Rethinking Roadways

A New Standard of Ecological Excellence in Road Network Planning

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THE CENTER FOR LARGE LANDSCAPE CONSERVATION

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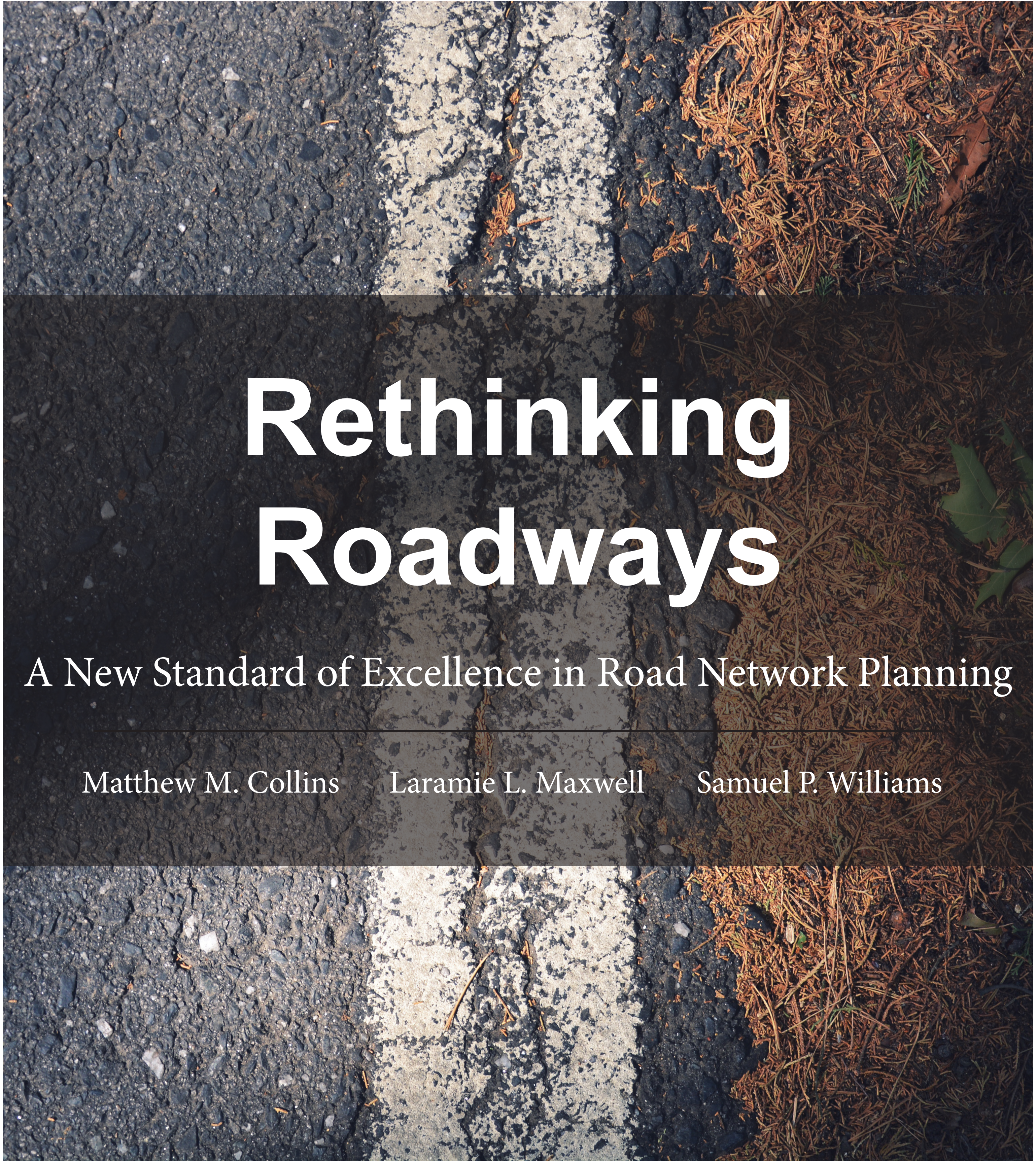

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A New Standard of Excellence in Road Network Planning

Matthew M. Collins Laramie L. Maxwell Samuel P. Williams

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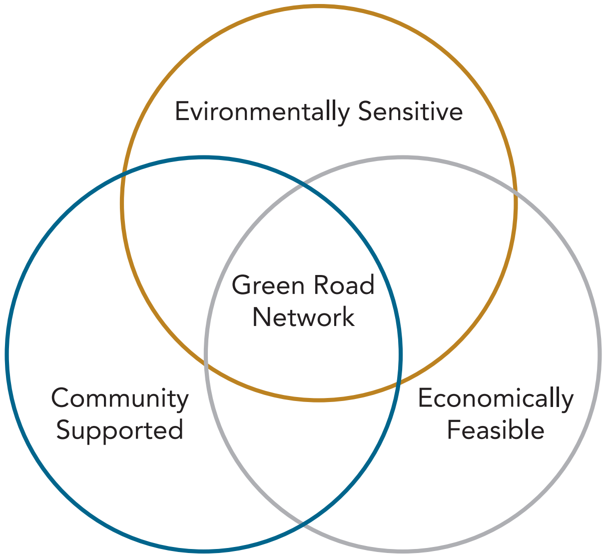
Executive Summary

This report provides a synthesis of the impacts of road networks on social and ecological systems. As the world faces the potential development of approximately 25 million kilometers of new roads by 2050, primarily in developing countries and biodiversity hot spots, smarter, green transportation systems are a development priority. We summarize the ecological and social consequences of transportation development and offer proven methods to mitigate negative impacts on ecological and human systems. The report is divided into three sections: Minimizing Ecological Footprint, Deploying Green Infrastructure, and Promoting Context Sensitivity within affected communities – social, cultural, and economic. New sensitivities in transport planning and practices address consideration for ecology, communities, and climate change. This report introduces the IUCN's Transport Working Group (TWG), which seeks to provide expertise in building and retrofitting a new generation of green road networks. The TWG mobilizes experts in road ecology and transportation from around the world to develop guidance in mitigating the impacts of transport on natural systems and ecological connectivity.

I. Overview

Roads provide for the efficient movement of goods, services, people, and information over land. Extending across communities, countries, and continents, they are the backbone of modern societies. Roads are, in their most basic capacity, connectors: allowing for the interchange among dispersed human populations, cultures, and resources, they are intended to improve the human experience. Roadways are often heralded as harbingers of development, and, by extension, an improved quality of life.

Numerous studies demonstrate the positive role of roads in community development.[1,2,3,4] These studies are supported in practice by the continued investment in transportation infrastructure by global financial institutions, such as the World Bank and the International Monetary Fund. Unfortunately, roadways also produce impacts that contradict their essential purpose. Roadways fracture ecological systems, produce externalities that endanger and impact communities, and contribute to the burgeoning threat of global climate change. As governments expand and improve transportation infrastructure in hopes of alleviating poverty and improving



quality of life, they often unintentionally trigger opposite outcomes, creating deleterious impacts upon natural and human communities.

In light of today's roadway proliferation, the global community is faced with how best to account for road impacts. One recent estimate predicts the construction of at least 25 million kilometers (over 15 million miles) of new roads by 2050: a 60% increase in total road surface miles from 2010.[5] Even more pressing, from an ecological standpoint, is nine-tenths of construction is predicted to occur in developing nations, home to immense stores of biological diversity. For example, there is significant road construction occurring in the tropical rainforests of the Amazon, Congo, and Southeast Asia.[6] Indeed, the developmental benefits of roads, including global economic integration, often drive new transportation infrastructure in remote, biologically important regions. [7]

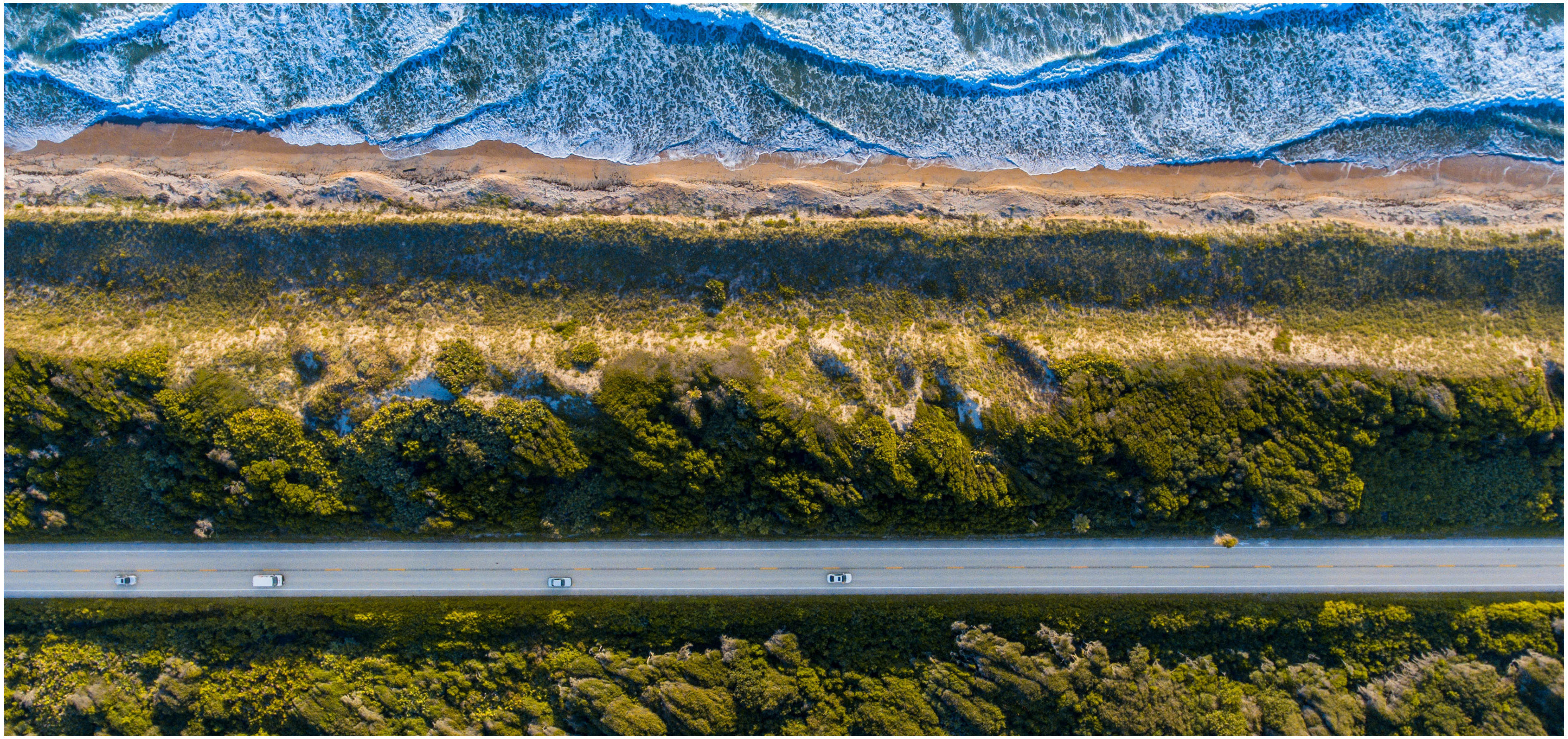
This paper provides guidance with the hope that transportation infrastructure produces the best possible outcomes for its beneficiaries, while imposing the least destructive consequences. First, it outlines the primary ways in which transport systems negatively impact our ecological, social, and economic health. Second, it provides an overview of strategies aimed at: (1) minimizing the ecological footprint of roads, (2) deploying green infrastructure, and (3) promoting socially, culturally, and economically context-sensitive solutions within effected communities. Third, within each section, the paper offers recommendations and opportunities to avoid or minimize the negative impacts of transportation infrastructure, provides examples of existing best management practices to mitigate such impacts, and discusses research horizons.

Absent efforts to minimize the detrimental effects of roads, infrastructure projects will continue to have considerable negative ecological and societal impacts.[8] However, by considering and implementing recommended measures to mitigate those effects where appropriate, decision-makers will not only help ensure proper accounting of infrastructure project impacts but will also encourage sustainable projects that are beneficial to society as a whole.

While roadway development has been a comparative laggard in the sustainable design community, it does not have to remain so. Instead, sustainable roads designed to minimize negative environmental impacts and invigorate communities are an achievable reality today.

II. Minimizing Ecological Footprint

Roadways have quantifiable impacts on ecological systems. Formally defined, road ecology "explores and addresses the relationship between the natural environment and road systems."[9] Because roads provide movement for goods and services across vast distances, road systems alter surrounding



ecosystems at a landscape scale. From the heartland of America to the depths of the Amazon rainforest, roads bisect most of the planet's unique landscapes. The below sections describe the negative impacts of roads on species and ecosystems and present opportunities to mitigate these impacts.

A. Detrimental Effects of Roads

Habitat Conversion

Habitat conversion is the loss of a natural habitat's integrity as a result of human activity.[10] Roads pave over natural habitat and permanently alter vast swaths of surrounding ecosystems. Roads enable human access to settle, extract natural resources, and otherwise develop land, all of which result in habitat conversion. For example, a narrow, primitive road built through the Amazon rainforest in 1971 is now a scar of converted habitat approximately 400 km wide.[11] The effect of roadway sprawl is important, considering a direct reduction in habitat is posited as a major contributor to species extinction.[12] In the next 30 years, an estimated 20% of remaining natural lands will be converted via various forms of development, while the global roadway network will expand by nearly 60%.[13] As ecologically important and relatively pristine regions of the world are subjected to development, it is important to protect what habitat remains to ensure continued healthy ecosystem function and climate resiliency.

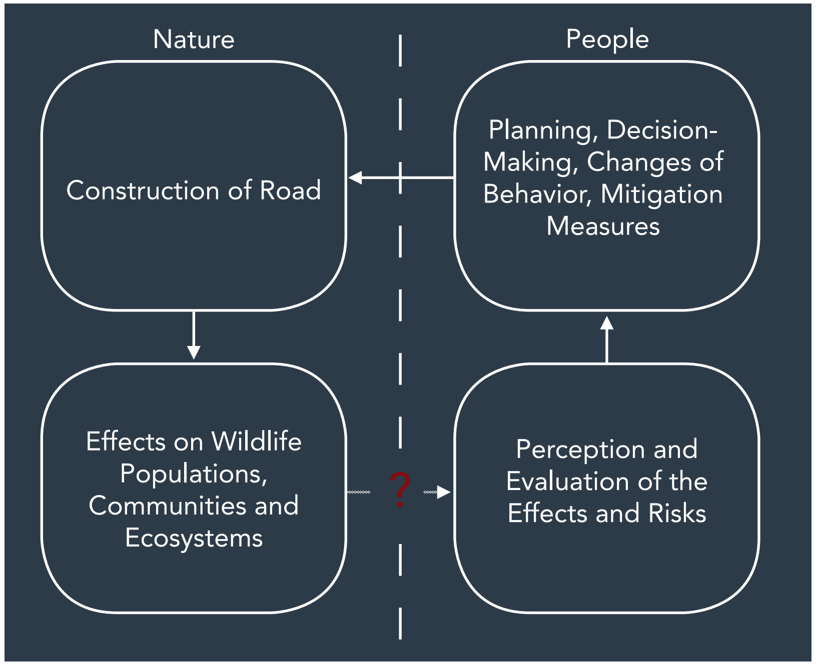


Figure (1): In most cases, initial evaluations of effects and risks of roadway development omit the impacts of wildlife and ecosystems. This "knowledge gap" inhibits mitigation measures, and ecolocially informed planning. Road ecology attempts to bridge the gap by examining roads cumulative effects on surrounding eosystems.

Habitat Fragmentation

Road development is one of the leading causes of habitat fragmentation. Fragmentation, or discontinuities within and among a species' habitat blocks, creates lasting impacts on both species and ecosystem resiliency. Of all human-generated ecological ills, habitat fragmentation is considered by many to have the greatest negative impact on natural systems.[14, 15] Roads play a major role here by preventing animals from moving to find: food, water, mates, and other necessities. Fragmentation also leads to decreases in genetic diversity, which increases the likihood of localized species extirpation.[16] Conversely, maintaining ecosystem-scale habitat connectivity helps mitigate species extinctions, especially in the face of climate change and other major stressors.[17]

Susceptibility to Climate Change

With impending changes in global precipitation patterns and temperature, animals will be forced to leave their natal ranges and follow shifting resource availabilities. Paleo-ecological records from the last glacial-interglacial transition demonstrate that shifts in range and dispersal are a species' primary adaptive response to dramatic climate shifts.[18] Without mitigation efforts, habitat loss, fragmentation, and other barriers caused by habitat conversion and road development will decrease the ability of natural communities to adapt to a changing climate.[19] A species' ability to adapt is a necessary tool for survival. Thus, roadways must mitigate negative environmental impacts to ensure the resiliency of species.

Edge Effects

Roads create distinctive edges across a landscape. An "edge effect" is created where the road's surface ends and the surrounding habitat begins, altering light and nutrient availability extending up to 15 meters (~50 feet) from the roadway.[20] This leads to a host of detrimental effects, including microclimate shifts, new points of entry for alien species, and associative species decline. Roads create between 55-98% more edge effect than clear-cut logging.[21,22] In the eastern United States, a region with high road density, edge effects have led to an observable decline among forest bird species.[23] The environmental effects of roadways, including stream and species dispersal alterations and sedimentation, extend up to 800m from road sides.[24] This "road effect zone" is estimated to cover a startling 73% of the continental United States.[25]

Mortality

Vehicle traffic causes significant animal mortality. In the United States, four million miles of public roads have a greater effect on vertebrate mortality than the effect of 14 million hunters.[26,27] A review of 79 empirical studies from a variety of eco-types determined that roads cause a net negative decrease in species richness and animal abundance particularly among large ungulates.[28] Mortality estimates from the Netherlands predicted 159,000 mammal and 653,000 bird deaths on an annual basis, and collisions within the United States cause upwards of one to two million large animal mortalities a year.[29] In ecosystems that are home to small breeding populations of endangered species, wildlife-vehicle collisions are often the leading cause of death. In the Sierra Mountains of western Nevada, for example, collisions cause more than 10 black bear deaths per year of a population of only 300 bears, leading mortality rates to surpass birth rates.[30] Targeted investment in mitigation efforts, such as wildlife overpasses and underpasses, lowered speed limits, and avoidance of ecologically sensitive areas, alleviate roadways' impacts on wildlife, thereby lowering the costs of wildlife-vehicle collisions.

B. Minimizing Ecological Footprint: Opportunities

As the "sleeping giant of conservation ecology,"[31] roads present an opportunity to invest in smarter, greener design. Working in collaboration with policy makers and transportation authorities, conservationists have an opportunity to enhance ecosystem function, limit costly wildlife-vehicle collisions, and foster climate resiliency among species by investing in ecologically sensitive road networks.

Road Network Theory

Roads interact with ecological communities on a variety of scales from continental to local landscapes. Ecological road network theory provides a framework to understand the effects of road networks on the environments within which they are built, in hopes of informing ecologically sensitive development projects.[32] Road networks truncate animal movement patterns across a landscape, fragment core habitat, and erode biodiversity.[33]

Traditional road grids inhibit natural ecosystem function.[34,35] Predators, including often-endangered mountain lions, bear, jaguars, and wolves as well as moose and other large ungulates, require road densities of

0.6 kilometer per square kilometer or less to maintain healthy, sustained populations.[36] That is to say, if road density is too great within a population's habitat block, it is unlikely that the population will thrive.

Road network plans that preserve large vegetative patches help ensure the space necessary for species that are highly susceptible to the disruptive effects of roads. These species, known as differentially road-sensitive species, have a very difficult time maintaining natural behavior when road densities exceed the 0.6 kilometers per square kilometer threshold. To decrease core habitat loss and fragmentation and ensure wildlife population viability in the face of growing transportation infrastructure, it is advantageous to bundle roads in close proximity to one another. Bundling enables planners to avoid paving over key un-fragmented habitat patches integral to ecosystem function.[37] Furthermore, road closures and elimination of underutilized stretches of road promote the reestablishment of large patches of habitat.

Collision Mitigation

Wildlife collisions cause net losses for both humans and ecosystems. In a single year in the United States (2007), traffic accidents involving large mammals caused death or injury to over 26,000 individuals at a cost to Americans of more than $8.3 billion.[38] Wildlife crossing structures, such as overpasses and underpasses, and associated fencing that funnels wildlife to these safe crossings, have reduced collisions by 86-99% among mammals.[39] Cost-benefit analyses of crossing structure construction determined that installing a crossing structure with fencing on a roadway segment with as low as 3.2 large mammal-vehicle collisions per km annually would bring economic benefits that exceed the structure's construction and maintenance costs.[40] In addition to

saving human lives and reducing injuries, crossing structures provide a host of ecological benefits including improved landscape connectivity and decreased wildlife mortality.

Improved Ecological Connectivity

Because roads are highly prohibitive barriers to many species' movement, they have a negative impact on a population's ability to adapt to shifting resource availability, especially in the face of climate change. An analysis of 25 years of peer-reviewed articles on habitat connectivity reveals that the most frequently cited recommendation for protecting biodiversity in the face of climate change is improved connectivity among wildlife habitats on a landscape scale.[41] Investment in wildlife crossing structures on highways increases connectivity, enables wildlife populations to extend their range and maintain high levels of genetic diversity among populations, and decreases wildlife-vehicle collisions.

Wildlife Crossing Structures

While planning new road development and reconstruction of old road systems, it is imperative to mitigate harmful effects to wildlife. Best practices for future road development include taking a systems-level approach that enables regional and local wildlife movement and ensures that ecological flows remain intact. Transportation projects that seek to maintain and/or restore ecological connectivity should assure collaboration among transportation and natural resource agencies.

Collaboration ensures that mitigation measures are included and appropriated, including selecting precise locations for crossing structures and other measures that promote system permeability. Plans should:

- Identify key areas of connectivity for species with the greatest conservation need.
- Identify corridors among core habitat that should remain protected from human development.
- Gather site- and species-specific data on wildlife movement including identifying barriers to movement.
- Identify high priority areas for future investment in mitigation measures such as crossing structures, fencing, road signage, and speed reductions.
- Conduct cost-benefit analyses of high priority areas to identify mitigation locations that minimize costs to society and maximize benefits to wildlife.

Once a high priority area has been identified, the type of crossing structure should be chosen. Animals of varying size and temperament prefer different styles of crossing structures. For instance, cougars and black bears tend to prefer smaller, confined underpasses, whereas wolves, grizzly bears, elk and deer typically prefer wider, open overpasses.[42] In many situations, a network of crossing structures will be necessary to maximize multi-species crossing potential in connectivity "hot-spots." Once crossing structures are in place, they should be monitored with camera traps, track beds (sand pits that capture animal tracks) and other track detecting media such as marble dust, to measure effectiveness of the mitigation efforts and provide data for future projects. Additionally, it is imperative that areas important for connectivity adjacent to crossing structures be protected from human development via conservation easements, wildlife management plans or similar measures to ensure the continued efficacy of the investment.

Because of the multidisciplinary expertise required, the above actions require collaboration among transportation authorities, ecologists and policy makers to make crossing structures and other mitigation efforts standard practice. Transportation professionals are ready to take this step. In a survey of 589 U.S. Department of Transportation (DOT) professionals, 84% of individuals queried expressed interest in building crossing structures to improve motorist safety and increase habitat connectivity.[43]

Crossing structures have been constructed across Europe, Asia, and North America with resounding success. European crossing structures with associated wildlife fencing have reported reductions in wildlife-vehicle collisions by up to 90%.[44] Along Spain's A 52 highway, 1.37 terrestrial vertebrates utilize the crossing structure on a daily basis.[45] Similarly, hair samples collected from crossing structures on the Trans-Canada Highway in Banff National Park, Alberta revealed that there were over 10,000 crossings of male and female bears between 2005 and 2009,[46] indicating the vital importance of such structures for wildlife movement.

III. Deploying Green Infrastructure

Continued population growth and infrastructure development are driving sustained increases in anthropogenic greenhouse gas (GHG) emissions. Climatic effects from the release of atmospheric carbon dioxide (CO_2) impact human and natural systems on a global scale,[48] and climate change poses the most significant long-term threat to transportation infrastructure worldwide.[49]

In December 2015, 187 countries agreed to terms of the United Nations 21st Conference of the Parties Accord (COP21), setting in motion a framework to fund climate change mitigation efforts and incentivize adaptation to the impending environmental and socio-economic effects. Countries agreed to:

- Limit average global warming to 2° Centigrade.
- Increase sectoral energy efficiency measures (transport, development, industry, etc.).
- Increase carbon stores through reforestation efforts.
- Invest in climate-resilient infrastructure.
- Invest $100 billion annually in investments to mitigate carbon emissions within developing nations.

In accordance with the agreement, governments and international agencies have a vested interest in funding

Case Study: Flathead Wildlife Crossings

U.S. Highway 93 snakes through the scenic Mission Valley and Flathead Indian Reservation of Northwest Montana, home to the Confederated Salish and Kootenai Tribes (CSKT). In the 1990s, the Montana Department of Transportation (MDT) proposed widening the highway, raising tribal concerns of the roadway's effect on wildlife. Big game species, including elk and deer, provide important subsistence for many CSKT families, while grizzly bear and grey wolves hold significant cultural value for many tribal members. After a decade-long impasse, the Federal Highways Administration (FHWA), MDT, and CSKT collaborated to develop a road plan sensitive to area wildlife and the Mission Valley's "Spirit of Place."

As one of the largest wildlife-sensitive highway design projects in North America, reconstructed US Highway 93 includes 41 fish and wildlife crossing structures, two livestock underpasses, and 16.6 miles of wildlife fencing along a 56-mile stretch. Wildlife mitigation along U.S. Highway 93 has led to a greater than 80% decline in collisions with large mammals when wildlife fencing installed with the mitigation measures exceeded 5 km in length. When fewer than 5km of wildlife fencing led to crossing structures, on average large mammal collisions were reduced by 50%.[47]

projects that consider vulnerability of wildlife and people to climate change and incorporate fewer GHG-intensive materials. For example, in the wake of Hurricane Sandy, the United States has awarded almost $3.6 billion in competitive grants to increase the resiliency of future infrastructure to rising sea levels.[50] Future transportation infrastructure projects are no exception and have the opportunity to leverage funding in a post-COP21 world where climate change resiliency planning and decreased carbon footprints are a shared global goal.

Transportation authorities are developing and implementing reproducible green carbon management practices, processes, and products that can aid in deployment of green infrastructure.

A. Practices

Roadside Carbon Sequestration

Best management practices that foster roadside vegetation growth have the potential to capture and store millions of tons of CO_2. Over time, with more active management by transportation authorities, roadside verge vegetation growth can offset CO_2 released during roadway development, maintenance, and use. Currently, roadside vegetation and soils naturally absorb CO_2 into carbon-based organic material, offsetting the emissions of 7.6 million cars along U.S. federal roadways.[51] A study conducted for the Federal Lands Highways Office of the U.S. Federal Highway Administration (FHWA) found that currently, roadside vegetation and soils along eight federal land management agencies' roads (i.e., National Park Service, U.S. Forest Service) which comprise 4% of the total length of all U.S. public roads, is estimated to store nearly eight million metric tons of carbon per year. This statistic represents passive storage; in other words, no management action is taken to increase roadside carbon sequestration.[52] To increase carbon capture and storage, the authors suggest roadways should be managed to:

- Minimize disturbance to existing soil and plant communities.
- Increase physiognomic (plant growth form, structure, and cover) complexity when relevant (e.g., planting woody shrub species in roadside grasslands has the potential to increase carbon capture and storage).
- Employ living shrub- or tree-based snow fences, where appropriate.
- Modify road maintenance to minimize the harmful effects of dust and salt on roadside vegetation.
- Maintain managed zone vegetation (mowed areas) at taller grass heights than occur under current management.

- Reduce emissions from roadside vegetation management by reducing mowing practices and associated fuel consumption, and modifying pesticide spraying where feasible.

Climate Resilience Planning

Globally, the effects of climate change will cost an estimated $4 trillion by 2030; infrastructure damage is the single largest associated cost.[53] Floods resulting from Hurricane Sandy caused $7.5 billion of infrastructure damage within New York City alone.[54] Organizations that do not acknowledge climate risk and fail to take necessary action will assume the brunt of future costs. Future projects should take a systematic, proactive approach to assessing a proposed project's vulnerabilities to climate change.

The precise impacts of climate change on transportation infrastructure and systems are a considerable uncertainty. Resiliency may be defined as "reducing vulnerability or enhancing adaptive capacity."[55] Planners should incorporate climate change vulnerability data, including potential future floodplains, relative rates of sea level increase, risk of forest fires, etc., into comprehensive risk assessments. Without this data, infrastructure developments may put motorists at risk and/or result in significant maintenance costs, creating uncertainties regarding the efficacy of roadway investment.

Life Cycle Analyses: Roadway Carbon Budget

Life Cycle Analyses (LCA) are a powerful tool for policy makers and transportation authorities to identify focal points for CO_2 reduction within a roadway's "cradle to grave" lifecycle. The construction and maintenance of roads along with the motorized travel they enable make them a significant contributor to the world's growing atmospheric carbon budget. Vehicle emissions aside, 1 kilometer of a two-lane roadway has a lifetime (50 years) of embodied CO_2, a key greenhouse gas, of 18.94 metric tons.[56] For bridges and tunnels, this number is 25 metric tons of CO_2. Road paving causes 80% of this CO_2 release. 33% is released during construction, 45% from maintenance, and 2% from deconstruction.[57] Traditional hot-mix asphalts (HMA) are energy intensive and a significant contributor to the overall carbon emissions of roadways. CO_2-intensive HMA causes the majority of life-cycle emissions on lightly traveled roadways. Alternatively, the greatest opportunities for GHG reduction on high-traffic roadways occur when roadways are smooth and well maintained.[58] As a result, alternatives to HMA must be comparable in durability. Forward thinking transportation authorities have incorporated recycled pavement (RAP) and warm mix asphalt (WMA) into projects to decrease the CO_2 footprint of roadway construction of a roadway without sacrificing durability.

B. Applications: Processes and Products

Warm Mix Asphalt (WMA)

Warm mix asphalt (WMA) is an general term for a variety of technologies allowing manufacturers of HMA to lower product mixing and road application temperatures by between 20-30° Celcius.[59] With a 20-35% reduction in energy consumption during manufacturing, WMA is a valuable, readily accessible technology to lower the energy consumption of road construction.[60] Furthermore, WMA provides multiple environmental benefits, including reducing embodied CO_2 by 30-40%, cutting harmful sulphur dioxide (SO_2), carbonic acid (CO) and nitrous oxide (N_2O) emissions by 24%, and decreasing smog formation by 10%.[61] The U.S. FHWA envisions a full transition from HMA to WMA in the near future, pending additional research and testing.[62] Transitioning to WMA requires simple plant modifications, which are reproducible in developing countries. HMA is marginally more durable, with a performance score of 52 as compared to 48 for WMA; further research and material manipulation have the potential to narrow this gap.[63]

Reclaimed Asphalt Pavement

Reclaimed ashphalt pavement (RAP) provides a cost effective strategy for transit authorities to reduce both material waste and embodied CO_2 associated with road construction and maintenance.[64] Recycled material paired with WMA technology further increases its efficacy. WMA can incorporate up to 50% RAP, decreasing overhead costs and waste for repaving and maintenance. In a survey of contractors within the United States, 100% utilized RAP in 2013, incorporating 67.8 million tons into asphalt mixtures.[65]

Low-Carbon Cement

Cement production accounts for 10% of anthropogenic CO_2 emissions.[66] Like asphalt, cement is heated to high temperatures in kilns to form limestone/alumino-silicate nodules, or clinkers, which make up the majority of cement mixtures. There is growing pressure to reduce the clinker content of cement, which, in turn, would reduce the CO_2 associated with its production. The Canadian Standards Association has introduced Portland limestone-cement (PLC) into road construction projects, reducing clinker content by 41% and cutting embodied CO_2 by 10%.[67] Furthermore, less intensively tested limestone calcinated clay cements have the potential to decrease production related CO_2 by 40%.[68]

Permeable Pavements

Permeable pavements have small voids in their composition, which allow water to flow through to a stone base. Pour-in-place permeable concretes and asphalts, and interlocking concrete pavers provide a host of ecological benefits. Their porous quality allows storm water to pass through into soils, reducing peak flow, runoff, and erosion, while increasing groundwater recharge, and pollutant removal.[69] Additionally, as global temperatures rise, permeable pavement's high albedo and porous qualities will help combat the urban heat island effect.[70] With heightened compaction rates and lower durability, permeable pavements are best utilized in low-traffic areas such as parking areas, sidewalks, and roadways with low speed limits.

Photovoltaic Roads

Under the COP21 accord, 187 countries set individual five-year renewable energy quotas to incentivize transition to greener energy grids. Recent technologic advancements have increased the efficiency and cost-effectiveness of solar panels, a technology that could help drive this transition. However, solar arrays require ample space to create adequate wattage. Roadways and their adjacent rights-of-way present significant opportunities for solar energy production. France, along with the National Institute of Solar Energy have developed solar technology to take advantage of this opportunity. Over the next five years, France aims to cover 1000 kilometers of existing roadways with durable polycrystalline silicon photovoltaic cells, with the goal of supplying renewable energy to five million people (8% of its population).[71] Transportation authorities should acknowledge their role as land managers, and convert under-utilized rights-of-way into venues for energy production and/or carbon capture and sequestration.

IV. Promoting Context Sensitivity within Effected Communities; Social, Cultural, and Economic

While the connective capacities of roadways bolster economies, [72,73,74,75] transportation plans often underestimate the exclusionary effect of road development on society.[80] In many developing nations, roads connect rural communities to political, economic, and cultural opportunities found in cities.[81] Although transportation development provides benefits such as emergency services, food security, and increased market reach,[82] transportation corridors also create avenues for exploitation, health issues, and other negative effects suffered disproportionately by under-served communities. Nine-tenths of road development is predicted to occur in third world nations over the next 30 years.[83] With that in mind, transportation planners ought to consider road development's disproportionately negative effect on low-income populations. The following sections highlight negative impacts to human communities affected by roads and provide a mitigation opportunity in the form of context-sensitive design.

Case Study: World's First Solar Roadway

An experimental bike path constructed with photovoltaic cells in the Dutch town of Krommenie has far exceeded expectations in energy production. The world's first solar roadway has a 70-meter bike lane comprised of a concrete base studded with silicon solar panels covered with a centimeter of heavily-textured glass coating.[76] The solar pathway has produced energy yields of 70 kilowatts per square meter, per year, an amount that, when tested in the lab, was on the upper end of the spectrum for possible energy production for this project.[77] Currently, the path supports 150,000 cyclists annually, while providing renewable energy for Krommenie.[78] Developed as a proof-of-concept test piece by SolaRoads, the bike path has driven interest in implementing solar roadways at a variety of scales in various locations.[79]

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A. Negative Impacts on Human Communities

Transportation Exclusion

Transportation exclusion "implies that the already disempowered segments of society are further disadvantaged by the lack of control they can exert over transport supply, so that they are deprived of basic levels of transport opportunities."[84] Poor, rural villages often lack the funds and social mobility to restructure their businesses for broader market relevance and instead find themselves laboring at the bottom of a larger system.[85] For example, the Ko Ho, an indigenous people of Vietnam, were reduced to coffee plantation laborers for the non-native Kinh, as they were unable to capitalize on the booming coffee industry, made more globally accessible by roads.[86] This is not an isolated event. Through transportation exclusion, ethnic minorities and the poor are forced to adapt to road-driven market economies that often exploit local resources for the benefit of outside interests.

Roads are Lethal

Road fatalities in the developing world will soon be the 5th leading cause of death, surpassing HIV/AIDS, malaria, and tuberculosis.[87] With increased access to motor vehicles and vehicle ownership, road deaths are posited to increase threefold from 1.24 million/year in 2014 to 3.6 million/year in 2030.[88] Ninety percent of deaths occur in the developing world, and densely populated nations such as Indonesia and Nigeria are experiencing between 120-140 fatalities a day, prompting yearly economic losses between 1-3% of gross domestic product.[89] Road fatalities continue to climb, but are failing to prompt a proportionate public policy response.[90]

From this perspective, road development can be viewed as a threat to public health. In addition to high death rates, reliance on motor transportation leads to adverse environmental and health effects. The United States' investment in road-reliant infrastructure throughout the 20th century has helped lead to an increase in smog, obesity, urban sprawl, and communal severance.[91]

Climate Change and Equity

Equity should be a priority when planning for climate resiliency spending. The Global Climate Risk Index rates countries on on the extent they have been affected by impact of weather-related loss events. The 2015 analysis determined that the top ten countries most susceptible to climate change, led by Bangladesh, Myanmar, and Honduras, were all of developing status.[92] Climate-resilient transportation planning should extend beyond the first world to enable disaster relief, food aid, and resilient infrastructure for nations with the highest risk.

B. Opportunites

Context-Sensitive Design

A more nuanced approach is needed to properly plan for, and design, transportation systems to meet the challenges of the 21st Century.

The utility of new roads should be assessed in terms of their impact on the economy, the environment, and the health and social well-being of affected communities. To do so, transport authorities must recognize that moving towards an increasingly transparent, stakeholder-driven planning strategy is in society's best interest. This type of holistic planning requires transportation planners to consider proposed developments within the context of the project's greater environmental and social landscape.

Planning should incorporate diverse perspectives through public outreach and multi-stakeholder focus groups. An engaged and educated citizenry improves public buy-in, ultimately enabling planning outcomes that incorporate the needs and perspectives of diverse stakeholders. Context-sensitive solutions (CSS) consider the interactions among road development and the social well-being, public health, and natural environment of the affected region and should be incorporated in final transportation plans.

The combination of increased public support of speed limits, seat belts and helmet use, with the development of sidewalks, roadway barriers, traffic calming designs, and signage, has the potential to significantly decrease road-based fatalities within developing nations.[94] Underserved populations in developed nations also benefit from such considerations. Often, environmental and social injustices are suffered by a large percentage of a nation's populous, no matter if the nation is

Case Study: Context-Sensitive Alternative Technologies

Currently the majority of rural roads in the developing world are dirt or earthen gravel. Without sealants that bind the contents of the road surface, they are significantly degraded by rainfall and vehicle travel, leading to unreliable access and isolation. Some communities are combatting this issue by repurposing agricultural waste products to seal road surfaces. For example, in Tanzania, residents use molasses from sugar production to mitigate dry-season road dust, while clay bricks fired from waste rice-husks provide durable, low-maintenance roads surfaces in Vietnam.

Beyond these localized examples, there is apparent potential for the application of local agricultural waste products as organic substitutes for road binders, cement, or bitumen on a larger scale. A study by the Global Knowledge Transport Partnership explores the potential for wood and palm lignin as binder substitutes, biomaterial asphalt blends for efficient roadway waterproofing, and silica-rich rice husk ash as an ingredient within Portland limestone cement.[93] This suite of materials can oftentimes be sourced locally through agricultural and manufacturing operations. By increasing demand for new agricultural crops, local economies are stimulated and the carbon footprint of road-building is reduced.

developed or developing. Outreach and engagement of marginalized populations should become common practice to alleviate the effects of exclusion and transportation inequalities. Through context-sensitive solutions planners have the opportunity to create a more resilient, ecologically-sensitive and socially-beneficial future for infrastructure development.

VI. The Future of Roads

Addressing the impacts of humanity’s largest, most pervasive infrastructure requires a comprehensive, innovative, and interdisciplinary approach to research, education, and planning. Improved methodologies and actions are needed to reconcile social and ecological values while meeting the transportation needs of society. Creating a global framework for green road design that ensures the preservation of biodiversity in a changing climate while enabling the beneficial values of transport systems is imperative. This section provides guidance on how to drive this process.

A. Global Connectivity Conservation: A Driver for Green Road Networks

The International Union for the Conservation of Nature (IUCN) has launched a new Connectivity Conservation Specialist Group (CCSG) within its World Commission on Protected Areas. The member-driven CCSG is charged with developing a new conservation area designation for the world's governments to adopt – Areas of Connectivity Conservation (ACC). ACCs are purposed to protect key natural and semi-natural landscapes that exist outside of the IUCN's traditional protected area designations, linking existing protected areas (i.e., National Parks, Marine Protected Areas, Wildlife Refuges, etc.) into connected matrices. The ACC designation offers

CONNECTIVITY CONSERVATION Specialist Group

a structure for governments to protect ecological and evolutionary processes across landscapes, fresh waterscapes, and seascapes, and promotes resiliency in the face of environmental change.

It is possible that ACCs may include an existing transportation infrastructure within their boundaries or may see future development of transportation within their boundaries. The CCSG formed the Transport Working Group to address the deleterious environmental effects of roads, rails, and the resulting traffic upon ecosystems within and beyond ACCs.

Transport Working Group

Within the CCSG, the Transport Working Group (TWG) provides direction in mitigating transportation infrastructure's impacts on ecological connectivity. The TWG is charged with retrofitting existing transportation infrastructure and designing new green transportation networks on international scales. The TWG is mobilizing road ecologists and transport professionals from around the world to develop connectivity-minded infrastructure guidance for governments and international financing corporations enabling them to adopt and incorporate these types of provisions into their transportation projects.

The TWG seeks to engage atypical partners including financial institutions, such as the World Bank Group, Inter-American Development Bank, Asian Development Bank, and others. International financial institutions have the ability to develop financing packages that require contractors to incorporate wildlife permeability, ecological connectivity, motorist and wildlife safety, and green materials utilization within transportation network design and construction.

While collaborative capacities will vary among states, provinces, and countries, the TWG seeks to establish an international standard of excellence in road network planning and design. It is hoped that the TWG's geographically diverse membership will offer context-dependent recommendations for consideration and adoption by diverse lenders and governments.

B. Recommendations for Rethinking Roads

Based on the research discussed in this report, the recommendations below are presented to help practitioners identify achievable best practices.

Collaboration

Interagency collaboration and multi-stakeholder involvement set the foundation for successful, ecologically informed road development projects. Projects should:

- Enhance social capital among transit authorities, ecologists, non-governmental organizations, and affected citizens.
- Facilitate diverse stakeholder and interagency involvement in planning to improve public trust, credibility, and overall project efficacy.

Among other examples, the FHWA's *Eco-Logical* framework contains transferable methods for mobilizing inter-agency, multi-stakeholder collaboration.

Data Collection and Application

Relevant scientific information must be utilized in plans to best inform green road network structure both to increase human safety and preserve ecosystem function. Projects should:

- Identify important connectivity areas for key species.
- Identify pathways among core habitat blocks that should remain free of human development.
- Gather site-specific species movement data, including identifying barriers to movement.
- Identify areas for future investment in crossing structures and other mitigation measures.

Conduct cost-benefit analyses of proposed and existing mitigation projects to identify locations that minimize costs of mitigation and maximize benefits to nature.

Planning

In order to capitalize on collaborative efforts and data application, plans should:

- Engage ecologists early in the transportation planning process. Ecologists help to incorporate scientific research aimed at maintaining ecosystem function and wildlife connectivity across a landscape, prioritize crossing structure locations, and identify vital habitats and biodiversity hot spots that should be avoided entirely.
- Engage stakeholders to ensure the needs of the surrounding environmental, cultural, and social landscape are incorporated into transport system design.
- Conduct climate resiliency reviews. Climate resiliency assessments must incorporate local projections of relevant risks (i.e., sea level rise, projected temperature changes).
- Conduct comprehensive environmental reviews documenting cumulative effects of road infrastructure.

Construction

While resource availability varies depending on a project's location, current sustainable road surface materials exercise an array of technologies applicable to all project budgets. While this report provides a few examples of such materials, more comprehensive information is available elsewhere, such as in the U.S. FHWA's Sustainable Pavement Guide. Projects should:

- Identify best use materials based on resource availability, cost, and carbon-reduction-capacity. Materials used should be context dependent (i.e., permeable pavement has limited durability under high traffic), and should

be applied appropriately. This includes utilizing available locally recovered materials (RAP) to avoid the use of virgin excavated materials.
- Conduct life-cycle analyses of building and maintenance regimes to identify steps in the road development process for CO_2 mitigation actions.

Roadway Management

Transportation authorities must recognize their roles as land managers and implement ecologically-minded management actions. Resilient roadside land management should include investment in roadside solar farms and specialized vegetation management to both sequester atmospheric carbon and produce clean energy. Roadside management should:

- Incorporate best practice management to increase carbon capture and sequestration on roadsides.
- Construct photo-voltaic panels in roadside verges/and or roadways, where appropriate.
- Preserve land adjacent to wildlife crossing structures to ensure continued efficacy of the investment through easements, wildlife planning, and other means of conservation.

Roadway Monitoring

Post-construction roadway monitoring and research must include attention to ecological effects. Monitoring should:

- Include observation by ecologists of wildlife-vehicle collision mitigation efforts (such as crossing structures) to create viable data-sets including type and frequency of species' usage.
- Reconcile collected data with any changes in wildlife-related collision patterns to assess structure effectiveness and inform future projects.

VII. Conclusion

By implementing the policies and practices set forth in this report, global road networks can improve their ecological resilience and, in so doing, advance the best interests of both humanity and nature. Promoting holistic transportation policies, plans, and projects ensures a brighter future for all species and the ecosystems upon which we collectively depend.

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