gagnon et al. 2007a), increasing traffic volume had no effect on passage rates during underpass crossings, even at very high traffic levels (Gagnon et al. 2007b).

Figure 4 shows elk passage rates at increasing traffic volume when crossing the highway at-grade (circles or lower line) versus when they cross below-grade at underpasses (triangles or upper line).

An even more dramatic benefit of passages in promoting permeability along Arizona State Route 260 was found for white-tailed deer, a species considerably more sensitive to highways than elk. Even narrow unreconstructed sections of Arizona State Route 260 were a near-total barrier to deer passage. But on reconstructed highway sections with passage structures, the passage rate was 433% higher (Dodd and Gagnon 2011). Like elk, traffic volume had no influence on deer passage when they crossed below-grade at underpass.

Following the reconstruction of US Highway 93 in Arizona, US, with three overpasses (where 90% of desert bighorn sheep crossed) and two underpasses, bighorn sheep permeability increased by 1,367% from the first year to the fourth year (0.03 to 0.44 crossings or approach). Permeability increased 528% from the before-construction passage rate average (0.07; Gagnon et al. 2014) to the passage rate (0.44) in the fourth year after reconstruction (Gagnon et al. 2017).

**Enhanced genetic interchange.** In addition to promoting permeability, wildlife passage structures have successfully promoted genetic interchange and increased genetic diversity. Grizzly bear populations across western North America have been documented as being genetically isolated by highways (Proctor et al. 2012). A recent research conducted in Banff National Park along the Trans-Canada Highway provides a compelling evidence that wildlife crossing structures are effectively helping maintain genetically healthy populations of black and grizzly bears that otherwise could have been isolated by this high-traffic highway (Sawaya et al. 2013).

**Figure 4: Traffic Effects on Elk Passage Rates at Underpass versus Highway Crossings**

Sources: J. W. Gagnon et al. 2007. Traffic Volume Alters Elk Distribution and Highway Crossings in Arizona. *Journal of Wildlife Management* 71:2318–2323; J. W. Gagnon et al. 2007. Effects of Traffic on Elk Use of Wildlife Highway Underpasses in Arizona. *Journal of Wildlife Management* 71:2324–2328.

#### 4. Asian Case Studies

In Asia, the most compelling example of the benefit of wildlife passage structures is demonstrated by the new Sixiao highway project through the Xishuangbanna Nature Reserve in the north-central PRC, where 82% of the pre-construction corridors used by Asian elephants were not used following construction (Pan et al. 2009). Associated with this project, 18 passage structures were constructed, including 16 open-span bridges and two tunnels (Wang et al. 2015).

In the first year after construction, 44% or eight of the passage structures were used by elephants for crossing under the highway, in addition to the use of two bridges. These results are remarkable for two reasons. First, there was no funnel fencing or other treatment to guide elephants to the passages and yet ten were used regularly for crossing. Second, most animal

species typically require a learning curve of 2 to 4 years to habituate to new passage structures (Clevenger et al. 2009, Gagnon et al. 2011b). Pan et al. (2009) also found that there was a strong correlation ( $r = 0.84$ ) between the passages that were used by elephants and proximity to established pre-construction corridors. Hence, determining natural animal corridor locations in which to construct passage structures maximizes their potential for successful use. These results refute the contention of Singh and Sharma (2001) that Asian elephants would not use underpasses, even though they did document use of canal bridges and believed that planned overpasses in India would successfully be used.

Yet another dramatic example of the success of Asian wildlife passage structures are those associated with the Qinghai–Tibet railway and highway, 1,142 km in length (Wang et al. 2015). To maintain migratory routes for Tibetan

antelope and other species, 25 bridged crossings were constructed along with seven at-grade crossings and a tunnel (Wang et al. 2015), at an additional 7% cost to the railway project.

In 2006, nearly 3,000 antelope were counted on their annual migration, of which 98% passed under the passage structures (Qisen and Lin 2008). Xia et al. (2005) found that use of the passages increased from 2003 to 2004, illustrating a learning curve. The use of passage structures was affected by structural design, presence of wolves, and vegetation recovery following construction. Wang et al. (2015) reported that the percentage of Tibetan antelope crossing through the bridges increased from 60% in 2004 during construction to 100% by 2007. The length required for animals to pass has dropped dramatically as part of this learning curve, from weeks in 2004 to just minutes by 2007 (Wang et al. 2015, Li et al. 2008).

Wang et al. (2014) recommended the construction of wildlife passage structures in the eastern PRC to address giant panda habitat fragmentation, of which highways

were a contributing factor. Wang et al. (2012) determined wildlife crossing zones along a highway in a nature reserve in the north-east PRC used by 10 mammal species, and at which passage structure construction would be appropriate to maintain permeability.

## D. Wildlife Fencing and Alternatives

An essential function of wildlife fencing when used alongside passage structures to reduce WVC has been stressed by Romin and Bissonette (1996), Forman et al. (2003), and van der Ree et al. (2015). Fencing's role in reducing WVC is well established, with reductions in WVC from 80% (Clevenger et al. 2001) to more than 95% (Gagnon et al. 2015, 2017). Woods (1990) reported 94%–97% reductions in WVC involving several species along the Trans-Canada Highway in Alberta, Canada with passage structures and fencing; while Clevenger et al. (2001) reported an 80% reduction in the same area, and a near total elimination of large ungulate (elk, moose) WVC (Clevenger et al. 2009). Similar decreases in moose–vehicle collisions in Sweden were attained with fencing (Lavsund and Sandegren 1991).



► **Facilitating migration.** Tibetan antelope using an underpass along Qinghai-Tibet highway (Yun Wang, China Academy of Transportation Sciences).



As fences themselves form effective barriers to wildlife passage across highways (Falk et al. 1978), fencing may potentially exacerbate the reduction in wildlife permeability along highways, especially where effective measures to accommodate animal passage are lacking. Yet the combination of effective passage structures and fencing that funnels animals to and through passage structures where traffic has little impact (Gagnon et al. 2007b) increased permeability (passage rate) compared to when no fence was present by 52% for elk (Dodd et al. 2007a) and 433% for white-tailed deer (Dodd and Gagnon 2011). This funneling role of fencing that guides animals to passage structures that otherwise may be minimally effective, along with limiting access to roadways and thus reducing WVC, justifies their use despite concerns on cost and maintenance.

Conversely, fencing can present concerns especially at the ends of the fence where animals cross; that may result to zones of increased incidence of WVC (Clevenger et al. 2001, Huijser et al. 2016) or animals breaching the fenced corridor; and some animals such as bears can readily climb over the fence (Gagnon et al. 2017). Furthermore, fencing is costly and requires substantial and continuous maintenance to ensure its effectiveness as a component of an integrated strategy to prevent WVC and reduce highway impact on biodiversity (van der Ree et al. 2015). Such cost potentially contributes to reluctance among transportation managers to fence extensive stretches of highways. Yet failure to erect adequate fencing to complement passage structures, even when structures are adequately spaced, was found to substantially compromise their effectiveness in reducing WVC and promoting permeability (Dodd et al. 2009, 2012). Huijser et al. (2016) found that stretches of wildlife fencing less than 5 km, erected in conjunction with passage structures, were largely ineffective and/or inconsistent in reducing WVC and promoting use of the structures.

A multitude of design options exist for wildlife funnel fencing (van der Ree et al. 2015, Huijser et al. 2015b). The most widely used has been wildlife exclusion fencing 2–2.4 m high, intended to deter highway crossings by ungulates (deer, elk, moose). The fence is constructed of woven wire attached to metal pipes or wooden support posts with intermediate metal T-posts or wooden posts. High voltage–low amperage electrified fence 2.2 m high has been used experimentally with success. Solar-powered options are available for remote locations (LaBlond et al. 2007, Gagnon et al. 2017). Some mammal species are capable of climbing over fences, including bears (Gagnon et al. 2017) and felids (Grilo et al. 2015), and may be deterred with flares at the top of the fence.



➤ **Wildlife crossing deterrents.** (Top) State Route 77, Arizona: ungulate mesh wire fence 2.4 m high constructed of metal posts and intermediate T-posts (photo by Norris L. Dodd). (Bottom) Highway 83, Florida: Fence with wooden posts (photo by Marcel Huijser). Both fences have buried small animal mesh at the bottom.

An even wider range of design options exists to prevent small-animal highway passage and roadway mortality, as well as to funnel them to passage structures, particularly for reptiles and amphibians (Jackson et al. 2015). Options include small mesh wire up to 1 m high, often buried to prevent digging under the fence by some species; smooth plastic or metal flashing that prevents climbing; and concrete barrier walls.

One of the biggest challenges to funneling animals to passage structures in much of Asia is presented by Asian elephants for which fencing can have limited deterrent effect and/or may require substantial maintenance, especially electrified fence used extensively to protect agricultural areas. Singh and Sharma (2001) report that the fence has been used along highways in India with success. Electric fence in conjunction with adjacent trenches have proven effective in the PRC. In India, the Wildlife Institute of India and Wildlife Trust for India have had success with barrier fences constructed of welded retired railroad rails; this design has held up well to

elephants when used adjacent to railways, especially when used in combination with green fencing such as thorny bamboo species.

Road management strategies (e.g., closing road at night) that limit traffic during animal activity periods may also reduce the need for fencing and its associated maintenance. And as stressed by Pan et al. (2009), Chogyel et al. (2017), and Clevenger and Huijser (2011), locating passage structures in established, natural wildlife travel corridors will reduce the need for fencing to funnel animals while improving structure use and effectiveness.

Singh and Chalisgaonkar (2006) proposed an innovative alternative to fencing associated with funneling Asian elephants to passage structures. They proposed using 75-millimeter (or larger) vertical steel posts sunk into the ground, with 2 m remaining above ground and spaced 1 m apart to create an impermeable barrier to adult elephant passage. This alternative allows humans to pass through the barrier.



➤ **Fencing design options.** (Left) On US Highway 441, Florida, a concrete barrier wall with lip limits access to roadways. (Right) Metal flashing is designed to funnel animals, especially reptiles and amphibians, to a highway crossing grate (photos by Marcel Huijser).





➤ **Elephant fence.** Welded retired railroad rail elephant barrier fence used in India along railways (photo by Wildlife Trust of India).



➤ **Elephant barrier.** Proposed by Singh and Chalisgaonkar (2006), alternative fencing funnels Asian elephants to passage structures, with 75 mm vertical steel posts spaced 1 m apart and sunk with 2 m remaining above ground to create an impermeable barrier to elephants.

## E. Arboreal Mammal Canopy Bridges

Where canopy integrity is disrupted by highway construction, it can affect arboreal mammal species that are often specialized in their use of forest habitats. Road impacts further add to impacts associated with agriculture, logging, and other activities (Soanes and van der Ree 2015). An array of designs is available to promote connectivity for arboreal mammals where canopy disruption is a concern. These designs range from simple ropes strung over highways, to more elaborate rope and cable bridges suspended above roads from poles or trees, to poles erected adjacent to roadways upon which gliding mammals can land (Soanes and Van der Ree 2015).

Rope bridges have been employed in Australia to link forest canopy bisected by highways and to provide connectivity for several arboreal mammal species (Goldingay et al. 2013, Soanes and van der Ree 2015). These bridges are relatively inexpensive and thus provide a

cost-effective means to help maintain forest canopy integrity and allow animals to cross highways without having to venture to the ground or be susceptible to WVC. Many taxa, ranging from arboreal primates to squirrels and martens, may benefit from canopy bridges (Soanes and van der Ree 2015). Since 2011, three species of primates have regularly used rope bridges for crossing a highway in Kenya (35–673 crossings per day), where 3% of the mortality adjacent to the highway occurs from WVC (Donaldson and Cunneyworth 2015). Locating rope bridges in good habitat and/or at established crossing locations contributes to their successful use. A fourth larger primate species did not use Kenya's rope bridges. Soanes and van der Ree (2015) also reported that rope bridges may not be suitable for larger primates.

Canopy bridge locations and spacing should be tied to the home range sizes and concentrated use areas for target species (Rajvanshi et al. 2001), as well as the degree of canopy integrity remaining in areas after road construction.



➤ **Canopy structures.** (Left) Australia's rope bridges provide animal passage over highways (photo by Kylie Soanes). (Right) A cable canopy crossing in Brazil promotes passage over highways for a range of arboreal mammals (photo by Marcel Huijser).

## F. At-Grade Crossings and Wildlife “Crosswalks”

Where passage structures are not feasible to address WVC “hotspots” due to cost, unsuitable (e.g., flat) terrain, or other factors, a potential alternative is to create at-grade crossings with wildlife fencing to funnel animals to designated location-specific crossings, or wildlife “crosswalks,” as done by Lehnert and Bissonette (1997). In conjunction with fencing, signage is critical to alerting motorists to the potential of encountering crossing animals. However, continuously operating signage typically results in motorist habituation (Lehnert and Bissonette 1997) that ultimately limits effectiveness of the crosswalk in preventing WVC (Huijser et al. 2015a). Yet at-grade crossings integrated with animal-activated detection systems (Huijser et al. 2015) intended to modify driver behavior, using time-specific flashing signs to warn when animals are adjacent to a roadway, have the potential to avoid motorist habituation (Huijser et al. 2015a), as accomplished by Gagnon et al. (2018) over a 9-year period in the US. These technologies are potentially quite expensive and require regular monitoring and maintenance to ensure effectiveness and

reliability of operation, which are critical to their success. Such applications may also be appropriate along railways at priority locations.

One limitation of at-grade crossings is the impact that high-traffic volume has on animal crossing passage rates, as animals typically repel away from roads as traffic increases. Where traffic volumes remain relatively high during nighttime hours or diurnal target species are active during peak traffic periods, even well-designed detection systems with at-grade crosswalks may be ineffective in promoting passage and addressing habitat fragmentation (Jaeger et al. 2005). Conversely, for lower-traffic roads or railways in Asia, well-designed systems have the potential to be effective. In the case of railways, an animal detection system would trigger an alert transmitted to approaching trains that are crossing animal presence. Though Huijser et al. (2009:102) evaluated nine commercially available products and technologies and found that five met their reliability criterion in a controlled setting, they still concluded that “experiences with installation, operation, and maintenance show that the robustness of [animal-activated detection systems] may have to be improved before the systems can be deployed on a large scale.”





- **Animal-activated detection systems.** An infrared camera enables detection of wildlife (*top*) while other devices such as break-the-beam, area coverage, or buried cable sensor systems (*bottom*) relay signals to activate road warning signs (photos by Norris L. Dodd).

# CHAPTER 5

## LINEAR INFRASTRUCTURE DESIGN AND MANAGEMENT CONSIDERATIONS

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### A. Overarching Design Principles

When planning and designing roads, highways, and railways through biodiversity-rich areas, the following design principles should be kept at the forefront. After due diligence has been exercised to consider alternative alignments that altogether avoid impact on high biodiversity areas, these principles along with green infrastructure and active management in the case of roads can help minimize impacts. In some, and likely in most instances, adherence to these principles will add cost to the construction of a new road or railway on the short term. But these higher upfront costs potentially represent a tradeoff in yielding long-term benefits such as maintenance of ecosystem service values (Turner et al. 2007) from minimizing transport infrastructure's impact on biodiversity and preserving ecological functions and services.

#### 1. Build the Roadbed Formation Once and Be Done

There is a universal propensity when designing and constructing new roads and highways to pursue initial design standards that reduce up-front construction costs but necessitate later (e.g., less than 20 years) upgrading and widening of the roadway to accommodate increasing traffic volume. Aside from the reconstruction disruption to commerce and the normal flow of goods and services, such reconstruction of roads within biodiversity-rich areas can be harmful.

The substantial impacts associated with road widening and reconstruction activities mirror those of constructing the initial new road

(Raman 2011, Gelbard and Belnap 2003). They further include cumulative impacts on forest canopy integrity, water quality degradation and erosion, potential spread of invasive species, and disturbance to threatened and endangered species. It is recommended that the initial construction of the roadbed formation be done to meet anticipated future design standards (e.g., forecasting traffic levels out for 30+ years) so as to minimize future need for road reconstruction, especially the removal of native vegetation and slope excavation. The width of the paved carriageway is of relatively minor concern compared to excavation and forest clearing during creation of the initial roadbed formation. Once the roadbed is constructed to meet anticipated future needs, carriageway paving can be widened with minimal environmental impact to accommodate increasing traffic volume.

#### 2. Build to the Minimum Width Necessary

While it is critical to design and construct the initial roadbed formation to a standard that precludes the need for reconstruction, it is equally important to limit the zone of construction impact to the absolute minimum necessary to implement the design standard.

Minimizing the degree of created edge effect and the extent of open verge habitat adjacent to the roadway and striving to maintain tree canopy connectivity and integrity yield many benefits (Raman 2001, Laurance et al. 2009). Most importantly, the narrower the zone of impact and the greater the degree of canopy retention, the better the prospect of minimizing the potential

establishment and proliferation of invasive plant species (Goosem 2015). In addition, maintaining canopy integrity minimizes the impact on connectivity and movement of canopy-dependent arboreal mammal species (Soanes and van der Ree 2015, Rajvanshi et al. 2012). Minimizing the establishment of herbaceous growth within the highway verge under an intact (or nearly as intact as possible) canopy will limit its attractiveness as forage for large mammal species and the potential for WVC associated with animals feeding along the roadside. Limiting herbaceous understory establishment will also help reduce fire risk from plants curing during the dry season and impacting forest biodiversity from unnatural fires—a growing concern with global climate change.

### 3. Limit Lateral Road Access

While the impact of a new highway corridor through a biodiversity-rich area can be significant on its own, providing lateral road access can greatly compound and exacerbate the impact on biodiversity and ecosystem function (Laurance 2015). Lateral road access can further cause habitat loss, result in increased disturbance to wildlife with traffic and noise, and promote both legal and illegal harvest of wildlife and other natural resources (e.g., timber). All of these impacts can affect biodiversity over a much larger area than that influenced by the new road itself. Experience from around the globe within regional biodiversity hotspots has shown that bisecting pristine or biologically rich areas with a new road often invariably has led to subsequent degradation of adjacent habitats through deforestation, wildlife poaching, development, and other impacts (Laurence 2015, Selva et al. 2015). Even without lateral road access, new roads provide improved human foot access to adjacent areas for illegal activities.

It is recommended that provisions for lateral access of new roads allowing intrusion into adjacent biodiversity-rich habitats be avoided unless absolutely necessary. Active management and enforcement should also be conducted to



➤ **Protecting forest biodiversity.** Narrow highway with intact overhanging overstory canopy and minimal verge habitat in West Virginia, United States (photo by Marcel Huijser).

prevent establishment of unauthorized lateral access roads, as well as foot access for illegal activities. The decision to provide for lateral access should be well reasoned and predicated on need (e.g., access to a remote village), both economic and social, coupled with active management and enforcement to ensure that lateral access is used only as intended. Lateral access for agency or administrative use can be limited to controlled access by proper gating or similar measures.

### 4. Focus Infrastructure Investment Where Land Tenure or Control Is Secure

Many green infrastructure measures, especially wildlife passage structures, can be costly to construct. Impacts from human land use patterns that occur immediately adjacent to such infrastructure can severely limit or even preclude intended use by wildlife, as documented by Chogyel et al. (2017) at an underpass used by elephants in Bhutan. As such, consideration should be given to focusing costly infrastructure in areas where adjacent land use may be controlled and/or regulated to maximize return on investment.



## 5. Keep it Simple— Minimize Maintenance

The importance of maintaining fully functional and reliable strategies to protect biodiversity is paramount. To minimize maintenance needs in the face of limited post-construction budgets and logistics, strategies should integrate measures and approaches anticipated to require as little short- and long-term maintenance as possible. Often the best low-maintenance approach is to pursue the simplest solution. There are significant benefits, albeit some with modest increased up-front construction cost, for oversizing (e.g., dual-use concrete box culvert to prevent washouts from extreme weather events) or over-engineering (e.g., fencing alternatives) to maximize infrastructure functionality and minimize future maintenance needs.

### B. Passage Structure Design Criteria

There are several key criteria and considerations for designing effective underpasses and overpasses, which include openness, size, spacing, and approaches.

#### 1. Underpass Openness

The openness of underpasses influences the amount of light that penetrates the interior and the corresponding view of the opposite side of the structure perceived by wildlife. It is related to the cross-sectional area of the opening and is greatly influenced by distance (length) through the structure (Clevenger and Huijser 2011). Openness is particularly important to ungulates (e.g., deer) and other “prey” species in being able to overcome their hesitancy to pass through unnatural, confined spaces that are perceived as a predation risk. Reed et al. (1975) were the first to put forth the concept of wildlife underpass openness, using an index to evaluate deer use of underpasses with the following formula (using metric units only):

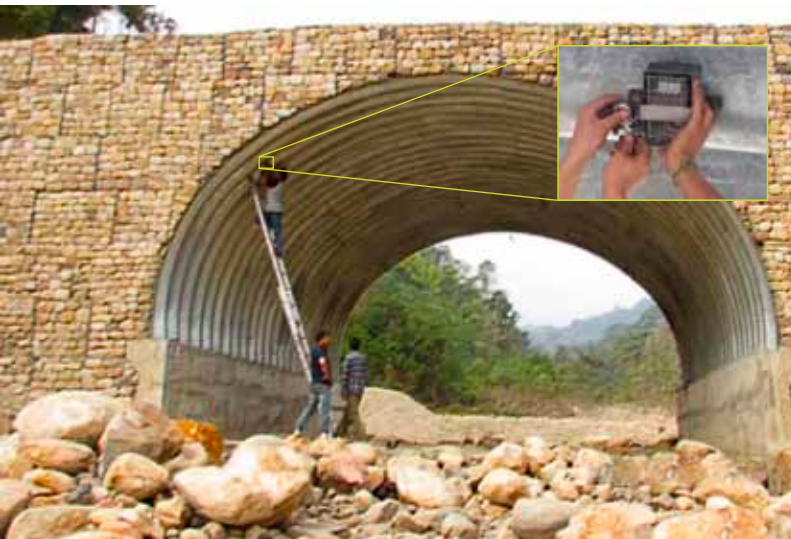
$$\text{Openness Index} = \frac{\text{Height} \times \text{Width}}{\text{Length}}$$

While acknowledging its limitations and the influence of other important underpass factors such as acoustics (Jacobson 2007, Clevenger and Huijser 2011), this metric nonetheless, provides a useful comparative design tool to evaluate crossing dimensions. Gordon and Anderson (2003) conducted rigorous experimental evaluation of varying openness indices on mule deer use of an underpass in Wyoming, US. They found that deer use was influenced more by underpass width than height, given constant length. They recommended a minimum index of 0.8 for deer and small ungulates, though Clevenger and Huijser (2011) cautioned against overreliance on such recommendations. Even still, Clevenger and Barrueto (2014), after 17 years of passage structure monitoring, found that openness strongly influenced deer, elk, and wolf use of the structures along the Trans-Canada Highway through Banff National Park, Alberta.

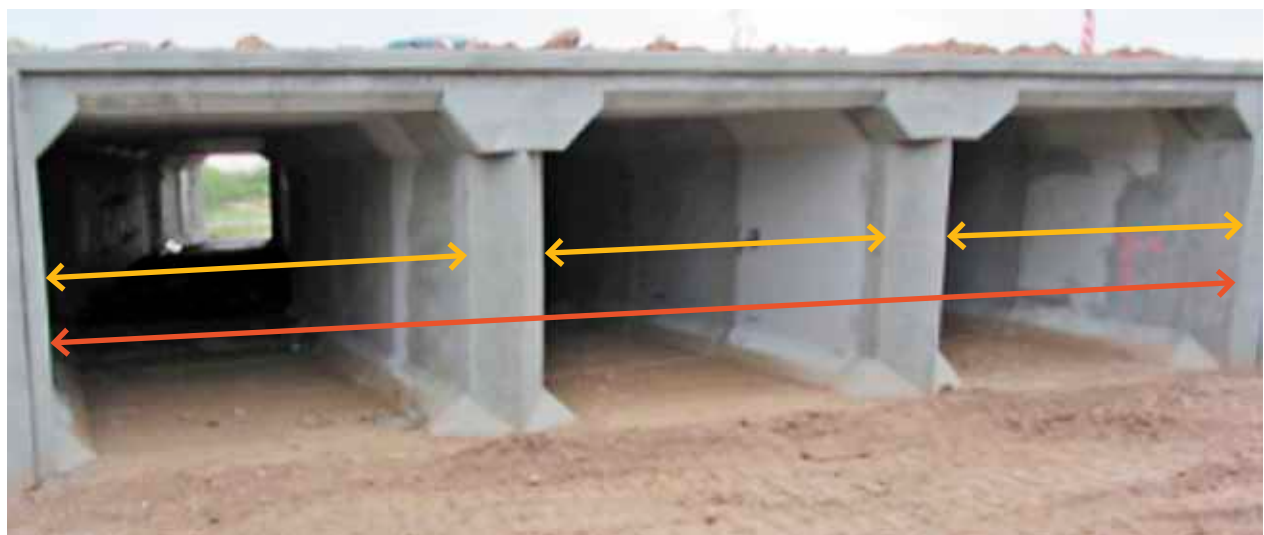
Sawyer et al. (2012) documented more than 49,000 mule deer passing through seven concrete box culvert underpasses in 3 years. All of these concrete box culverts had openness indices of 1.10. An underpass constructed in Kenya, which was readily used by African elephants and has since received sustained elephant use (Weeks 2015), has an openness index of 2.25. Likewise, four large metal plate



➤ **Open tunnel.** Partially constructed replacement concrete arch underpass at State Route 86 in Arizona, United States, before the existing box culvert was fully removed, and their comparative openness indices (photo by Norris L. Dodd).



➤ **New wildlife underpass.** (Left) Located in southern Bhutan, use of the underpass was monitored with an infrared camera (insert). (Right) A group of Asian elephants uses the underpass (photos by ADB).



➤ **Culvert Openness Calculation.** The openness of multi-cell/barrel concrete box culverts is based on the width of each individual cell/barrel (yellow arrows) and not the width of the entire structure (red arrow) (photo by Norris L. Dodd).

arch underpasses (average openness index = 5.5) in southern Bhutan were readily used by Asian elephants and four other IUCN-listed species soon after construction (Chogyel et al. 2017). In India, however, long underpass tunnels measuring 5 m wide × 5 m high × 111 m long (openness index = 0.22) were not successfully used by Asian elephants (Singh et al. 2011). The objective of any underpass application is to maximize

openness consistent with terrain, budget, and other factors.

With multi-cell/barrel concrete box culverts, it is important to stress that openness is perceived by approaching animals based on the width of individual cells/barrels, and not on the entire culvert width. This is another reason that small underpass structures (e.g., arch underpasses) are more effective than drainage culverts in promoting passage.



## 2. Passage Structure Size

Every species of wildlife has a unique preference for passage structure design, dimensions, and size. Yet some species groups or taxa exhibit general similarities in preference for passage structure size. For Asian wildlife species, Table 3 provides general recommended dimensions for four underpass size categories ranging from small to very large. These recommendations are consistent with the research of Clevenger and Huijser (2011) and Ruediger and DiGiorgio (2007) and numerous Asian studies. The general size recommendations for underpass width and height assume relatively short (e.g., single-lane roadway) underpass lengths. Actual dimensions are dependent on the width of the roadway and structure length. Longer underpasses may require wider and higher dimensions to maintain openness. For example, a medium-sized underpass (6 m wide × 3 m high) with a 15 m long would have an openness index of 1.2. For an underpass with a 35 m long under a wider road, the width would need to be increased to 8 m to maintain the same degree of openness, pointing to the utility of the openness index in developing and comparing underpass sizes for different roadway scenarios.

Small underpasses include corrugated metal pipes, concrete box culverts, and small arch structures. Small underpasses are suitable for small mammal passage up to mustelid-sized animals (e.g., civets and martens), and reptiles and amphibians. Medium-sized underpasses are considerably larger than small underpasses, suitable for use by small ungulates (e.g., deer), small canids (e.g., foxes) and small felids (e.g., cats), and even larger bears. Clevenger and Barrueto (2014) found that American black bears preferred longer, confined concrete box culverts, more so than 10 other species documented using underpasses. Medium-sized underpasses are thus considered adequate for Asian bear species.

Large underpasses, either large arch or bridge structures, must exhibit a high degree of openness for the target species for which this is an important criterion, including large ungulates, large felids, canids (wolves, dhole), and bovids (water buffalo, gaur). Clevenger and Barrueto (2014) found that mountain lions and wolves preferred passages exhibiting high openness. The large size of Asian elephants, coupled with concerns that they are often hesitant to enter and pass through confined passages (Singh and Sharma 2001), warrants very large underpasses

**Table 3: Wildlife Underpass Types, Size Categories, and Recommended Dimensions**

Size Class	Underpass Structure Type				Focal Wildlife Taxa	Minimum Underpass Dimensions			
	CMP	CBC	Arch	Bridge		≤20 m Length		35 m Length	
						Width (m)	Height (m)	Width (m)	Height (m)
Small	X	X	X		Reptiles Amphibians Mustelids	2.0	2.0	3.0	2.5
Medium		X	X		Small ungulates Small felids Bears	6.0	3.0	8.0	3.0
Large			X	X	Large ungulates Bovids Large felids Large canids	10.0	4.0	15.0	4.5
Very Large			X	X	Asian elephant	12.0	5.5	15.0	6.5

CBC = concrete box culverts, CMP = corrugated metal pipe culverts, m = meter.

Source: Asian Development Bank consultant's estimates.

that are both wider and higher than large underpasses. Table 3 shows wildlife underpass size categories and recommended dimensions, and the acceptable types of structures to accommodate passage for various Asian wildlife species groups or taxa.

**Overpass widths.** Even though some successful North American overpasses are 30 m wide or less, Clevenger and Huijser (2011) recommend that overpasses should be 50–70 m wide to accommodate large, high-mobility mammal species. Like underpasses, the longer the overpass span, the wider it should be. While retrofit wildlife overpasses were recently constructed in Thailand and Singapore, limited information is available to gauge their effectiveness. Overpasses are expected to be as effective as those in Europe and North America. This includes overpasses to accommodate Asian elephant passage, especially when they are located within documented travel corridors (Pan et al. 2009) and integrated with funneling treatments.

Singh and Sharma (2001) and Rajvanshi et al. (2001) recommend 50-meter overpass widths, and Singh and Chalisgaonkar (2006) recommend 60-meter widths to accommodate Asian elephants. These widths will also accommodate passage for many other species. Singh and Chalisgaonkar (2006) also recommended side walls 2.5 m–2.75 m high to guide crossing elephants and buffer them from disturbance and noise below. Putman (1997) recommends 30-meter wide overpasses for deer at the widest point with funnel-shaped approaches as an option.

### 3. Passage Structure Spacing and Placement

Among the many considerations in developing road and conservation strategies that integrate effective passage structures for projects that bisect high-biodiversity areas, one of the first questions often asked by project engineers due to associated cost considerations is “how many passage structures are needed?” While

several factors influence how many passages (or spacing) are needed along a road, some of the more important determinants for passage placement include:

- mix, distribution, and abundance of “target” wildlife species present and needs for structures to promote permeability tied to the relative mobility of the target species;
- proximity to special habitats such as wetlands, salt licks, springs, and rivers; and
- location of travel corridors, trails, and/or seasonal migration routes.

Passage structure placement should accommodate multiple species where possible, ranging from small to large, thus necessitating the application of a commensurate range of structure sizes and designs (Table 3). Such a mix also helps address potential interaction between predator and prey species, allowing each to use different structures of their preference, as documented by Clevenger and Barrueto (2014). Little et al. (2002) suggested that passage structures might be used by predators to ambush prey concentrated at structures. However, there is minimal empirical evidence of such interaction occurring with larger species, even during long-term comprehensive studies of passage structure use (Clevenger and Barrueto 2014, Dodd et al. 2012, Gagnon et al. 2011). Though Mata et al. (2015) and Harris et al. (2012) documented predator–prey interactions between small- to medium-sized species in Spain and Australia, respectively, Mata et al. (2015, 190) nonetheless concluded that the evidence for predator–prey interactions was “scarce” and in need of further study. Passage structure design can maximize openness to benefit prey and avoid use of features that favor predators such as ledges atop soil retaining walls (Dodd et al. 2007), especially where rare prey species are present.

To guide the objective determination of the passage structure placement and spacing along roads, Bissonette and Adair (2008) recommended spacing tied to allometric scaling of home ranges. Their spacing

recommendations, while limited by the assumption of homogeneous distributions of animals across landscapes, nonetheless provide spacing guidance intended to promote landscape connectivity. They found that the square root of home range sizes for various species, derived from published reports, provided the most useful scaling distance in guiding passage structure spacing. They reported spacing recommendations for 52 North American terrestrial species, ranging from 0.1 km for mice, 17.2 km for mountain lions, to 38.7 km for their widest-ranging species reported, the wolverine. Even with these guidelines, closer passage structures may be warranted in instances where travel or migration corridors or other special habitats are present.

Wildlife species for which Bissonette and Adair (2008) calculated passage structure spacing recommendations were aggregated into eight species groups or taxa, wherein average home range sizes and allometric spacing guidelines were derived. In addition, published home ranges for 14 representative Asian species were also assigned to the species groups or taxa and their home ranges included in the calculation of average home range sizes and spacing. Spacing guidelines ranged from 1.3 km for small ungulates (e.g., barking deer) to 13.6 km for

Asian elephants. In the case of elephants, actual spacing may need to be considerably closer owing to other factors such as the presence of corridors of concentrated use of special habitats. For example, in Bangladesh, two planned elephant overpasses and an underpass associated with a new railway will be spaced just 0.5 km apart due to the high use of the area as an established corridor (ADB 2018). Table 4 shows these passage structure spacing recommendations (minimum) for a range of wildlife taxa and species, small to large, based solely on mean home range sizes reported by Bissonette and Adair (2008) and modified to include representative Asian species.

**Spacing example.** Consider a hypothetical 50-kilometer road being planned that crosses through an area supporting Asian elephants, common leopards and tigers (large felids), clouded leopards (small felids), and large Indian civets (mustelids). Here, it is assumed that these species are all distributed fairly and evenly along the proposed highway (which is seldom the case). Table 4 lists the sizes and numbers of passage structures required to help lessen road impact and to promote permeability for the corresponding taxa or species. Using these passage structure spacing guidelines, a worksheet can be used

**Table 4: Passage Structure Spacing Recommendations for Asian Wildlife Species**

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

km = kilometer, km<sup>2</sup> = square kilometer.

Note: It is important to stress that these recommendations are solely based on average home range, and other factors must also be considered.

Source: Asian Development Bank consultant's estimates, based on Bissonette and Adair. 2008. Restoring Habitat Permeability to Roaded Landscapes with Isometrically-Scaled Wildlife Crossings. *Biological Conservation* 141:482–488.

to approximate the number of different-sized passage structures needed. Table 5 illustrates an example worksheet to determine the number of different-sized passage structures required along a hypothetical 50-kilometer road associated with target wildlife species exhibiting different spacing requirements. The worksheet reflects the premise that the passage needs for each taxa may be met with its corresponding recommended size (Table 3), and all larger-sized passages recommended for other taxa.

For the hypothetical 50-kilometer road in Table 5, the recommended structures are:

- four very large passage structures to accommodate Asian elephant passage (around 13.6 km spacing), though other species would also be able to use these structures;
- six large passage structures for large bovids (gaur), requiring high openness and visibility (around 5.2 km spacing or 10 total structures, including the four very large structures above);
- eight medium passage structures to accommodate small felids such as the clouded leopard (around 2.8 km spacing, 18 total structures needed) along with

the four very large and six large passage structures above. Some structures could be dual-purpose drainage structures “oversized” for wildlife passage and increasingly frequent extreme weather events; and

- eighteen small passage structures to accommodate the large Indian civet (around 1.4 km spacing, 36 total structures needed), along with the 18 larger structures above.

When considering roads through biodiversity-rich areas, especially wherein the mitigation goal is to achieve no net loss in biodiversity value and function, passage structure spacing is expected to be commensurate with existing premiere road and conservation projects throughout the world, with documented passage structure benefit. While this may be arbitrary (without baseline biodiversity assessment information to formulate data-driven strategies), this metric provides a benchmark for consideration. Passage structure spacing on these road and conservation projects ranges from 1.0 km to 2.1 km, with an average spacing of 1.6 km. Table 6 presents premiere highway and conservation projects across the world, including the number and spacing of wildlife passage structures constructed.

**Table 5: Example Worksheet of Passage Structures for a 50-Kilometer Road**

Target Taxa/Species	Passage Spacing (km)	Total Passages Needed in 50 km	Number of Passage Structures Recommended by Size along 50 km of Highway						
			Very Large		Large		Medium		Small
Asian elephant	13.6	4 Very large	4	+	Will not use	+	Will not use	+	Will not use
Large bovids (Gaur)	5.2	10 Large+							
Small felids (Clouded leopard)	2.8	18 Medium+			6		8		
Mustelids (Indian civet)	1.4	36 Small+							18
ALL	Average = 1.4/km	36	4		6		18		36

km = kilometer.

Source: Asian Development Bank consultant's estimates, based on Bissonette and Adair. 2008. Restoring Habitat Permeability to Roaded Landscapes with Isometrically-Scaled Wildlife Crossings. *Biological Conservation* 141:482–488 (and studies involving Asian wildlife species).

**Table 6: Wildlife Passage Structures in Premiere Highway and Conservation Projects**

Project (Location)	Number of Passage Structures	Total Highway Length	Passage Structure Spacing	Source
<b>Sixiao Highway</b> (Yunnan Province, People's Republic of China)	18	18 km	1.0 km	Pan et al. (2009)
<b>Trans-Canada Highway</b> (Alberta, Canada)	44	65 km	1.5 km	Clevenger et al. (2009)
<b>State Route 260</b> (Arizona, US)	17	27 km	1.6 km	Dodd et al. (2012)
<b>US Highway 93</b> (Montana, US)	42	90 km	2.1 km	Huijser et al. (2013)

km = kilometer, US = United States.

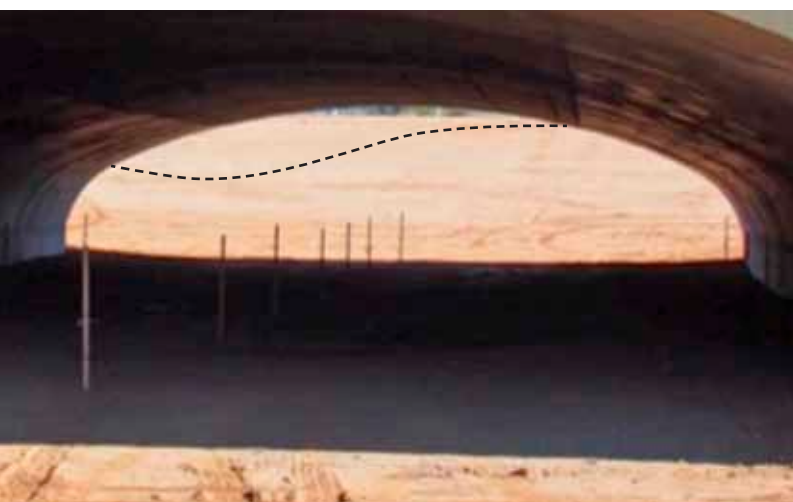
Source: Asian Development Bank consultant.

#### 4. Passage Structure Approaches

The approaches used by animals to travel to and through the entrances of underpasses and across overpasses are an often-overlooked critical factor in achieving the successful use of structures. The use of even the best-designed structure may be limited or even precluded if approaches are not well implemented. The single most important consideration is ensuring that there is a clear line-of-sight visibility entirely through the structure, free of obstructions. The view through underpasses should be as

unimpeded as possible, and animals should be able to see daylight through underpasses from the opposite side when approaching.

Where possible without further removal of native vegetation or destabilizing slopes, soil embankments which emanate outward from underpass openings should be excavated to flare away from the underpass openings as wide as possible, preferably 45 degrees or greater. Creating such wide, open approaches will enhance visibility and avoid creating approaches within drainages that are perceived as confining to animals.



➤ **Importance of line of sight.** (Left) View at State Route 77 in Arizona, United States, through an underpass under construction with limited line-of-sight visibility for approaching animals to see daylight on the opposite side due to insufficient slope excavation. (Right) This slope was excavated (dashed line on left photo) to provide improved sight visibility by ungulates and other wildlife (photos by Norris L. Dodd).





➤ **Underpass improvement.**

In southern Bhutan, the underpass approach slope was excavated to enhance openness and visibility for approaching animals. Flaring of slopes outward 45 degrees or more is preferred (photo by ADB).

Excavated slopes may need to be treated with retaining walls or other soil stabilizing treatment.

Just as visibility through an underpass is critical to successful use by wildlife, so is the substrate of the approaches and within the underpass itself. Continuous and extensive application of rock rip-rap or larger boulders to address drainage and erosion issues may negate passage benefits associated with otherwise suitable structures. Natural or sandy soil or earthen floor substrates are preferred over concrete associated with passage structures, especially concrete box culverts; and rock rip-rap should be avoided especially for smaller animal passage. Strategically placed rocks, logs, vegetation, and other cover can promote passage by smaller animals, including reptiles and amphibians (which benefit from created microenvironments), without hindering large animal passage (Jackson et al. 2015, Clevenger and Huijser 2011).

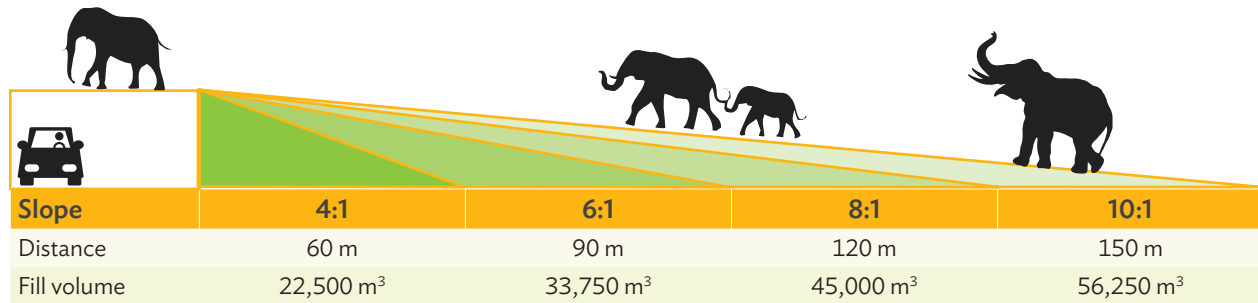
For overpasses, one of the most critical approach considerations is the steepness of the approach slopes on each side of the overpass structure. Where overpasses do not bridge existing ridgelines or span cut slopes, fill material is needed to create approach



➤ **Swath of large boulders.** Placed at the mouth of a new wildlife underpass at State Route 260, Arizona, United States, the boulders address roadway drainage and runoff issues, but severely limit animal passage and effective use of the passage structure (photo by Jeffrey W. Gagnon).

slopes that animals negotiate to cross up and over the structure. The excavation and transport of fill material to the site can add substantial cost. The volume of fill required for a 10:1 gentle approach slope is 2.5 times that of steeper 4:1 slopes. Figure 5 shows a comparison of the extent and size of overpass approach slopes at varying steepness, from gentle 10:1 to steeper 4:1 slopes, and linear distances outward from the overpass and fill volumes based on a 15-meter-high and 50-meter-wide overpass structure.

Figure 5: Comparison of Overpass Approach Slopes



m = meter, m<sup>3</sup> = cubic meter.

Source: Asian Development Bank consultant's estimates.

Ideal approach slopes are those that are gentle (more than 8:1 slope, run to rise) though they impact habitat a greater distance outward from the structure and have higher cost. Such gentle 8:1 slopes were recommended for Asian elephants by Rajvanshi et al. (2001). However, steeper slopes (6:1 or even 4:1) have proven to be readily used by some animals, including pronghorn in the US. Even still, the gentler the approach slopes are (consistent with fill availability and budget), the more likely the structure is to be used by a variety of wildlife.

## 5. Underpass or Overpass—Which is Better?

With the increased application of precast concrete and metal plate arch designs, the application of wildlife overpasses has become increasingly cost effective and widespread (McGuire et al. 2015), including retrofit applications over existing large highways. Whereas traditional girder bridge overpasses were often designed to accommodate both static and dynamic loading—increasing their

➤ **Approach slope.** Overpass in Wyoming, United States facilitates successful crossing by pronghorn after negotiating relatively steep (e.g., less than 6:1) approach slopes (photo from WWF/Wildlife Conservation Society).







➤ **Retrofit passageways.** (Left) Precast concrete arch wildlife overpass under construction at Interstate 80, Nevada, United States (photo by Contech Engineered Solutions). (Right) Completed overpass integrated with the existing ridgeline on each side of the structure, requiring minimal fill material for the approaches (photo from Nevada Department of Transportation).

size and cost—they now are being designed to primarily address loading associated with only the fill material atop the structure deck, further making them more cost-effective (McGuire et al. 2015). There are two primary considerations as to when an overpass may be better suited for providing wildlife passage than an underpass: (i) terrain, and (ii) target wildlife species preference.

The terrain found at a wildlife crossing or linkage site where a passage structure is warranted is a vital consideration as to the best suited structure type. Canyon and drainage situations are ideally suited to underpasses promoting below-grade passage by animals. Conversely, situations where highways or railways traverse deep cut slopes or lie between continuous ridgelines upon which animals regularly travel are ideally suited for overpasses such as in the right photo above. In such situations, the need for fill material to create suitable approaches is minimized. However, where terrain does not exist to support an underpass, or based on target species' preference for more open unconfined passages, overpasses may

nonetheless be warranted in situations that necessitate construction of approach slopes with fill material (as with the freestanding overpass photo at the bottom of page 26).

The other key factor in determining whether overpasses or underpasses are more appropriate relates to the target wildlife species for which passage is being addressed—some species exhibit strong preference for one over the other. Along the Trans-Canada Highway within Banff National Park, a total of 152,154 animal crossings were documented for 11 different medium- to large-size mammal species (Clevenger and Barrueto 2014). Some species exhibited strong preferences for a type of crossing structure. Grizzly bears, moose, wolves, elk, and deer almost always used overpasses instead of using the closest underpass (Clevenger et al. 2010).

On US Highway 93 in Arizona, US, researchers recorded over 6,500 desert bighorn sheep visits to three overpasses and two underpasses in the first four years following construction. Of these, the vast majority of sheep crossings (90%) occurred at the overpasses, as sheep prefer the increased visibility afforded by

overpasses. Several overpasses have recently been constructed for pronghorn, a species which inhabits open grasslands in North America. These overpasses have been readily used by pronghorn while only limited use of underpasses has been documented in the past (Plumb et al. 2003, Sawyer and Rudd 2005). Sawyer et al. (2016) found that of over 40,000 mule deer and nearly 20,000 pronghorn that crossed US Highway 191 in Wyoming, US, 92% of pronghorn crossings occurred at two overpasses while 79% of deer crossings were made at six underpasses. Dodd et al. (2009) recommended overpasses as the preferred passage type for pronghorn, along with large viaducts that provide high visibility for crossing animals inhabiting open habitats. Olson and van der Ree (2015) likewise recommended overpasses over underpasses for large ungulates such as Mongolian gazelles inhabiting the open plains and grasslands of Kazakhstan, Mongolia, and other areas of Central Asia.

### C. Wildlife Fencing and Alternatives

As stressed in Chapter 4.D, wildlife funnel fencing has been repeatedly demonstrated as being integral to achieving desired outcomes from wildlife passage structure construction (Huijser et al. 2016), including preventing wildlife and vehicle collisions and promoting highway permeability. But with the high cost of fencing and the required lasting commitment for constant maintenance and upkeep in remote regions of Asia, judicious application of fencing, as well as viable alternatives to fencing, are urged. This is especially the case in regions where Asian elephants are present. There are three general strategies for fencing application in conjunction with passage structures:

- No fencing
- Strategic (limited) fencing
- Project-wide fencing

Given the success reported by Pan et al. (2009) for the Sixiao Highway project through the Xishuangbanna Nature Reserve in the PRC, where nearly half the constructed passage structures were readily used by Asian elephants without fencing, there are indeed instances where no fencing may be similarly appropriate. In their case, many of the passages were constructed at known or traditional travel corridors which contributed to their use. Furthermore, large passage structures and/or bridges spanning river or stream habitats and drainages that typically are preferred travel corridors by many species of wildlife may be used without funnel fencing to guide animals to such locations (Chogyel et al. 2017). Where roads are subject to enforceable nighttime (dusk–dawn) closures when most animals are active (Chapter 5.D.1), a no-fencing strategy may be appropriate as a cost-effective strategy to prevent wildlife–vehicle collisions and limit traffic impact on permeability; though the potential for WVC during dawn and dusk periods remains if the road closure does not encompass these hours.

In rare cases where data from baseline assessments can establish animal crossing locations and support the development of data-driven fencing strategies, limited fencing can indeed be an option that may yield success. However, Huijser et al. (2016) found that stretches of fencing less than 5 km in length in association with wildlife passage structures were generally ineffective. Along the premiere US 93 highway and conservation project in Montana state, strategic fencing in conjunction with passage structures informed by historic WVC data has proven successful, though most stretches of fencing have exceeded 5 km in length (Huijser et al. 2013) (Table 6). As part of an ongoing research project supporting adaptive management, the data of Dodd et al. (2007b) guided strategic extension of wildlife fencing based on the global



positioning system (GPS) tracking of elk crossings. Fencing half a highway section (in pieces) to intercept animal crossings (where 89% of elk crossings occurred) reduced WVC by 84% (Dodd et al. 2007a); some of the fencing stretches were less than 5 km, though having GPS crossing data made this project an exception to the findings of Huijser et al. (2016). Having the luxury to conduct detailed studies in advance of construction is rare, especially with expensive GPS telemetry. However, lower-cost animal track assessments (Pan et al. 2009) and the use of remote cameras can inform the development of similar strategies, especially at identified migration or movement corridors or special habitats with concentrated animal use. If pursued, post-construction monitoring of effectiveness is warranted to ensure success and to make subsequent remedial modifications when necessary.

With the growing body of knowledge regarding the vital role of fencing in successful wildlife passage structures, fencing of entire project lengths has generally become the default approach in Australia, Europe, North America, and parts of South America. There, fencing has been recognized as vital to reducing impact on wildlife within biodiversity-rich areas.

One of the key considerations when employing fencing, especially under a strategic fencing approach, is where to terminate fencing so as to avoid potential concentrated wildlife end-runs (Clevenger et al. 2001, Huijser et al. 2016). Fencing ideally should be terminated at wildlife crossing structures, tied into cliffs or steep cut slopes, or ended in large canyons. Where such options do not exist, fencing may be flared outward away from the highway corridor to “guide” animals away from the roadway. Signages, including place-specific flashing signs at fencing termini (Huijser et al. 2015a),

intended to alert motorists to the potential for crossing animals, is warranted. Gagnon et al. (2018) successfully employed an animal-activated detection system at a fence terminus that triggered flashing and message signs when animals were present, with only a single deer-vehicle collision at a designated “crosswalk” where over 2,000 deer and elk crossed over 9 years, and without measurable motorist habituation (where motorists ignore signage over time) to alert signage.

## D. Road Management Activities

The manner in which a road is managed after construction has the potential to further minimize road impacts and complement the benefits of green infrastructure. Aside from posting lower speed limits within protected and high-biodiversity areas where potential WVC are a concern (Rajvanshi et al. 2001), there are also a wide range of management activities that may be pursued to reduce impact on, and even achieve a net benefit to biodiversity. For road construction through high biodiversity and/or protected areas, pursuing joint road and conservation projects is encouraged. Unlike road projects wherein wildlife and other environmental considerations are pursued as mitigations usually after projects have been designed, road and conservation projects are predicated on sound biological assessment insights to help inform final road alignment and to proactively address the full range of needs of wildlife via the road design process. Pursuit of road and conservation strategies involves a commitment to action and follow-through, and ultimately, funding to implement the conservation measures. While conservation funding should not be limitless and must be balanced appropriately with road costs, it should involve designing road projects with a measurable commitment to biodiversity protection.

## 1. Evening/Dusk-to-Dawn Road Closures

One of the simplest yet potentially most effective activities to help address the impact of roads on wildlife permeability and WVC risk is to institute and enforce daily road closures during nighttime hours, utilizing physical barriers (e.g., gates), guard stations, or other measures where needed and appropriate. Recognizing that the greatest impact of a road is associated with the traffic that travels upon it (Jaeger et al. 2005), eliminating public conveyance on the road during nighttime and crepuscular hours when animals are typically active would effectively eliminate the traffic-associated impact on both WVC and permeability of all taxa of wildlife, including the most susceptible reptiles and amphibians (Laurance et al. 2009). Nighttime closures would constitute a balance between providing needed public conveyance and promoting economic development in a region while protecting the valuable resources within high biodiversity and/or protected areas.

One of the best examples of the efficacy and benefit of nighttime closure of roads in biodiversity-rich areas of Asia is provided

by the Royal Bardia National Park of Nepal (Rajvanshi et al. 2001). After a 4-year nighttime travel ban through the park was lifted, the incidence of WVC in the following 3 years increased 6-fold. It was estimated that nearly half of the traffic travelling the road—many of which are commercial vehicles—occurred during nighttime hours.

While nighttime closure of roads can help reduce WVC, it might not totally eliminate the occurrence of WVC or the risk to motorists due to the peaks in collisions that occur near dawn and dusk hours during daylight hours (Figure 3). Haikonen and Summala (2001) reported that a large peak in WVC, 46% of moose and 37% of white-tailed deer collisions, occurred within 3 hours around sunset tied to circadian rhythms associated with light. Dodd et al. (2006) found an even more dramatic peak near sunset—67% of WVC involving elk and 64% of deer collisions occurred within a 3-hour departure of sunset, many during daytime hours. Gunson and Clevenger (2003) noted similar dusk peaks for elk. Dawn and dusk WVC are associated with peaks in daily feeding patterns and movement to and from cover areas (Figure 3). The incidence of WVC near



➤ **Gated road closure.** This barrier blocks traffic to prevent impacts to animals during nighttime when most are active (photo from Westcom Photos).

dawn and dusk is also affected by poor lighting conditions that motorists encounter, limiting their ability to avoid animals. As such, measures such as motorist alert signage, wildlife passage structures, and/or fencing are still appropriate even with nighttime closures, unless closure periods are extended further to encompass daylight hours associated with high animal activity periods at dawn and dusk.

In some areas of Asia where security issues are a concern, nighttime closure of roads can help ensure public safety by limiting travel during the evening hours when illegal activities generally occur. Nighttime closure would also limit public exposure to potentially harmful and even fatal WVC should they encounter elephants and other large animals on the road, as documented by Pan et al. (2009) in the PRC and Singh and Sharma (2001) in India. Pan et al. (2009) regularly noted Asian elephants using the paved road surface, primarily at night, and even remarked on the high level of adaptability of the species to using the new road surface. Nighttime closures would greatly reduce the risk of unwanted vehicular and human lateral access, and consequently prevent associated and cumulative impact (e.g., noise, poaching); thus enforcement of road closures is vital to achieving the desired benefits.

Lastly, dusk to dawn closures of roads can lessen the need for costly and maintenance-intensive measures such as fencing or alternatives to fencing intended to limit access by animals to the roadway and to funnel them toward passage structures.

## 2. Seasonal Road Closures

Singh and Sharma (2001) recommended consideration of full (daytime and nighttime) seasonal road/highway closures to address Asian elephant connectivity and highway passage (and motorist safety) during migration periods. Yet they also recognized that this might not be politically popular, and indeed it would have an impact on public access and

rural economic development and commerce that would come to rely on new roads. Typically, seasonal closures are utilized to address lateral access off highways or to address seasonal weather issues (e.g., snow accumulation during winter) or peak and concentrated wildlife migrations. Some low-traffic highways are seasonally closed for the benefit of endangered species in North America, though in these cases there are often alternative travel routes. Seasonal closures could also employ just dawn to dusk closures during key wildlife movement periods, such as breeding season for ungulates when they move furthest or for elephant migrations.

## 3. Roads as a Resource Protection Asset

In many of Asia's high-biodiversity and even protected areas, illegal harvest of wildlife, timber, and other resources is already occurring, even without improved road access. In fact, such limited road access makes enforcement a difficult proposition, which is often made even more difficult during the summer monsoon with high flows in unbridged rivers and streams. With the construction of roads, enforcement personnel can conduct intensified patrols to address illegal incursions for poaching and damage to resources. Enhanced infrastructure such as observation towers and anti-poaching outposts (ADB 2018, Rajvanshi et al. 2001) to support law enforcement can further enhance resource protection as well as enforcement personnel safety. Integration of enhanced patrol capability with evening road closures that allow enforcement personnel to focus on illegal entry can be particularly effective, including ensuring that unauthorized lateral travel off roads does not occur. However, it is paramount that commitments be made to ensure that new roads are used as an asset to enhance resource protection, ecosystem integrity, and conservation management rather than becoming a liability with unwanted lateral access that provides the portals to resource impact and destruction (Maisels et al. 2013).

#### 4. Monitoring and Adaptive Management

Finally, a road and conservation project should entail meaningful post-construction monitoring to evaluate the effectiveness of green infrastructure in minimizing impacts on biodiversity. Sound monitoring need not be an expensive proposition yet should yield dividends from helping evaluate and make appropriate modifications and improvements to green infrastructure efficacy, strengthen future conservation strategies, and generate public awareness and support. One area

where monitoring is particularly appropriate is in evaluating the efficacy of wildlife funnel fencing and/or alternatives to fencing where wildlife passage structures have been constructed. Employing a combination of cameras at passage structures to measure passage rates (Dodd et al. 2007c, Gagnon et al. 2011b) and to determine use by wildlife, along with WVC tracking, can validate the success of the approach or identify the need for additional fencing or alternative measures. Clevenger and Huijser (2011) and van der Ree et al. (2015) present various strategies and options for monitoring.

##### ➤ Monitoring measures.

Remote cameras, with date and time stamp capability, installed on the ceiling of a precast arch wildlife underpass on State Route 86, Arizona aim to monitor wildlife use and structure effectiveness (Left). A mountain lion is photographed by the cameras crossing through the underpass (Bottom) (photos by Norris L. Dodd).





## E. Reconstruction and Retrofitting Opportunities Benefit Biodiversity

Much of this report focuses on the new construction of roads and other transportation projects employing a range of infrastructure design and management activities. Indeed, the construction of new or major reconstruction of existing roads is the best time and opportunity to develop comprehensive and integrated strategies to protect biodiversity. However, the construction of new roads and other transportation projects through biodiversity-rich areas is a relatively rare occurrence compared to the number of existing roads and highways that exhibit an ongoing impact on biodiversity, whether from wildlife-vehicle collisions or as barriers to the free movement of animals.

As mentioned earlier, when many roads in Asia were constructed in the past, there was a propensity to implement initial design standards that reduced up-front construction costs but necessitate subsequent upgrading and widening of the roadway to accommodate increasing traffic volume. And while such reconstruction of existing roads may impact vegetation and soil stability associated with widening of roadbed formations, such projects also present excellent opportunities to address ongoing impact on wildlife and biodiversity, including WVC and connectivity/barrier effects. Where existing drainage structures are present, including bridges and large concrete box culverts, they may be linked with wildlife fencing (or alternatives) to create cost-effective and potentially effective wildlife passage structures (Kintsch and Cramer 2011; Gagnon et al. 2015). Where existing structures suitable to provide effective wildlife passage are not present, “drop-in” applications of prefabricated underpasses (metal-plate or precast concrete arches) can be accomplished with minimal disruption

to traffic flow (Sawyer et al. 2012, 2017). After excavation, forming foundations, erecting prefabricated arches, and backfilling can usually be accomplished in a week. Increasingly, retrofit overpass applications are being pursued, even on large highways with precast arch designs that also minimize disruption of traffic.

Also as discussed earlier, one of the more cost-effective means to provide for wildlife passage is to integrate passage and drainage function into upgraded drainage structures during widening and reconstruction projects when drainage structures are being enlarged or even oversized. This will promote infrastructure resilience to extreme weather/precipitation events and reduce long-term maintenance and repair costs. Effective wildlife passages can be achieved with the proper design of enlarged concrete box culverts or small arch structures.

The paving of unpaved roads may have the benefit of stabilizing the road surface and reducing dust and sedimentation into streams and lakes, thus improving water quality and fish habitat. Conversely, where WVC incidents are a concern, paving such roads may increase vehicular speeds and collision risks, which can be addressed with safety measures such as signage and traffic calming treatments.

Lastly, many green infrastructure measures may be pursued and implemented as standalone “retrofit” applications to address priority wildlife biodiversity issues outside of road construction or reconstruction projects (Gagnon et al. 2015, 2017), though funding such projects can be problematic. However, where roads or other linear infrastructure (railways, canals) are limiting recovery efforts for threatened or endangered wildlife species, funding for standalone retrofitting may be more readily available. The downside of such projects, however, is since they are not part of a larger road construction or reconstruction project, they will have to bear the full costs

of project mobilization, overhead, and contingencies. Nonetheless, standalone projects in the US focused on resolving WVC issues have reached a breakeven point wherein benefits exceed project costs in just 3–5 years (Gagnon et al. 2015, Sawyer et al. 2012).

Asia's growing experience demonstrates how a well-designed green infrastructure can effectively mitigate the impact of road and other transport projects on wildlife connectivity and the risks of collisions with

vehicles and trains. A wide array of structural and management options exists to develop strategies to balance the growing need for construction of new and upgraded transport infrastructure vital to Asia's economic growth with the protection of its tremendous and economically-important wildlife biodiversity. The guidelines provided in this report are intended to ensure that future applications of green infrastructure are effective in meeting their objectives for the multitude of species and biotic conditions found across Asia.



➤ **Drop-in applications.** Installation of prefabricated arch underpasses provides efficient means to secure wildlife passage and protect biodiversity (photo by Norris L. Dodd).

# APPENDIX

## CONDUCTING BIODIVERSITY BASELINE ASSESSMENTS AND EVALUATING ROAD IMPACTS

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**S**cientifically credible biodiversity baseline assessment (BBA) is vital in developing sound strategies to minimize the impact of roads and other transportation infrastructure within biodiversity-rich areas through proactive alignment selection and road design. While there is no single approach to conducting BBA or developing experimental designs, this section provides some general guidelines and considerations, which are intended to be applied early in the road design process to planning outcomes that proactively minimize transport impacts on Asia's biodiversity. These guidelines are broken down based on desktop analyses and field studies, with desktop analyses being essential to the development of sound field study design. More refined and detailed information on the design and conduct of field assessments in support of environmentally friendly road design are provided by Clevenger and Huijser (2011) and van der Ree et al. (2015). Guidance on the integration of BBA into the road project environmental assessment process is provided by Tsunskawa and Hoban (1997) and Rajvanshi et al. (2001).

### A. Asian Development Bank Safeguarding Framework

ADB's *Safeguard Policy Statement* (SPS) (2009) and *Environment Safeguards: A Good Practice Sourcebook* (2012) largely provide the framework for environmentally sustainable projects and biodiversity assessments that support good project design, preparation, and implementation. Likewise, the environmental, health, and safety guidelines of the International Finance Corporation (IFC)—both the general guidelines (including roads and erosion and invasive species control) and industry sector guidelines for infrastructure (toll roads, railways) and forestry (forest harvesting operations)—provide for more specific guidance in the development of roads and other transportation infrastructure.

The overarching framework of ADB's SPS is to proactively: (i) assess all relevant impacts and risks of proposed projects early in the process, (ii) assess project compliance against the SPS and national environmental laws and regulations, and (iii) incorporate impact avoidance and mitigation early in the project design process. One of the various steps enumerated under ADB direction is *screening*, to categorize proposed project types and the associated scope of required environmental assessments. Of the three impact-related categories, most of the new and major reconstruction road projects within biodiversity-rich areas

will likely be Category A, which have anticipated significant and irreversible adverse impacts that may extend beyond the project footprint requiring an environmental impact assessment (EIA).<sup>1</sup> In some instances, projects may fall into Category B, which have somewhat lesser impacts and for which mitigation measures may be more readily designed to address impacts. For Category B projects, an initial environmental examination is required. The presence of threatened and endangered species, associated natural and critical habitats, and/or protected area status can further elevate a proposed project to Category A, and impacts not associated with biodiversity may also elevate classification to Category A.

Category A projects, and the full-scale EIA they require, necessitate the conduct of BBA that aims to:

- identify and quantify the potential project impacts, compared to a biodiversity baseline;
- design measures to avoid, minimize, or mitigate adverse impacts, and compensatory measures as needed to achieve no net loss, or even a net gain of biodiversity value; and
- evaluate the prospects of achieving no net loss of biodiversity value when impacts are balanced against achieving measurable conservation outcomes.

ADB's SPS (2009) and environmental safeguards sourcebook (2012) provide the framework for classification of habitats within proposed project areas and the respective limits for habitat degradation associated projects. The two primary classifications include *natural* and *modified* habitats. Within natural habitats, a proposed project may not significantly degrade habitat value unless (i) no other alternatives are available (thus, a critical aspect of the biodiversity assessment), (ii) the project's benefits exceed costs, and (iii) impacts are fully mitigated.

For natural and modified habitats, ADB's SPS and environmental safeguards sourcebook provide the framework for determining the *critical habitat* for endangered and/or limited distribution and/or endemic species, with consideration of the potential for projects to occur within critical habitat areas exhibiting high biodiversity value and legal protection, or that are required for the survival of critically endangered or endangered species. Within critical habitats, proposed projects can have no adverse impacts that impair biodiversity value and ecosystem function, and are not anticipated to reduce populations or habitat for critically endangered or endangered species; and all lesser impacts of the proposed projects

<sup>1</sup> Environmental Categories: Category A projects likely to have significant adverse impacts, with an Environmental Impact Assessment required; Category B projects with potential adverse impacts less than Category A and more easily mitigated, with initial environmental examination required; and Category C projects likely to have minimal adverse impacts with no environmental assessment required, but environmental implications reviewed. ADB. 2009. *Safeguard Policy Statement*. Manila. <https://www.adb.org/site/safeguards/policy-statement>.



are fully mitigated. The determination of critical habitat for candidate species employs the criteria and thresholds described in the SPS and further enumerated in the *IFC Performance Standard 6 Guidance Note* (2012, as amended in 2019).

The conduct of sound BBA, with proper experimental design, geographical scale, and temporal scope or duration is essential to addressing the substantial and oftentimes challenging ADB policies above, particularly for Category A projects. Sound biodiversity assessment is the key to thoroughly evaluating and comparing proposed transportation project impacts with alignment alternatives, including those that may avoid impact on high-biodiversity areas. Such assessment can also support effective project design incorporating green infrastructure and other safeguard measures. To assist with framing the scope of biodiversity assessment, thorough desktop project analysis employing various resources is essential and can potentially help streamline subsequent BBA field studies.

## B. Desktop Analysis Resources

Desktop analysis associated with a proposed road or other linear infrastructure project constitutes the vital first step and foundation upon which the project will be evaluated and designed. Thorough desktop analysis is essential to the proper development of sound field BBA and can help identify the presence of natural and modified habitats.

### 1. Desktop Biodiversity Screening

The online Integrated Biodiversity Assessment Tool (IBAT) constitutes an indispensable global biodiversity decision support resource for conducting desktop biodiversity screening of proposed projects.<sup>2</sup> Similar national screening tools may be available for use. IBAT can be used to identify various biodiversity components spatially (in report form or via data download for geographic information system [GIS] analysis), including

- protected areas at local, regional, and international scales;
- key biodiversity areas; and
- the International Union for Conservation of Nature (IUCN) Red List of globally threatened species grid limits of distribution.

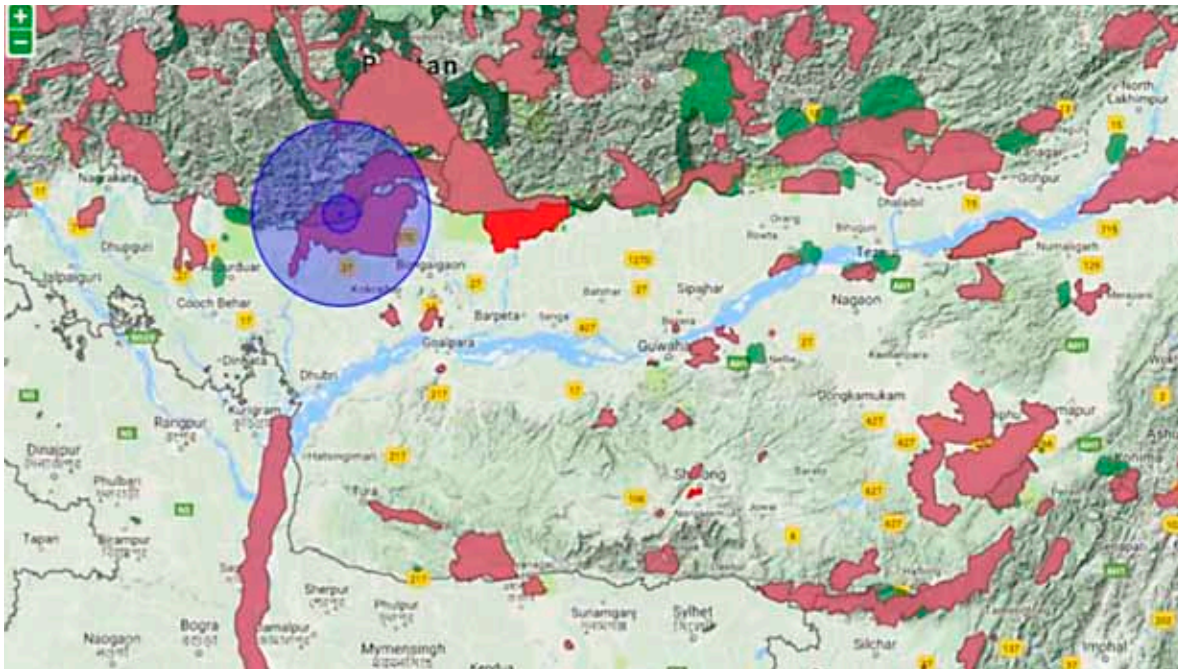
The proximity analysis tool within IBAT allows the user to specify buffer distances from the proposed project area (e.g., 1 kilometer [km], 5 km, 25 km, 50 km) to assess direct project-area impacts, and identify those at the larger landscape and regional scales to support the identification of alternative road alignments with lower impacts, as well as the analysis of cumulative effects (Figure A1). This information, as well as those from other sources, is critical

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<sup>2</sup> IBAT Alliance (BirdLife International, Conservation International, IUCN, UN environment, and WCMC). *Integrated Biodiversity Assessment Tool*. <https://www.ibat-alliance.org/>.

to determining the geographic scope of the area to be studied as part of the field study aspect of the BBA. Where far-ranging and mobile threatened species are involved, BBA field studies may need to extend at least 5 km or more on each side of a proposed road alignment to fully evaluate the potential impacts.

**Figure A1: Map Sample of Integrated Biodiversity Assessment Tool Map Viewer**



km = kilometer.

Note: The Integrated Biodiversity Assessment Tool with proximity analysis tool shows protected areas and key biodiversity area polygons, with 1 km, 5 km, and 50 km buffers (purple circles) from a proposed road project.

Source: IBAT Alliance (BirdLife International, Conservation International, IUCN, UN environment, and WCMC). Integrated Biodiversity Assessment Tool. <https://www.ibat-alliance.org/>.

The online site of the IUCN Red List is a comprehensive inventory detailing the global conservation status of endangered, vulnerable, and near-threatened plant and animal species.<sup>3</sup> Individual species profiles detail a wide range of information, including geographic range, population status, habitat and ecology, threats, and conservation actions. Maps of geographic ranges are provided, along with a listing of protected areas occurring within the species' range and the percentage overlap; and GIS compatible spatial data may be downloaded. The information from this site is particularly useful in determining critical habitat status for critically endangered, endangered, and nationally listed species.

<sup>3</sup> International Union for Conservation of Nature. Connectivity Conservation. [www.iucnredlist.org](http://www.iucnredlist.org).

## 2. Satellite Imagery and Normalized Difference Vegetation Index Modeling

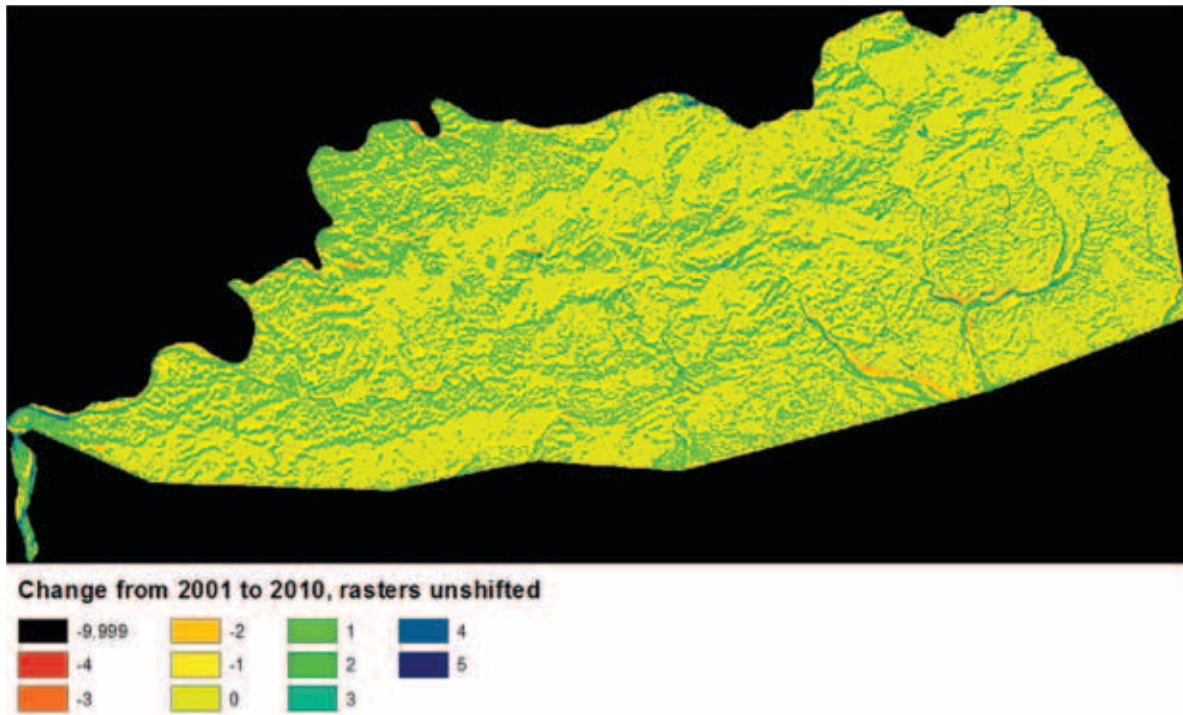
High-resolution satellite imagery (e.g., LANDSAT) can be very useful in project scoping and development of strategies for conducting biodiversity assessments, evaluation of road alignments, and even project design. Such imagery, including that displayed on Google Earth™, can be especially useful in digital format upon which proposed road alignments and other features (e.g., proposed drainage structures, bridges) may be superimposed using GIS. Depending on resolution, satellite imagery may be useful in identifying habitats modified by agriculture, forest conversion or logging, and other activities. The imagery may allow identification of special habitat features (e.g., wetlands, springs, salt licks). With sufficient ground validation, satellite imagery can be used to identify different vegetation types, assisting with field assessment experimental sampling design (e.g., stratification of effort among types).

Normalized difference vegetation index (NDVI) modeling can be employed to assess differences in forest vegetation density and land use cover over time (Yacouba et al. 2010, Alam et al. 2014). GIS analysis employing NDVI can assess differences in satellite imagery spectral bands to yield a measure of the fraction of absorbed photosynthetically active radiation present in vegetation at a given time. This fraction can be compared across years and correlated to various parameters such as canopy closure. By subtracting the canopy closure density class codes by pixel/raster between years, a process termed “differencing” (Yacouba et al. 2010), changes over time can be displayed and analyzed. This information can be used to assess temporal changes in vegetation reflecting anthropogenic (e.g., logging, conversion to agriculture) or natural (e.g., fire) influences, and assist with the classification of habitats. Figure A2 illustrates the NDVI changes in forest density classes at Phipsoo Wildlife Sanctuary in Bhutan, between 2001 and 2010, showing the degree of change in forest canopy density over time by pixel/raster, either more (positive numbers) or less (negative numbers) dense, or exhibiting no change (0).

## 3. Other Resources

**Connectivity and corridor assessments.** Where they exist, national or regional biodiversity connectivity and corridor assessments can be an invaluable resource in identifying priority sites for strategies to promote connectivity in conjunction with road and other transportation infrastructure projects. Large-scale corridor assessments typically attempt to link large blocks of relatively intact habitat and protected areas (core areas) via corridors. These corridors or linkages are intended to maintain connectivity between the core areas or blocks, providing for wildlife movement and dispersal (Beier et al. 2008). As such, it is equally important to promote passage across the corridors as it is the biodiversity core areas they link.

**Figure A2: NDVI Changes in Forest Density at Phipsoo Wildlife Sanctuary, Bhutan (2001–2010)**



NDVI = normalized difference vegetation index.

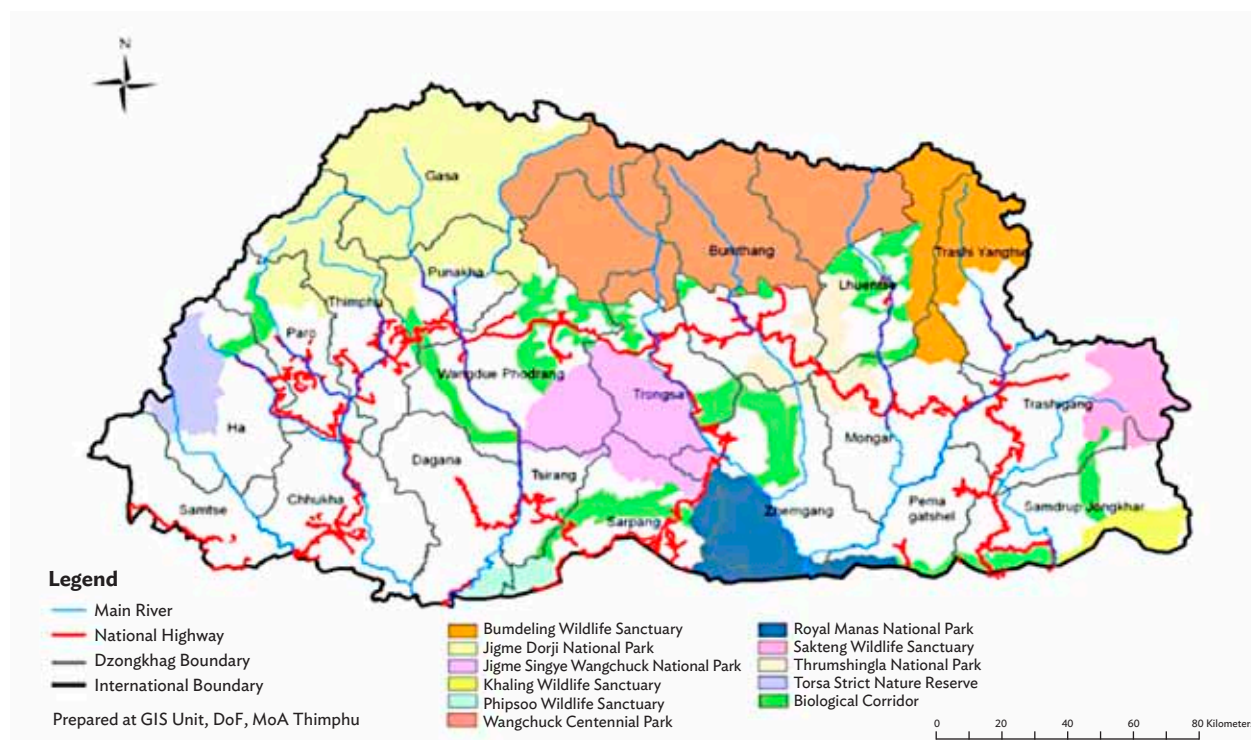
Source: Analysis using data provided by World Wildlife Fund-Bhutan, reported in ADB. 2018. *Biodiversity Baseline Assessment: Phipsoo Wildlife Sanctuary in Bhutan*. Manila.

Examples of biodiversity connectivity and corridor assessments are presented in Figure A3, a national level assessment showing Bhutan's protected areas in green color with corridors linking them in orange color; and in Figure A4, a regional or transboundary level assessment of the Greater Mekong Subregion Biodiversity Corridors Initiative, showing biodiversity conservation landscape blocks, protected areas, and corridor scales in green color.

The IUCN's World Commission on Protected Areas has recently formed a Connectivity Conservation Specialist Group. This group seeks to increase awareness of the importance of protected areas in preserving biodiversity and connectivity by linking landscapes and reducing landscape fragmentation to promote functional ecosystems. This group is working to prepare and disseminate expert guidance materials and to offer specialist advice on all aspects of global connectivity conservation and strategies for developing interconnected protected area systems to preserve biodiversity, which should be available in 2019.



Figure A3: Protected Areas and Biological Corridors of Bhutan



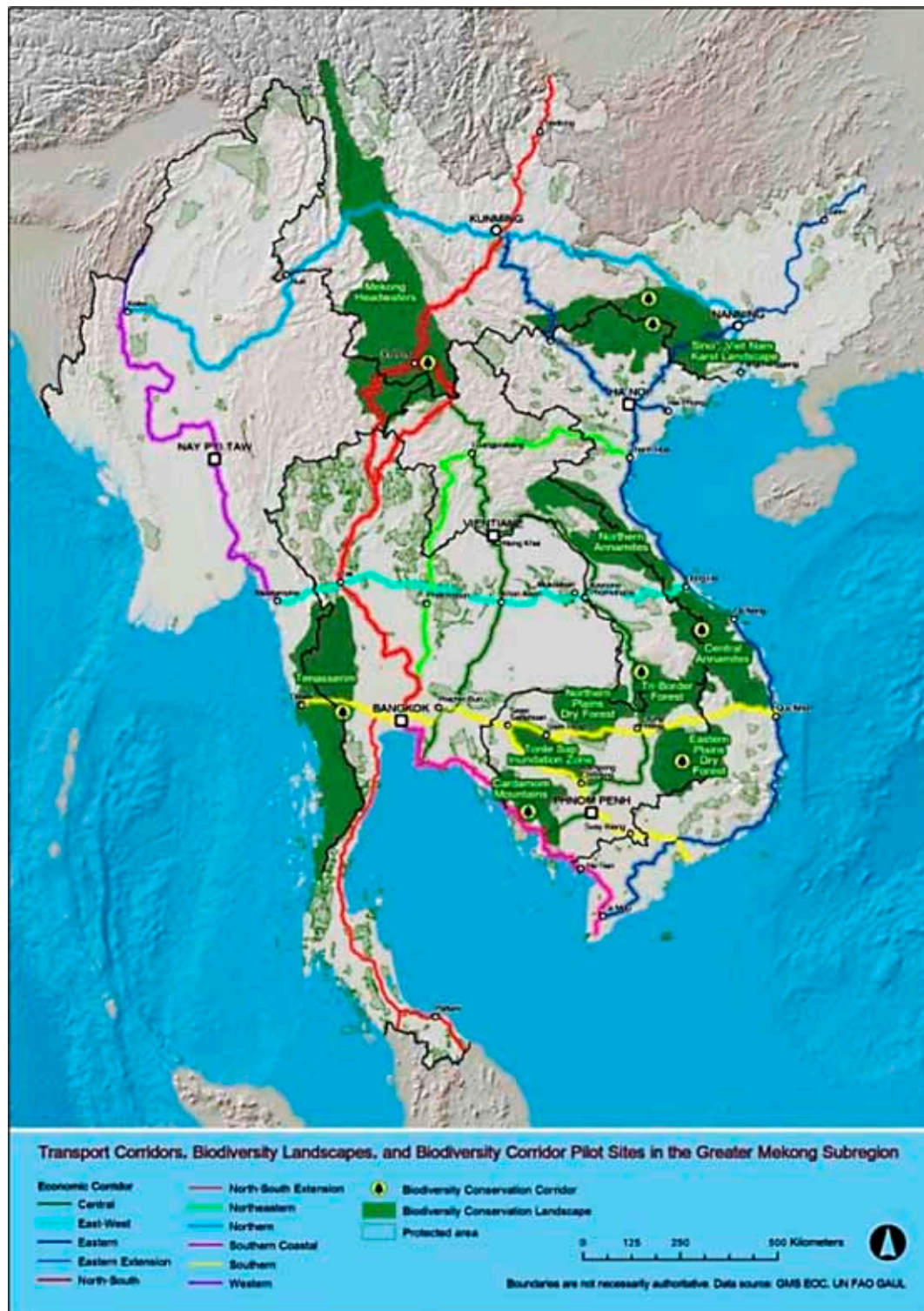
Source: Royal Government of Bhutan, Ministry of Agriculture and Forests, Department of Forests and Park Services. 2009.

At the project-level scale, GIS-based cost-distance resistance modeling using the corridor design toolbox (Beier et al. 2007) may be employed to identify potential corridors (and thus passage structure locations) across landscapes that address the passage needs of multiple wildlife species.<sup>4</sup> However, such modeling is dependent on the availability of sufficient species-specific data to conduct modeling.

**Area management plans.** Conservation agency management plans for protected areas (e.g., national parks, wildlife sanctuaries, nature preserves) and other biodiversity-rich areas often exist. Where such plans do exist, they can be an invaluable source of information that can complement desktop biodiversity screening. Information in management plans includes detailed area descriptions; vegetation and animal species presence; distribution and relative abundance; as well as management challenges, needs, and multiyear plans. Such information is useful in developing biodiversity assessment experimental design, and also provides insights into management needs, which may be suitable for potential conservation offset programs to help achieve no-net loss of biodiversity value associated with road projects.

<sup>4</sup> International Union for Conservation of Nature. Connectivity Conservation. <https://www.iucn.org/commissions/world-commission-protected-areas/our-work/connectivity-conservation>. Corridor Design. [www.corridordesign.org](http://www.corridordesign.org).

**Figure A4: Transport Corridors, Biodiversity Landscapes and Corridor Pilot Sites in the Greater Mekong Subregion**



Source: Greater Mekong Subregion Environment Operations Center. *International Best Practices and Potential Joint Actions in GMS Transboundary Landscapes*. Bangkok. <http://www.gms-eoc.org/uploads/resources/1201/attachment/4-B.Transboundary-Biodiversity-Cooperation-International-Best-Practices-Jeffrey-McNeely.pdf>; Food and Agriculture Organization of the United Nations. 2015. *Global Administrative Unit Layers*. Rome. <http://193.43.36.146/map?entryId=f7e7adb0-88fd-11da-a88f-000d939bc5d8&tab=about>.

**Engineering feasibility reports.** Depending on which stage of the design process a proposed transport project is, preliminary engineering feasibility reports may be available. Such reports contain background information on the proposed road and rail project, including identification of potential alignment alternatives and associated general design characteristics (e.g., slope, roadbed formation width, alignment length). This information can be used to calculate and compare direct habitat loss to natural versus modified habitats (critical habitat determination typically requires BBA survey) where identified by satellite imagery and/or NDVI modeling (Table A1). Feasibility reports also include preliminary drainage structure needs inventory (i.e., concrete box culvert, corrugated metal pipe culvert, bridges), which can be very useful in developing integrated wildlife passage structure design strategies employing dual-use structures where possible.

Table A1 provides a comparison example for three transport project alignments and the anticipated direct habitat loss to natural and modified habitats (based on road formation widths  $\times$  length), using information typically available in preliminary engineering feasibility reports. Alignments A and B are of equal length, but A passes entirely through natural habitat (and has the highest area loss) while B passes through equal lengths of natural and modified habitats. Alignment C is 50% longer than A and B, and passes entirely through modified habitat to avoid natural habitats as per ADB's SPS (2009), yet still has the lowest direct habitat loss of the alignments, underscoring the importance of impact Avoidance under the mitigation hierarchy in project assessment and design (CSBI 2015).

**Table A1: Comparison Example of Three Road Alignments and Anticipated Direct Habitat Loss**

Proposed Alignment	Habitat Type	Road Lengths and Area Impacted by Terrain Slope Steepness Class							
		Gentle (10 m wide)		Moderate (20 m wide)		Steep (30 m wide)		All Slopes	
		Length (km)	Area (ha)	Length (km)	Area (ha)	Length (km)	Area (ha)	Length (km)	Area (ha)
Alignment A	Natural	10	10	20	40	20	60	50	110
	Modified	–	–	–	–	–	–	–	–
	All	10	10	20	40	20	60	50	110
Alignment B	Natural	–	–	10	20	15	45	25	65
	Modified	10	10	15	30	–	–	25	40
	All	20	20	20	40	–	–	50	105
Alignment C	Natural	–	–	–	–	–	–	–	–
	Modified	50	50	25	50	–	–	75	100
	All	50	50	25	50	–	–	75	100

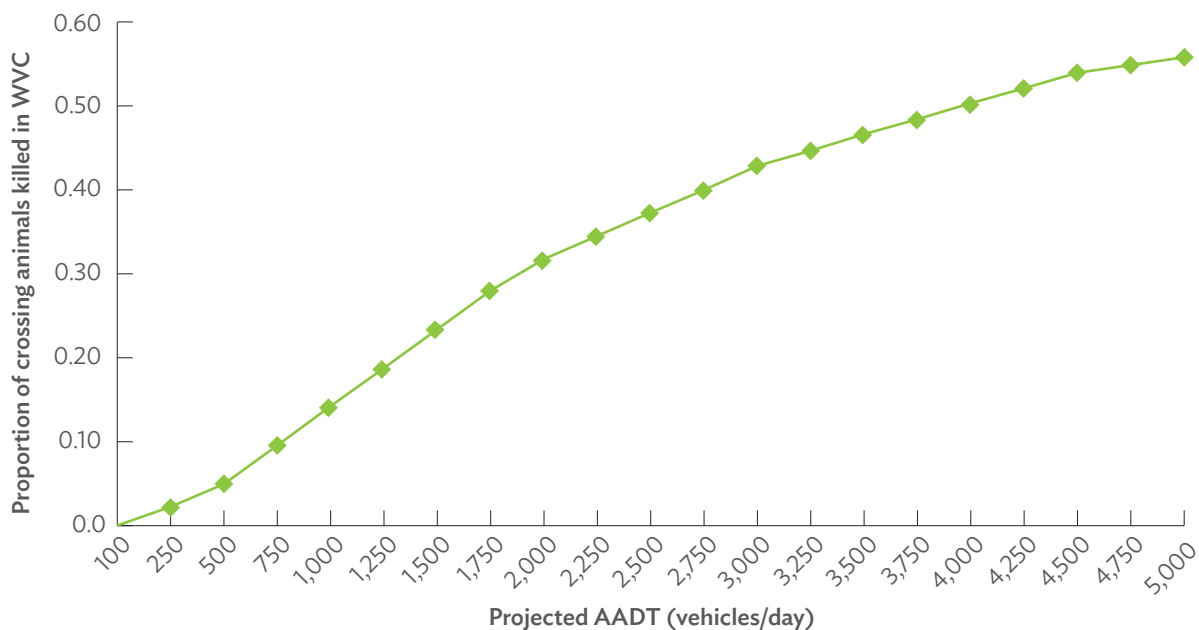
ha = hectare, km = kilometer, m = meter.

Source: Asian Development Bank consultant's estimates.

Traffic projections are often provided in feasibility reports, that can be used to assess potential road impact on wildlife associated with wildlife–vehicle collisions (WVC) and permeability, both of which are traffic-volume dependent. The potential direct impact of traffic volume on wildlife populations may be estimated using the theoretical model of Seiler (2003) (Figure 1, page 16). While theoretical, this model remains the best resource available to yield predictive insights into the direct impact of roads on wildlife, though these relationships have been empirically validated by research in North America (Gagnon et al. 2011, 2012) and Sweden.

Figure A5 shows projections of the proportion of animals attempting to cross roads at increasing annual average daily traffic (AADT) that would be killed in WVC without measures to reduce highway impact. Projection estimates were obtained from Seiler’s model (2003). The lower end of the Seiler graph’s AADT range of  $\leq 5,000$  vehicles per day was expanded for road traffic levels that are appropriate for rural Asian roads. Figure A5 allows for estimation of the proportion of animals attempting to cross that would be killed in WVC. This information can be used with mammalian BBA survey information to compare potential direct impacts by road alignment reflecting relative abundance along various alignments.

**Figure A5: Projected Animals Killed in Collisions Without Measures to Reduce Highway Impact**



AADT = annual average daily traffic, WVC = wildlife–vehicle collision.

Source: Asian Development Bank consultant’s projection estimates derived from the model of Seiler. 2003. *The Toll of the Automobile: Wildlife and Roads in Sweden*. Dissertation. Uppsala: Swedish University of Agricultural Sciences.



As an example, a proposed road is projected to have an AADT in the first year after an estimated 1,250 vehicles per day, increasing to 2,750 vehicles per day in 10 years, and to 3,750 vehicles per day in 20 years. Figure 10 shows that the proportion of animals attempting to cross that road and would be killed in WVC increases from 20% in the first year to 43% in year 10, and to 52% in year 20, provided there are no measures put in place to minimize WVC. This information helps analyze and compare the potential short- and long-term impact of a proposed road, as well as provide justification for green infrastructure and road management strategies to reduce the direct impact on wildlife and promote motorist safety.

**Expert, agency, and organization coordination.** The value of early and frequent communication and discussions with all personnel involved with a proposed transport project can be an important source of insight and understanding. Such contacts include but are not limited to roads department/agency engineers and consultants, natural resource managers and rangers associated with various conservation agencies, and representatives from various non-government organizations (e.g., WWF, IUCN). Often, such individuals, agencies, and organizations can provide critical support and resources, including reports, GIS files, and satellite imagery. More importantly, good cooperation and communication can help identify key issues to be addressed and help steer a biodiversity assessment away from potential logistical and political pitfalls.

### C. Biodiversity Baseline Assessment Experimental and Sampling Design

The desktop assessment aims to inform and support the development of a comprehensive BBA field study experimental approach and study plan. In developing a BBA study plan, it is paramount to consider and structure its design to ensure adequate accomplishment of all requirements put forth by ADB's SPS (2009) and environmental safeguards sourcebook (2012). The ability to satisfy the overarching goals of the ADB guidance for assessing and comparing project impacts and risks, satisfying environmental compliance, and developing strategies for impact avoidance and mitigation via project design is predicated on a sound BBA experimental design.

However, while stressing the need for conducting scientifically creditable, thorough, and comprehensive BBA, especially for Category A transport projects, it is important to consider designing field assessments that are both financially (e.g., consistent with budgets) and logistically feasible, and also minimize security risks to field personnel that may be a concern when working in some remote areas. BBA study design should incorporate an element of flexibility with contingencies for the unexpected. The recommendations provided in this report reflect the range of BBA scenarios from full-blown studies to rapid biodiversity assessments.

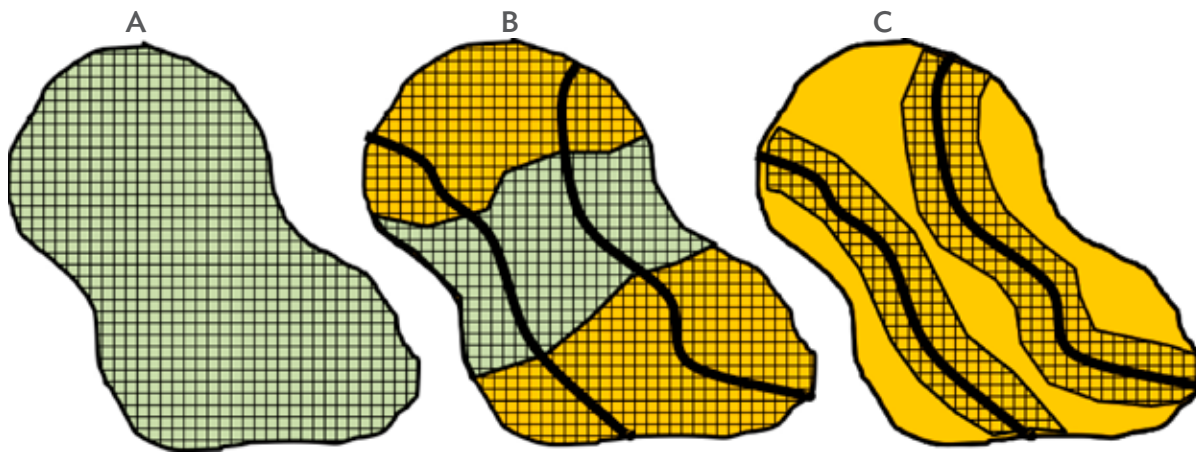
When beginning the process to develop a BBA study plan, it is essential to understand the status of the project design process. Ideally, where a proposed road or railway crosses through a biodiversity-rich and/or protected area, the process should not have progressed beyond accommodation of alignment modification or alternatives based on still yet to be collected BBA information. Ideally, preliminary engineering feasibility analysis entails multiple road alignments reflecting a range of design parameters and associated impacts to be evaluated and compared as part of the BBA. At least one alignment must be evaluated to satisfy ADB's SPS requirement for roads sited in natural habitat to have no viable alternative outside natural habitat. Where such an alternative alignment has not yet been proposed, the identification of modified habitats to support an alternative may be a priority.

## 1. General Sampling Approaches

There are countless approaches than can be taken to structuring a BBA depending on assessment objectives and preliminary road design status. However, BBA field study and sampling generally fall into one of three broad approaches, though variations and combinations of each may be suited to a particular site or project (Figure A6):

- **Area-wide assessment.** An entire high-biodiversity or protected area is surveyed, as well as neighboring areas for potential alignment alternatives. This approach is especially suited in the unusual case where no road alignments have been designated through the area, and an alignment could be sited within areas exhibiting the lowest biodiversity (assuming technical feasibility). This approach is well suited to a grid design from which sampling sites may be selected for survey. This approach may also be suited to BBA where resources (e.g., budget, time) are not constrained.
- **Zone assessment with stratified sampling.** The high-biodiversity or protected area is segregated into zones based on vegetation type, terrain (e.g., gentle, moderate, steep) or other classification. Sampling and/or survey can be stratified proportionally based on the area covered by each zone (ADB 2018). Comparison of impacts considers the proportion of each proposed alignment crossing through the different zones and its overall biodiversity value and proportion of modified, natural, and/or critical habitat through which they cross. This approach is preferred where resources are not limited and allow wide coverage of the area.
- **Alignment-based assessment.** Sampling and survey are conducted within corridors around each proposed road alignment through a biodiversity-rich or protected area, either with equal or stratified sampling effort based on the length of each alignment through the area. Comparison of impacts considers the overall biodiversity value within each corridor and the proportion of modified, natural, and/or critical habitats through which they cross. Under circumstances of budget and time constraints, this approach is generally the most efficient and cost-effective.

**Figure A6: General Biodiversity Baseline Assessment Approaches for High-Biodiversity or Protected Areas**



A = area-wide assessment, B = zone assessment with stratified sampling, C = alignment-based assessment.

Note: The grids refer to areas where the biodiversity baseline assessment survey is conducted.

Source: Asian Development Bank consultant's estimates.

Regardless of the general approach taken to the BBA, sampling site selection can be done by: (i) randomly selecting grid cells or randomly generating sites for survey, which is generally preferred, or (ii) systematically selecting even-spaced grid cells or points. Most important is striving to minimize the potential for sampling bias in site selection while ensuring sufficient (and proportionally equal) sampling intensity of all zones or proposed road corridors.

## 2. Sampling Coverage for Alignment-Based Biodiversity Baseline Assessment

The scale of coverage (or distance outward from proposed transport projects) at which BBA sampling/survey is conducted can be best determined from the IUCN list of mammal species known or likely to occur within the area, identified during desktop biodiversity assessment by IBAT screening and other sources. The sampling coverage at which field survey is conducted will influence the ability to reliably determine the distribution and relative abundance of the various “target” species or taxa (essential to determining the need and location of passage structures and other green infrastructure) and to capture natural habitat variability across the landscape.

Transport projects within biodiversity-rich areas can affect a variety of wildlife species exhibiting a wide range of relative mobility in their movements and home ranges. For alignment-based assessments, sampling coverage distances that are scaled to the relative mobility of the furthest ranging species or taxa anticipated to be present within a road project area is recommended (Table A2).

BBA sampling and survey coverage extending away from a proposed road could range from 0.5 km for very low-mobility small mammals and/or reptiles and amphibians, to 2.0 km for small felids (leopard cat), large ungulates (e.g., sambar), and/or bears (e.g., Asiatic black bear), to 5.0 km or more for very high-mobility large canids (e.g., dhole, wolf) and Asian elephants (Table A2). The BBA sampling and/or survey coverage under the area-wide and zone assessment approaches (Figure A6) would likely exceed the recommended coverages due to the larger areas they encompass compared to the survey corridors under the alignment-based approach.

**Table A2: Recommended Biodiversity Baseline Assessment Sampling or Survey Coverage**

Target Species Group or Taxa	Relative Mobility	Sampling Coverage (Distance on each side of alignment)
Reptiles and amphibians Small mammals (rodents, squirrels)	Very low	0.5 km
Small ungulates Mustelids Langurs	Low	1.0 km
Small felids Large ungulates Bears	Moderate	2.0 km
Large bovids Large felids	High	3.0 km
Large canids Asian elephant	Very high	≥5.0 km

≥ = greater than or equal to, km = kilometer.

Source: Asian Development Bank consultant's estimates.

### 3. Sampling and Survey Intensity

One goal of any BBA should be to obtain sufficient amounts and quality of data to support meaningful inferences (e.g., statistically valid) when comparing datasets and biodiversity metrics among road alignments or assessment zones. Thus, sampling and/or surveying a large enough number of sites that are sufficiently well-spaced apart to capture natural variability is critical to meaningful analysis and comparison among road alignments and zones, among others. This goal must be balanced against project constraints of budget and time, as well as logistical realities for conducting and accomplishing the BBA.

A BBA reported in ADB (2018) employed an average sampling intensity of one sampling site (i.e., mammal camera trapping, forest tree overstory) for every 5 square kilometers (km<sup>2</sup>) of assessment area, which yielded sufficient quality data to make statistically meaningful comparisons. At this intensity, a proposed road alignment 20-km long within habitat inhabited by high-mobility wildlife species necessitating a 6.0-kilometer-wide survey corridor (Table 8), would require approximately 24 sampling sites where various types of surveys would



be conducted. Depending on resource availability, a higher sampling intensity can be used, but this is a reasonable guideline to ensure that sufficient quality data are obtained for alignment-based assessment approaches, and to support meaningful comparison. Lower intensity may be appropriate for area-wide and zone assessment approaches covering substantially large areas. Table 8 shows the recommended biodiversity baseline assessment sampling and/or survey coverage distances outward from proposed road alignments based on the relative mobility of target species groups or taxa.

#### **4. Duration and Frequency of Biodiversity Baseline Assessment Sampling or Survey**

It is generally accepted that BBA should be done for at least 1 full year with each season covered as appropriate to capture seasonal variation among animal presence, distribution, and relative abundance, as well as seasonal understory vegetation phenology. Furthermore, several Asian countries have environmental compliance requirements associated with EIA for a minimum of a year of field assessment. This is not to say that all field sampling and survey activities must be carried out continuously for a full year; rather, those BBA elements where substantial seasonal variation is anticipated should be prioritized for year-long and multi-season assessment.

Mammal abundance and distribution often vary seasonally and are a priority for year-long assessment, which can be accomplished by remote camera “trapping” or repeated track count transects where budgets are limited. Conversely, some BBA elements (e.g., forest overstory tree composition, snags) only need to be surveyed once during a year. In many instances, the conduct of avian (bird) surveys can often be sufficient if accomplished at least twice during the year (though more surveys may be necessary), and survey of reptiles and amphibians and fish populations should be accomplished (at a minimum) at least once during the year. Multiple surveys of fish populations may be needed where migratory species are involved. Table A3 presents various general BBA methods used to conduct sampling and/or surveys of wildlife taxa and vegetation, number of seasons of survey recommended, and associated relative cost of equipment and labor intensity.

Where resources limit field activities to the conduct of rapid assessments, the preliminary results can be used to determine (prioritize) those BBA elements of greatest concern for subsequent focused study and/or survey. Even under full-blown BBA field studies, continued supplemental study may be warranted, especially in monitoring potential road construction impact or focusing BBA activities to a selected alignment to gain higher-quality resolution data to facilitate implementation of green infrastructure, such as passage structures and/or wildlife fencing.

**Table A3: Biodiversity Baseline Assessment Methods of Wildlife Taxa and Vegetation**

Survey Type or Taxa	Survey Method	No. of Seasons	Equipment Cost			Labor Intensity		
			High <sup>a</sup>	Mod. <sup>b</sup>	Low <sup>c</sup>	High <sup>d</sup>	Mod. <sup>e</sup>	Low <sup>f</sup>
<b>Mammal</b>	GPS telemetry	4	X				X	
	Remote camera trapping	4		X				X
	Track counts	4			X	X		
	Observation surveys	4			X	X		
<b>Avian</b>	Transects	2			X		X	
	Point counts	2			X		X	
<b>Fish</b>	Electrofishing	1–2		X			X	
	Seine netting	1–2			X		X	
<b>Reptile or Amphibian</b>	Visual encounter	1–2			X	X		
	Pitfall trapping	1–2		X		X		
<b>Roadkill (WVC)</b>	Observation/searching	4			X		X	
<b>Forest Tree Overstory</b>	Plot sampling	1			X		X	
	Plotless (prism) sampling	1			X			X
<b>Understory Vegetation and Orchids</b>	Plot sampling	2			X		X	
<b>Snags</b>	Plot sampling	1			X			X
<b>Illegal Tree Harvest</b>	Plot sampling	1			X		X	
	Transects	1			X			X

GPS = global positioning system, Mod. = moderate, No. = number, WVC = wildlife–vehicle collision.

<sup>a</sup> More than \$15,000

<sup>b</sup> Up to \$15,000

<sup>c</sup> Less than \$500

<sup>d</sup> 1–2 sites per day

<sup>e</sup> 3–4 sites per day

<sup>f</sup> More than 5 sites per day

Source: Asian Development Bank consultant's estimates.

## 5. Survey Methods

38. There are a multitude of different methods that may be successfully employed to conduct BBA sampling and survey. However, the focus should remain on the collection of sufficient high-quality data (e.g., distribution, relative abundance, relative composition) to establish sound biodiversity baselines and make meaningful comparisons among road alignments, and not just compiling species occurrence lists. Every project will require application of methods that are effective and logistically feasible; selection requires some creativity and the best methodologies are not necessarily the most expensive. In addition to BBA sampling/surveying methodologies, BBA data collection is augmented by collection (recording) of incidental observations of IUCN-listed species, special habitats, and presence of modified habitats (e.g., extent of illegal tree harvest).

It is assumed and recommended that the various applicable BBA methodologies (Table A3) will be conducted concurrently while in the field, and at the same sampling/survey sites which will facilitate efficiency and assessment of relationships among datasets and parameters (e.g., forest overstory tree and wildlife species composition).

**Mammalian sampling and/or survey.** Mammalian species data are often some of the most powerful data collected during any BBA. It is also the data that can most directly support the application of green infrastructure in transport projects to promote wildlife passage and connectivity. Data from mammalian species sampling and/or survey are vital to developing sound conservation and mitigation strategies, including species distribution and relative abundance, essential to determining the number, size, and spacing of wildlife passage structures. Several models of reliable, high quality cameras can be purchased for approximately \$250, and higher cost options are available for cameras integrated with cellular image transfer.

Where BBA funding is limited, relatively labor intensive but equipment-free track (and other sign) surveys and/or ground or foot observation surveys may be appropriate. In areas with high mammal species diversity and abundance, systematic and repeatable track count transects can provide excellent comparative information (Rai 2006), as can well-structured ground or foot observation surveys for relatively visible species within open habitats; however, relying on the latter within dense forest habitats may not yield reliable or consistent data. Observation data nevertheless are valuable to augmenting surveys for species that are not readily camera “trapped” such as arboreal primates.

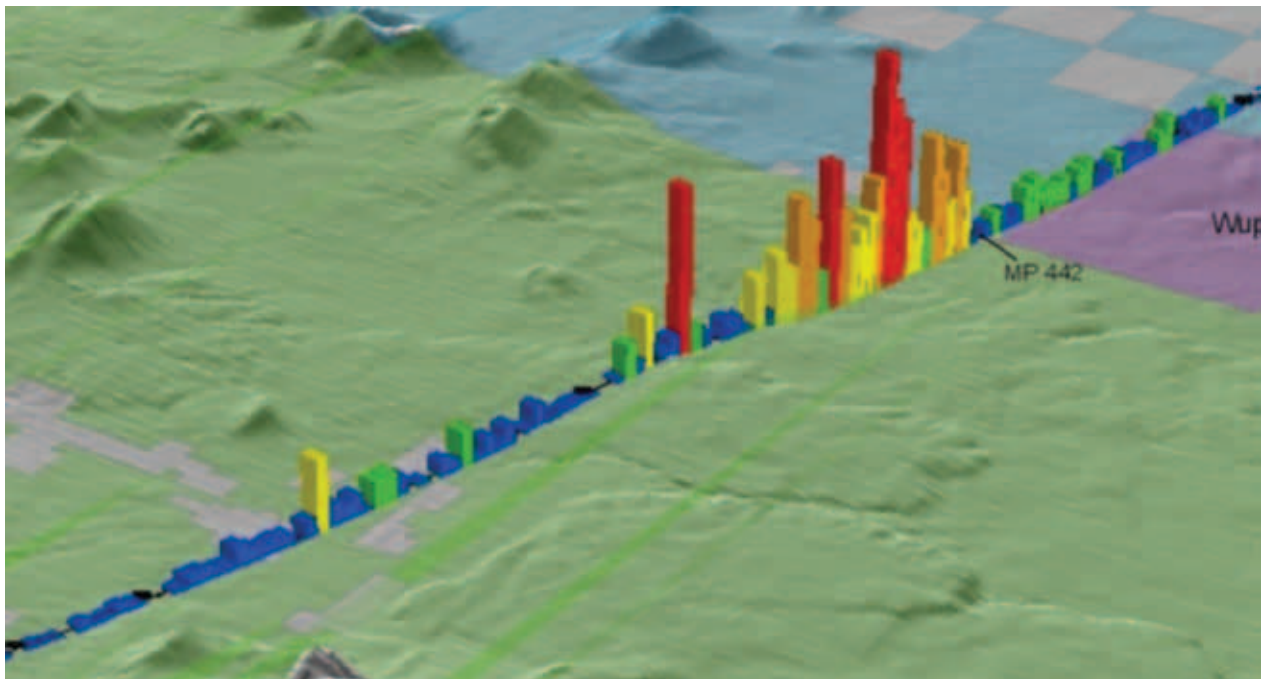
The application of relatively inexpensive (less than \$200 each) and reliable yet high-quality infrared remote-triggered cameras has revolutionized the effective and efficient sampling of mammal species and populations across the world (Trolliet et al. 2014). This now constitutes the preferred method by which a rapidly growing number of studies are being conducted, especially in remote roadless areas.



➤ **Camera trapping.** Infrared remote-triggered cameras are placed in a forest, improving animal monitoring for better management and protection for Asian elephants and the common leopard (photos by ADB).

Remote camera “trapping” can be used to determine species occupancy, relative abundance, animal behavior, temporal activity patterns, and even identification of individual animals important for management and recovery of some species (e.g., tiger). Remote cameras can be installed at the onset of a year-long project; and depending on the number of images recorded and video options selected, remote cameras may need to have batteries replaced only once, typically after about 6 months. This may be accomplished when doing avian, vegetation, and/or other surveys. Within biodiversity-rich areas, it can be anticipated that more than 1,500 images may be recorded by each camera over a year. Asian camera trapping studies have recorded as many as 30 mammalian species, of which half were IUCN-listed species (ADB 2018). Efforts must be made to ensure that camera fields-of-vision are not obstructed, especially by moving vegetation that can trigger cameras, consequently recording many images without animals and depleting batteries. Cameras can be programmed to record both images (and “bursts” of images) and video; time-lapse recording can be used, though it requires large amounts of tedious analysis in search of images with animals; however computer programs are now available to assist with time-lapse analysis.

Unless budgets preclude their use, the use of mammalian camera trapping in BBA is recommended. Their up-front cost is offset by the sheer amount and quality of consistent and comparable data and ability to assess mammalian species and population parameters that otherwise would not be possible, as well as their relatively low overall labor requirement.



► **Tracking animals by telemetry.** Frequency of pronghorn GPS fixes are recorded along Highway 89, Arizona to determine potential locations for overpasses and fencing. The three red peaks in frequency distribution by 0.15-kilometer segment represent the best locations for overpasses, with fencing to link the overpasses (photo from Dodd et al. 2009).



Global positioning system (GPS) telemetry has been employed with success, especially in North America, to determine large mammal movements, habitat use, and distribution patterns. It facilitates locating wildlife passage structures in association with highway projects (Dodd et al. 2007), and is increasingly being used in Asia for such purposes. GPS telemetry can be quite expensive (up to \$5,000 per collar with satellite upload subscription), and requires considerable initial effort (and immobilization drugs in some instances) to capture animals. However, once captured, there would be no additional costs, and GPS data are regularly uploaded via satellite and posted online for retrieval. Collars can be programmed to drop off animals for recovery and subsequent cost-effective collar reuse. GPS telemetry collars can be programmed to record frequent GPS fixes (e.g., 1–2 hours apart) that allow identification of specific locations for passage structures and associated extent of wildlife fencing. In Asia, telemetry may be suited to tracking Asian elephants and other far-ranging species to locate large and costly passage structures, thus maximizing their effectiveness (Pan et al. 2009) and minimizing the need for maintenance-intensive fencing or fencing alternatives. Battery life for elephant GPS collars can exceed 9 years providing large amounts of data as well as insights into short- and long-range movements.

**Avian surveys.** These can be accomplished using transect or point count methodologies. Point counts are one of the most commonly used survey techniques for determining avian species composition and abundance (Bibby and Burgess 1992, 2000), and can be conducted in conjunction with mammalian survey sites. Point counts are especially suited for use in difficult terrain where it is not possible to establish transects or other techniques (Bibby and Burgess 1992)—as often encountered in Asia.

Avian surveys are most effective when conducted during the early morning hours immediately after sunrise when birds are most active and calling with most consistency, typically lasting over a 4-hour period (Ralph et al. 1995). Within this “window,” up to two separate sites can be surveyed, and an additional survey can be done in the late afternoon or evening when birds are again active. Surveys should only be conducted under suitable conditions (e.g., no high winds). Preferably, avian surveys should be conducted at sites at least twice during the year, during the spring (breeding) and winter (migratory) seasons. Experienced personnel familiar with local birds and their calls should be enlisted to assist with surveys, and should be involved in all surveys to maintain consistency.



➤ **Avian survey.** Monitoring of birds such as this red-breasted parakeet is best done in the early morning when birds are most active (photo from istockphoto.com).



► **Fish sampling.** Seine nets are employed for sampling fish in rivers and streams (photo by ADB).

**Fish population survey.** The survey of fish populations inhabiting large rivers can be challenging and difficult, while survey of smaller, wadeable rivers and streams can be readily accomplished. Barbour et al. (1999) provide excellent guidelines and protocols for the sampling of fish populations by electrofishing methodologies, which they characterize as the single most comprehensive and effective method available. Protocols address not only the sampling approach and techniques, but also safety considerations for personnel. Unfortunately, commercial backpack electrofishing units are often not readily available in Asia and their cost can be quite high. Nonetheless, their use may be justified in areas where the potential impact of transportation projects is high, and/or repeated sampling or monitoring is deemed necessary.

An alternative cost-effective approach to electrofishing is to employ fish seine hauling techniques consistent with standard fish sampling protocols for streams, described by Backiel and Welcomme (1980). Seine nets of varying lengths (e.g., 3–15 m) are employed to sample stream reaches. Fish are driven into a stationary “blocking” net by seine hauling and then placed into buckets for identification, aging, counting, and measuring. Seining is done along several reaches of a stream or river using either fixed-distance sampling or proportional-distance sampling based on the ratio of stream width to length (e.g., sampling length =  $40 \times$  width). Sampling results are presented as fish captures by species per unit effort.

**Reptile and amphibian survey.** One of the more challenging taxa in which to accomplish reliable and consistent BBA survey is herpetofauna, or reptiles and amphibians. The latter are particularly sensitive to environmental change and thus are excellent indicators. Regardless of the method used, herpetofauna survey is labor intensive even under a rapid assessment context. Even extensive surveys employing multiple methods have the potential to underestimate species richness (Hutchens and DePerno 2009). While many different approaches have been employed to survey reptiles and amphibians, there are two general methods appropriate for road project BBA: (i) use of pitfall trapping, and/or (ii) visual encounter observation. Pitfall trapping, whether done in grids or arrays, requires the transport and installation of pitfalls (e.g., buckets) and, in most applications, aluminum or fiberglass screen mesh to serve as funnel fencing to enhance animal capture rates. Thus, this method may be most appropriate for surveys within limited areas and for conducting long-term population monitoring and/or surveying of difficult-to-observe species such as those residing in leaf litter (Sung et al. 2011).

Visual encounter observation survey can be accomplished with either intensive searching of fixed-area plots (e.g., 20 m × 20 m) or along transects. Transect surveys are constrained by either distance or time for standardization and consistency. Sung et al. (2011) reported that fixed-distance transects proved to be the most effective at sampling reptile and amphibian species richness in Asia, compared to pitfall trapping, which was more effective at capturing large numbers of animals. Sung et al. (2011) recommend the use of transect surveys for rapid biodiversity assessment of herpetofauna. Survey is best accomplished typically during the summer, especially if only done once during the year when reptiles and amphibians are most active. Survey in areas subject to monsoon activity should be accomplished soon after heavy rains abate.

**Vegetation or forest inventory.** A critical element of the BBA is thoroughly measuring and quantifying the vegetative component of the proposed project area, including tree overstories and understory herbaceous vegetation. To measure forest overstory species composition, two broad methods can be employed: (i) fixed plot sampling, or (ii) variable plot or “plotless” sampling. Fixed-plot sampling entails identifying, counting, and measuring the diameter at breast height (dbh) of all trees within a fixed-area plot (e.g., 0.5 ha). From this information, species composition, stem density, and basal area can then be computed. Such counts can be time consuming and difficult to accomplish on steep, rugged terrain.

The variable plot (or plotless) overstory tree sampling approach employs the use of wedge prisms to estimate tree density and basal area contributed by the different species present in the forest canopy (Avery 1975, Zobrist et al. 2012). Such an approach is considered plotless as the sampling of trees is dependent on tree distribution and size. Larger trees are “tallied” further away from the sampling point than smaller trees. The number of trees tallied using the wedge prism for each site is multiplied by the prism’s basal area factor to yield the number of trees per hectare and basal area per hectare contributed by each species. This method is more expedient than the plot method, especially on steep, rugged terrain since individual trees do not need to be measured. This allows more sites to be sampled, thus capturing more natural variability in the forest overstory. The drawback of this method is that, it does not yield the number of total stems by tree species present at a site like the fixed-area plot method, though estimates can be calculated (Zobrist et al. 2012).



➤ **Forest tree sampling.** A scientist measures tree density in a forest tract using a wedge prism (photo by ADB).



The understory vegetative component typically is measured by fixed-area plot sampling (e.g., 10 m × 10 m plots), where the number of plant stems are counted. Plants can be categorized by size or maturity classes. Orchids are of particular interest as they are considered indicator species due to their environmental sensitivity to forest canopy integrity, air quality, and other factors. Orchids may be classified by their growth habit: (i) epiphyte (on trees), (ii) terrestrial, or (iii) lithophyte (on rocks or rocky substrate).

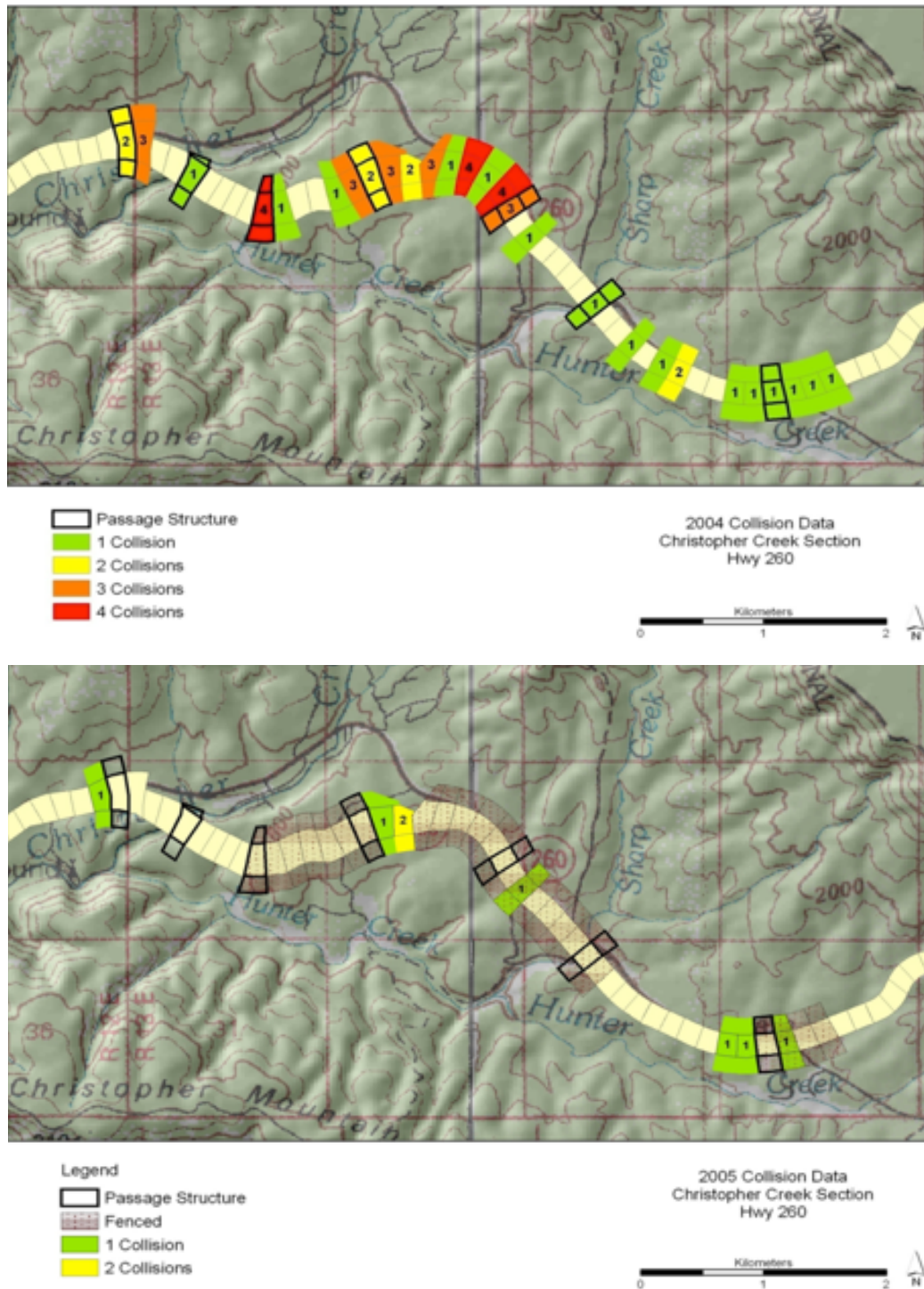
Snags (dead standing trees) are an important component of forests as many species of birds and bats rely on them for nesting and feeding. Snag density can be estimated at sample sites using circular plots (e.g., 50 m radius) centered upon the point where overstory tree prism sampling is conducted. Snags may be assigned to size classes as a measure of relative quality: (i) small (e.g., less than 20 centimeters [cm] in diameter), (ii) medium (e.g., 21–50 cm), and (iii) large (e.g., more than 50 cm). Snag densities can be converted to the number per hectare by size class.

**Roadkill or WVC tracking.** Where a proposed project involves upgrading or reconstructing an existing road, and where WVC are already occurring, the consistent tracking of WVC and roadkill can provide valuable information for developing conservation strategies. Though many factors contribute to where WVC occur, there is a strong association between where wildlife species cross (or attempt to cross) roadways and where they are killed in WVC, especially at the 1-kilometer scale ( $r = 0.837$ ; Dodd et al. 2006). Thus, WVC and roadkill information, when available, is a good surrogate for costly wildlife movement data obtained from track count and other movements studies (e.g., GPS telemetry). Peaks in WVC and roadkill data, especially involving special-status species, can be used to identify where wildlife passage structures and/or wildlife funnel fencing are warranted to promote highway permeability and safety with reduced WVC incidence (Figure A7).

Consistent tracking of WVC and/or roadkill requires a commitment to accurately document and record locations, species involved, and other pertinent information (i.e., date, time). The creation of shared databases, concise WVC tracking forms, and the growing use of cellphone applications to record WVC and roadkill help facilitate consistent documentation. Monitoring WVC and roadkill incidence after road project construction is vital to evaluating the effectiveness of conservation measures and green infrastructure, and the potential need for modification such as erection of additional fence (Figure A7).



**Figure A7: Wildlife Passage Structure with Fencing Result in Reduced Elk—Vehicle Collisions**



WVC = wildlife-vehicle collision.

Note: (Top) Based on the monitoring of elk crossing along an 11-kilometer stretch of highway at State Route 260, Arizona, in wildlife passage structures without fencing, 51 WVC occurred in a single year. (Bottom) After 5.5 kilometers of wildlife fencing were erected, this resulted in eight WVC cases or 84% reduction.

Source: Dodd et al. 2007a. Role of Fencing in Promoting Wildlife Underpass Use and Highway Permeability. In 2007 *Proceedings of the International Conference on Ecology and Transportation*. Raleigh, North Carolina, US: Center for Transportation and the Environment, North Carolina State University.

## 6. Expert Assistance for Surveys

While field personnel experienced with all surveyed taxa are desirable, the identification of species within some taxa is inherently more challenging and necessitates the support and involvement of experts. While field guides (with photographic documentation) can substantially aid in the identification of species encountered during BBA surveys and sampling, especially for mammalian camera trapping, and fish, reptile, and amphibian survey—making expert support less critical—expert knowledge is critical to the accurate accomplishment of other types of survey. In particular, due to the tremendous number of plant species found across Asia’s biodiversity-rich areas (and difficulty in identifying many tree species due to inaccessible, high canopies), experts with experience in forestry and/or botany are highly recommended for field surveys to make accurate species identification. Likewise, due to the large diversity and number of bird species found in Asia, experienced birders and/or ornithologists are essential to accomplishing accurate avian surveys, especially when relying on bird calls.

## 7. Biodiversity Metrics

To facilitate the meaningful comparison of survey data among assessment zones and/or proposed road alignments, biodiversity baseline assessment should allow the collection of sufficient quality data to calculate biodiversity metric mean values with associated acceptable levels of variance to support appropriate statistical analyses, where reasonably possible. Metrics associated with BBA survey/sampling sites include the following:

- Number of plant or animal species per unit effort (*species richness*)
- Number of total animals or plants recorded per unit effort (*relative abundance*)
- Proportion of all plants or animals recorded per unit effort (*composition*)

In addition to the above sampling metrics, the occurrence (occupancy) of the different species within each taxa across sampling/survey sites provides insight into how widespread or restricted each species’ distribution is across the project area. This information is valuable not only in assessing potential project impacts but also in developing conservation strategies to minimize road impact, including how many, what size, and what spacing of wildlife passage structures are needed to promote permeability and connectivity. Occupancy information can be displayed both quantitatively (e.g., percent of sites where each species was recorded) and graphically.

One of the most frequently reported and used biodiversity metrics is the Shannon-Weaver diversity index (SDI), a widely accepted measure of species biodiversity (Shannon and Weaver 1949, Jost 2006). The SDI reflects biodiversity as a function of: (i) the number of different species in a community (*species richness*), and (ii) the proportion of individuals of

each species compared to the number of individuals of other species in the community, or a relative reflection of how rare or common each species is (*species evenness*). The SDI can be computed for each surveyed taxa at each sampling and/or survey site, and averaged across assessment zones or road alignment corridors for comparison.

In addition to the SDI, there are many other diversity metrics that can be considered for use, including the proportion of *species overlap* and *species composition similarity* between or among assessment zones or road alignments.<sup>5</sup>

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<sup>5</sup> For discussions of appropriate biodiversity metrics and their application, see Jost (2006).

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## **Green Infrastructure Design for Transport Projects**

### *A Road Map to Protecting Asia's Wildlife Biodiversity*

Asia harbors immense biodiversity that is increasingly threatened by expanding transport networks across the region. While considered essential for economic development and human activity, roads and railways are widely regarded as a primary driver for the rapid loss of natural ecosystems and living species. This report discusses the impacts of transport projects on wildlife and biodiversity, and how these impacts can be addressed by proactively integrating road ecology principles and green infrastructure into projects to balance construction with the conservation of Asia's biodiversity. It details the variety of green infrastructure and other conservation measures available—from environmentally sensitive road design to animal passage structures and management guidelines—to reduce transport project impacts on wildlife.

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