



Wildlife Connectivity

Fundamentals for Conservation Action

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THE CENTER FOR

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CONSERVATION

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About the Center for Large Landscape Conservation

The Center for Large Landscape Conservation strategically connects ideas, individuals, and institutions to catalyze collaboration and amplify progress toward the imperative of our time: to conserve Earth's resilient, vital large landscapes.

Our vision is a dynamic collaboration of ideas, individuals, and institutions that creates a **network of connected natural areas resilient to large-scale environmental challenges.**

Our mission is to **catalyze, advance, and support large landscape conservation** by advocating policies and strategies that champion ecological connectivity, advancing science that informs critical decision making, and building communities of invested stakeholders around large landscape issues.

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WILD NORTH PHOTOGRAPHY

Foreword

In the face of global threats, large-landscape conservation has become established as a science-based response to large-scale habitat fragmentation and degradation. Large-landscape conservation advances the concepts of ecological integrity and connectivity, wildlife corridors, and comprehensive landscape conservation. More recently, this approach has been embraced to facilitate adaptation of biodiversity to climate change and other large-scale stressors.

Conserving nature's parts and processes requires working at ecosystem, landscape, and bioregional scales. Size matters in ecology; in general, the larger the scale of focus, the better the chance of conserving critical ecological processes such as hydrologic function, natural disturbance regimes, species life cycles, and functional trophic interactions. These processes not only sustain nature, but provide vital ecological services that support human livelihoods.

Conservation at such large scales increases the complexity of decision making because collaboration and consensus among diverse stakeholders, with diverse values, is required. Large-landscape partnerships work across jurisdictional and cultural borders on multi-faceted issues that span ecological, social, and economic values. They promote resilience to changing conditions. We find growing interest in ecological connectivity and wildlife corridor conservation among our conservation partners. This document is our contribution to the many dedicated people striving to address these serious and challenging issues.

On behalf of the Center for Large Landscape Conservation, we hope this primer guides your path in advancing wildlife corridor and ecological connectivity conservation.



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WILD NORTH PHOTOGRAPHY

Executive Summary

Wildlife species are becoming increasingly isolated in patches of habitat, surrounded by a human-dominated landscape. Current protected areas are simply not large enough to encompass the variety of species, processes, and habitats necessary to fully conserve biodiversity. As a result, the distribution of many wildlife populations in the U.S. continues to shrink, in part because of habitat loss, degradation, and fragmentation. For example, within the Northern Rockies, wolverine, lynx, and pronghorn all currently exhibit contracting ranges, compared to the area they occupied historically.¹ Climate change further exacerbates the problem of isolation as fragmented landscapes are less resilient to ecological disturbances, to resisting native species loss, and to reducing emerging threats, such as disease. The combined threat of climate change and fragmentation is the most important conservation challenge we face.

A review of 25 years of peer-reviewed articles reveals that the most frequently cited recommendation for protecting biodiversity is improved connectivity conservation to ensure species can move and adapt in response to climate-induced changes.² Researchers have concluded that wildlife corridors increase movement between habitat patches by approximately

50%, compared to patches that are not connected by corridors.³ Linking protected areas, such as national parks and wilderness areas, as well as other crucial habitats, ensures larger, cohesive landscapes of high biological integrity that allow for the migration, movement, and dispersal of wildlife and plants. Improving connectivity is not only strategically smart, but a proven method of allowing wildlife to move in response to environmental change.

This report is intended to provide a high-level summary of the fundamentals of wildlife corridors and ecological connectivity to people engaged in management and conservation actions. We clarify the terms used to describe connectivity and provide tangible examples of different kinds of corridors and linkages and how they work. We describe the many different ways to identify places on the landscape for connectivity and wildlife corridors, including a wide range of methods, tools, and models. Finally, because policy is critical to support conservation efforts and ensure their longevity, we provide examples of existing policies that support wildlife corridors and connectivity and how they can be replicated or expanded to other jurisdictions.





WILD NORTH PHOTOGRAPHY

An Introduction to Connectivity

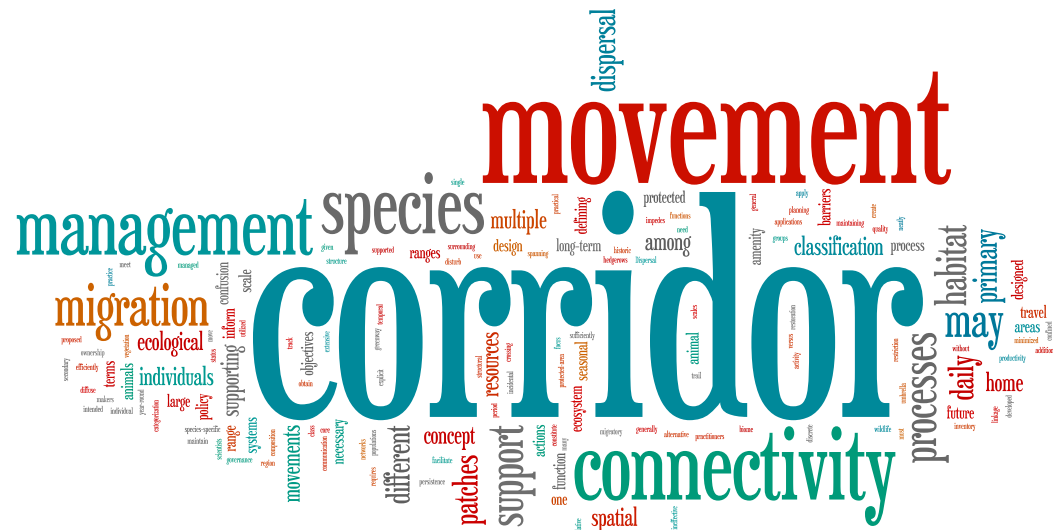
Wildlife need to move. They need to access resources, ensure gene flow, shift their ranges, and establish new territories, among other things. Connected landscapes allow for the movement of plants and wildlife and facilitate ecological processes. These are common concepts in conservation, and as climate change and other stressors act on the landscape, connectivity becomes even more important in allowing animals to adapt to changing conditions.

There are many terms used to describe the facets of connectivity. In some cases, there is a variety of definitions for the same term. This can cause confusion. The following is an introduction to the terms and concepts and how they are used.

A *corridor* is a distinct component of the landscape that provides connectivity. *Wildlife corridors* specifically facilitate the movement of animals, while other types of corridors may support connectivity for plants or ecological processes. Although the term is frequently used synonymously with corridor, *linkage* refers to broader regions of connectivity important to maintain ecological processes and facilitate the movement of multiple species.

Connectivity is defined as “the degree to which the landscape facilitates or impedes movement.”⁴ *Permeability* is essentially synonymous with connectivity, referring to the degree to which regional landscapes, encompassing a variety of natural, semi-natural, and developed land cover types, are conducive to wildlife movement and to sustain ecological processes. There are two ways to increase connectivity: (1) focus on conserving areas that facilitate movement, and (2) mitigate landscape features that impede movement, such as roads. Both strategies together produce the most effective results.

Nutrient flows, energy flows, predator-prey relationships, pollination, seed dispersal, and many other ecological processes require landscape connectivity. Connectivity includes both structural and functional components. *Structural connectivity* refers to the physical relationship between habitat patches; *functional connectivity* describes the degree to which landscapes actually facilitate or impede the movement of organisms and processes. Ecological connectivity supports the movement of both biotic processes (animal movement, plant propagation, genetic exchange) and abiotic processes (water, energy, materials) and can be species or process specific.



To put connectivity into a broader context, **ecological networks** result from the interaction of species and ecosystems at a large-landscape scale. Functional ecological networks that conserve biodiversity and provide for sustainable use of natural resources are often the goal of conservation and land management efforts. The ecological network concept embodies several key elements: (1) conservation core areas; (2) corridors and linkages; (3) buffer zones and sustainable use of non-conservation lands; and (4) the inclusion of human cultural and socioeconomic factors along with the consideration of wildlife needs, such as rural communities that coexist with wildlife. An ecological network is a coherent system of natural or semi-natural landscape elements configured and managed with the objective of maintaining or restoring ecological function as a means of conserving biodiversity while also providing appropriate opportunities for the sustainable use of natural resources.⁵

The Importance of Wildlife Corridors

Corridors are an important component of functional ecological networks. The primary focus of corridor

conservation is usually on supporting animal movement. Movements crucial to long-term viability of wildlife populations include daily foraging bouts among local resource patches, seasonal migrations between summer and winter ranges, once-in-a-lifetime dispersal events to seek new territories, and multi-generational range shifts in response to climate change. Wildlife use habitat corridors for different purposes, in different patterns, and at different scales, depending on the species. One way to identify a corridor is by the species-specific needs and the movement function they provide; this is considered a fine-filter approach. An alternative coarse-filter approach is to define corridors based on integrity and continuity of landscape features or natural conditions, which requires the assumption that swaths of connected natural areas are likely to support movement of a variety of species.⁶

Coarse-filter approaches are useful for providing a high-level overview of areas of potential importance for connectivity. Particularly at finer scales, maintaining different movement processes requires different corridor designs and management.

A corridor designed to support a given movement of one species may not support other movement processes of that species or movement of other species without additional management actions. Similarly, the spatial scale of a corridor is determined by the species and process it is intended to support. These types are not dependent on scale, biome, region, ownership, or governance, although management actions may vary as a function of these attributes. These concepts are illustrated in the accompanying case study examples.

Wildlife corridors are important to link areas of crucial habitat and facilitate movement, thus reducing the negative impacts of fragmentation and allowing greater flexibility to adapt to stressors.

Types of Wildlife Movement Facilitated by Corridors

<i>Daily travel</i>	Continuous movement of individuals among primary habitat patches within home ranges.
<i>Migration</i>	Predictable, periodic round-trip or cyclic movement of groups of individuals among discrete areas not used at other times of year.
<i>Dispersal</i>	Movement of individuals that maintain genetic and demographic connectivity among populations.
<i>Future movement</i>	Movement of individuals to and through areas expected to provide connectivity under future conditions (e.g., following natural extreme events, anthropogenic disturbance, and climate change).
<i>Incidental movement</i>	Fortuitous movement in areas primarily designed or managed to provide amenities to people.

Daily travel is the continuous movement of individuals among primary habitat patches within home ranges.

Daily Travel

Many animals must move regularly among multiple habitat patches to obtain all the resources they need (this is also called *station-keeping*⁷). Corridors among patches may be necessary for individuals to maintain sufficiently large home ranges

when the distance they travel on a daily basis is larger than the patches of primary habitat available to them. Management of these corridors would be similar to how primary habitat areas are managed.

CASE STUDY

Bozeman Pass: Creating Habitat Connectivity in the Northern Rockies⁸

The U.S. Northern Rockies includes portions of Montana, Idaho, and Wyoming and three relatively intact ecosystems: the Crown of the Continent centered around Glacier-Waterton national parks, the Salmon-Selway wilderness areas of central Idaho, and the Greater Yellowstone Ecosystem. Due to these intact ecosystems, there is still a full complement of native wildlife that includes wolf, bison, lynx, wolverine, fisher, marten, goshawk, eagle, grizzly and black bear, and mountain lion. With increasing human development, however, wildlife habitat between these protected areas is becoming fragmented.

American Wildlands and their partners applied a least-cost model to delineate routes across the landscape that provide the best opportunities for successful travel between habitat areas. They focused on three species (grizzly bear, elk, and cougar) and four variables (habitat suitability, habitat complexity, weighted road density, and building density). Field workers also compiled road-kill data, track surveys, and remote camera data to confirm wildlife use. They found that Bozeman Pass was used by the three species they planned for as well as many other species (including wolf, red fox, deer, marmot, mink, and weasel). The result was the Bozeman Pass Wildlife Corridor located about 40 miles north of Yellowstone National Park between the towns of Livingston (to the east) and Bozeman (to the west). The corridor links the Bridger and Bangtail mountains (to the north) with the Absaroka Mountains (to the south) and encompasses approximately 908 km² or 223,917 acres.

The project mitigated several critical barriers:

- *Transportation corridor.* Highway I-90 and the parallel Montana Rail Link bisect the area. Taking advantage of a scheduled resurfacing and bridge replacement project, Montana Department of Transportation agreed to rebuild a highway bridge across the railroad tracks and install fencing and moose guards to redirect wildlife under the interstate through existing bridges and culverts.
- *Wildlife-vehicle collisions.* Montana Department of Transportation and the Western Transportation Institute worked together to deploy changeable message signs and highway radio advisories to inform motorists of wildlife movement in an effort to reduce wildlife collisions and maintain and improve wildlife movement.
- *Land development.* Homes and the potential of increased land development were additional sources of fragmentation. To protect the land within the corridor from further development, over 2,000 acres are under conservation easements; county zoning restrictions limit further housing development on 20,000 acres; and coalbed methane development has been prohibited on 18,000 acres.

The Bozeman Pass Wildlife Corridor initiative was effective because it brought together constituents with interests in this area (federal, state, and county agencies; conservation and research organizations; and land trusts), and together they identified feasible strategies and committed their efforts toward achieving them.

Migration

As environmental conditions, such as vegetation composition and productivity, snow cover, and water availability change seasonally, many species (e.g., ungulates⁹) travel between seasonal home ranges to access the resources they need. Seasonal migration also facilitates access to breeding and spawning grounds for some species (e.g., salmonids¹⁰). Often, migratory animals follow the same routes year after year. An effective migration corridor must maintain the resources

necessary at the right time of the year to support the focal species during its migration, but not its long-term occupancy, since the corridor is used primarily for travel from one place to another. Corridors should allow for rapid movement as necessary to accommodate the extent and pace of migration. Because migration corridors are not used year-round, human activities that may disturb the species need only be restricted during the migration period.

Migration is the predictable, periodic round-trip or cyclic movement of groups of individuals among discrete areas not used at other times of year.

CASE STUDY

North Atlantic Right Whale Migration

The right whale migration route along the Atlantic coastline stretches from the calving areas off South Carolina, Georgia, and northeastern Florida to the northern waters of Cape Cod and Nova Scotia for feeding and mating. Whales spend a lot of time near the surface of the water, which puts them at risk of entanglement in fishing gear and ship strikes in this heavily traveled region. Right whale population numbers have been of concern for decades; they were listed as endangered under the Endangered Species Act in 1973, and as “depleted” under the Marine Mammal Protection Act.

The National Marine Fisheries Service (NMFS) has taken both regulatory and non-regulatory steps to reduce the threat of ship collisions.¹¹ By implementing a traffic separation scheme (TSS; i.e., shipping lanes) and designating an Area To Be Avoided (ATBA), a protected migration corridor was created. The National Oceanic and Atmospheric Administration (NOAA) estimated that implementing an ATBA and narrowing the shipping lane by one nautical mile (1.9 km) would reduce the relative risk of right whale ship strikes by 74% during April-July (63% attributed to the ATBA and 11% due to the narrowing of the TSS).¹²

Mandatory vessel speed restrictions in Seasonal Management Areas and voluntary speed reductions in Dynamic Management Areas were also implemented. NOAA finalized a rule in December 2013 maintaining vessel speed restrictions implemented in 2008 (which were scheduled to expire) to reduce the threat of collisions between ships and North Atlantic right whales.

To address entanglement in fishing gear, the NMFS established the Atlantic Large Whale Take Reduction Team. This team developed a plan to reduce the incidental serious injury and mortality of right whales and other whales impacted by commercial gillnet fisheries in the Atlantic through safe disentanglement.¹³ Not all large whales react the same way to disentanglement efforts; North Atlantic right whales are the most difficult whales to disentangle because their muscular body structure is designed to push their large open mouth through the water while feeding. NOAA Fisheries Service and disentanglement network partners are pursuing ways to improve techniques for successful rescue.

In addition to these efforts, scientists continue to track whale population dynamics and the impacts of these protection measures; public education and outreach are increasing awareness for conservation efforts. Although numbers remain dangerously low, there has been a recent positive trend in population growth, which may signal the start of a slow recovery.¹⁴



NOAA

Dispersal is the movement of individuals that maintain genetic and demographic connectivity among populations.

Dispersal

Dispersal is a function critical to both plants and animals. Movement of young adults from their maternal home range to establish territories of their own and find mates maintains healthy genetic and demographic diversity.¹⁵ The different drivers of dispersal movements, compared to daily home range movements, may lead to different responses to the landscape.¹⁶ For example, young grizzly bears need to be able to move from one mountain range to another to establish

their territory, but they don't need to use that route for anything but travel. Thus, dispersal corridors can be permeable to movement without needing to support long-term occupancy. The habitat quality of dispersal corridors generally doesn't need to be managed to support residency or reproduction, and management may instead focus on minimizing barriers to movement. Continuously occupied areas (e.g., by "corridor dwellers"¹⁷) are considered to be habitat, not corridors.

CASE STUDY

Maintaining Connectivity for Lynx Dispersal in the Northern Rockies

Landscape connectivity is important for gene flow to maintain wildlife population viability, particularly for species that live on the edge of their range, where they may be more susceptible to stressors, such as climate change and human disturbance. For these species, they must either disperse to allow gene flow with other populations, or the population may become isolated and result in population extinction. Recent studies have found that Canada lynx in the northern Rocky Mountains rely on dispersal behaviors to maintain healthy population genetics.¹⁸

In order to identify dispersal corridors used by lynx, researchers used GPS collar data to study habitat use and movement patterns.¹⁹ The study area focused on connectivity between the northern Whitefish Range at the Canada border

south to the Swan Range in Montana, and the connection between the east side of Glacier National Park and the Bob Marshall Wilderness Complex. They looked at seasonal patterns of habitat use and the corresponding landscape characteristics that facilitated movement or created barriers.



U.S. FISH AND WILDLIFE SERVICE

Canada lynx were regularly traveling distances of 100-1,100 km;²⁰ longer dispersal routes were primarily used in the summer when prey was most available.²¹ Least-cost paths between lynx habitat in Canada and high-quality patches in the United States revealed that lynx dispersal is probably supported by only a few presumed corridors. This information is useful for management to protect segments crucial to

movement and mitigate the impacts of barriers, such as roads, where there is a high likelihood of crossing.

Future Movement

Major disturbances such as fire, human development, and climate change may impact the quality and distribution of habitats and necessitate the movement of both plant and animal species. When we can predict how disturbance will change patterns on the landscape (e.g., planning for roads or large-scale developments), we can better identify corridors

that will support species' need to escape from the disturbance, to disperse, migrate, and move daily to continue to meet their habitat needs. In this case, management will require the prediction of areas expected to support movement under future change scenarios and protection for these areas from incompatible land uses.

Future movement is the movement of individuals to and through areas expected to provide connectivity under future conditions.

CASE STUDY

Wildlife Movement in Response to Climate Change

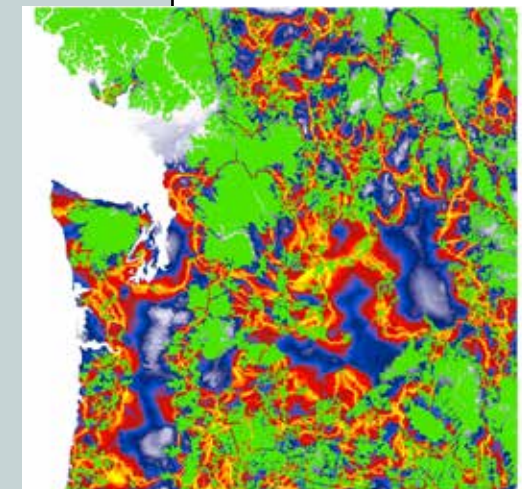
Before humans dominated the landscape, wildlife were able to freely move in response to disturbances, such as fire, or shift their range as needed to adapt to new environments. This is much more difficult today, given the extent of landscape disturbance and the rapid rate of change (related to climate or land use). The critical challenge is thus to anticipate how habitats may shift and how and where wildlife species will need to move to survive. Several recent studies have delved into this issue, exploring connectivity models and making projections of wildlife movement.²²

An approach developed by the Washington Wildlife Habitat Connectivity Working Group focused on the Pacific Northwest (state of Washington, extending into Idaho and Oregon) projected species movement specifically related to changing temperatures.²³ They developed a temperature gradient based on climate data and topographical characteristics of the landscape and used that information, together with landscape integrity, to model tradeoffs between distance traveled and the difficulty of travel (see further description of cost-distance modeling in the Methods, Tools, and Applications section). This approach has particular utility for predicting habitat changes for plants and animals with narrow climate niches.

Another approach projected suitable climatic areas for 2,903 species of wildlife under ten different projected future climate scenarios, and determined the linkages for each species between current and suitable future areas as they shifted.²⁴ They used a circuit theory model approach (Circuitscape; further described in the section on Methods, Tools, and Applications) resulting in a continuous map of movement probabilities. Resistance to movement across the landscape was based on the degree of human development and the distance to be traveled. They applied this approach across North and South America, at a relatively coarse scale. This approach helped identify where human development will severely constrain species movement; where potential barriers may arise; and areas that are likely to experience a high degree of movement.

Both of these approaches help us conceptualize what the future landscape may look like as the climate changes and where to invest in conservation to maintain species and ecosystem viability.

Map of western Washington showing results of the Washington Connected effort to map connectivity based on climate gradient.



Connectivity Areas Defined by Climate Gradients

Core Areas Low Connectivity Resistance
High Connectivity Resistance

Incidental movement is the fortuitous movement in areas primarily designed or managed to provide amenities to people.

Incidental Movement

Many corridors are intended to support multiple species. Multispecies corridors could be designed effectively by treating them as composites of multiple single-species corridors. A coarse-filter, non-species-specific approach may also be useful for identifying broad areas of potential connectivity for multiple species. For example, some corridor designs are based primarily on landscape integrity and structural connectivity,

the inclusiveness of umbrella species, or financial or social opportunity (e.g., least cost analysis). These landscape linkages are important to increase landscape connectivity, though they may or may not best meet the needs of individual species. Multispecies approaches may be particularly well-suited in the context of extensive ecological networks of cores and corridors (e.g., the Pan-European Ecological Network, the Yellowstone to Yukon Conservation Initiative).

CASE STUDY

Wildlife Corridors in an Urban Setting

When Los Angeles County, California passed its General Plan in 1980, it created a special designation to help natural areas remain self-sustaining. Significant Ecological Area (SEA) designation was provided to lands that contain irreplaceable biological resources. SEAs are a mix of undisturbed and lightly disturbed habitat areas that are interspersed among developed areas of the county. These natural areas support valuable or threatened species, and are designed to provide linkages and corridors among patches to promote species movement.

The Santa Monica Mountains SEA, engulfed in the Los Angeles metropolitan area, includes a national recreation area and four state parks. Wildlife, including mountain lion, roam between high-quality habitat areas, sometimes passing through residential areas. The topographic complexity and geographic linkages allow movement between large open space areas within the SEA as well as between areas outside the SEA, such as the western extent of the Santa Monica Mountains in Ventura County. The genetic flow through these areas is crucial to maintaining the diversity and viability of species.

In 2001, the Santa Monica Mountains Recreation Area was expanded by 3,700 acres to include a wildlife corridor between the mountains and the Simi hills. The acreage was donated by public and private entities to the recreation area's conservancy. In 2002, a ballot initiative asked if property owners wanted to assess themselves no more than \$40.00 per year over thirty years to fund the acquisition

and preservation of nearby open space and parkland, and to annually clear brush to reduce fire hazards in their acquisition area. The initiative passed by more than 70%.

Now the Santa Monica Mountains Conservancy is considering whether to provide \$200,000 for the California Department of Transportation to study alternatives to mitigate road impacts and allow for safe wildlife crossings. Open space linkages between Kanan Road and Calabasas Parkway along Highway 101 are of particular importance for continued wildlife movement, due to the lack of alternative routes and encroachment by development. Although there are significantly large open spaces within the SEA, contiguous habitat linkage between them is critical for long-term sustainability. The California Department of Transportation has so far unsuccessfully sought federal funding for a \$10-million tunnel crossing. In the meantime, the conservancy has begun to advocate that a wildlife overpass (rather than a tunnel underpass) is a better option.



GREG HOME/WIKIMEDIA COMMONS

Amenity corridors,²⁵ such as greenbelts, recreational trail systems, hedgerows, and even golf courses, are common in urban and suburban landscapes.²⁶ Amenity corridors are designed and managed primarily for aesthetic and recreational use by people, but wildlife also use them. For example, wildlife may use a recreational trail network for movement because it provides some permeability between one habitat and another; although the habitat or conditions in that area are not optimal, it may be the best option available and may thus become an established route. Restrictions on habitat conversion or human activity in these cases are often a secondary consideration. Wildlife movement through these areas may become an amenity (e.g., wildlife viewing), or it may be that management actions will need to address the potential for human-wildlife conflicts (e.g., elk on a golf course).

Benefits of Wildlife Corridors

The main benefits provided by ecological connectivity are related to biodiversity conservation, adaptation to climate change, and provision of ecosystem services. Ecosystem services, such as water purification, oxygen production, erosion control, and insect pollination of important food crops, benefit people as well as plants and animals. Biodiversity conservation is greatly enhanced by connectivity that maintains ecological function across the landscape. Plants and wildlife need corridors for many kinds of movement and in order to sustain healthy populations. Movement will become even more critical as climate conditions change and species need to adapt and adjust. The ability to move through connected habitats and landscapes will increase species' and ecosystem resilience to climate change.

While there are many benefits of a connected landscape, some potential negative impacts should also be considered. Some social impacts include a potential increase in wildlife-human conflict, including negative public perception of large carnivores repopulating areas near where people live and recreate. Connectivity allows for the movement of plants and animals, which can include invasive, exotic, and otherwise harmful species. Likewise, ecosystem processes that move across a landscape can include the spread of pathogens, disease, and harmful insects. Connecting aquatic systems can spread disease, invasive fish and animals, and change the quality of the habitat (for example, increasing water temperature). These potential negative consequences should be identified and mitigated to the extent possible when designing landscape connections. Efforts to connect landscapes that have not historically been connected should also be avoided as this may aggravate the risk of the above negative impacts on natural communities, as well as erode local adaptation.

Some Additional Benefits of Wildlife Corridors

Depending on their location, wildlife corridors can benefit urban, suburban, rural, and wild environments. There are many values for conserving wildlife corridors; they:

- Protect urban and suburban open space
 - Protect our natural heritage and conserve biodiversity
 - Improve environmental quality and quality of life
 - Provide recreation opportunities
 - Provide an opportunity for people to interact with nature, including educational opportunities that stimulate the senses and imagination
 - Enhance property values (possibly)
-



Elk cross a road in Paradise Valley, Montana, north of Yellowstone National Park.

Economic Cost/Benefit of Wildlife Crossing Structures

Wildlife crossing structures are often key components of wildlife corridors that mitigate the barrier of roads. Although crossing structures may be costly to install and maintain, studies suggest that the monetary benefits these structures provide by reducing expensive collisions with large mammals often outweigh their costs. A variety of measures aimed at mitigating wildlife-vehicle collisions (WVCs) have been developed, with varying rates of effectiveness. Most, such as warning signs and removal of vegetation to improve visibility, demonstrate less than a 50% reduction in WVCs. Others, such as elevated roadways or road tunnels, are highly effective, but prohibitively expensive. In contrast, wildlife crossing structures, such as under- and overpasses (with associated elements like fencing) and automatic detection systems (to

warn drivers when animals approach or are on the road), have been observed to reduce wildlife-vehicle collisions by 79-97%.²⁷ Cost-benefit analysis indicates that, when installed at suitable sites, crossing structures can simultaneously enhance human safety, preserve wildlife, and save taxpayer dollars.²⁸

To date, the monetary benefits of maintaining or enhancing connectivity, which include ecosystem services such as wildlife viewing, have not yet been comprehensively assessed. More research is needed to examine all the economic costs and benefits of crossing structures and the corridors in which they are embedded to give decision makers and the public a more complete accounting.



HNTB-MVVA

Concept design for the winning entry in the 2010 ARC International Wildlife Crossing Infrastructure Design Competition by HNTB Corporation with Michael Van Valkenburgh and Associates.

Road Ecology

The transportation network overlaying the natural landscape is the largest human artifact on earth.²⁹ Roads have been named the single most destructive driver of habitat fragmentation.³⁰ While less than 1% of the land area of the United States is covered by roads, their zone of influence occupies an estimated 20% of U.S. land area.³¹ For example, approximately 80% of all lands in the conterminous U.S. fall within 1 km of a road, and only 3% lie more than 5 km away from a road.³²

Roads tend to alter natural ecologic flows and can create barriers to the movement of terrestrial and aquatic species.³³

Roads may:

- act as barriers that impede or limit dispersal, potentially isolating habitats and populations;³⁴
- increase noise and degrade habitat due to negative edge effects;³⁵ and
- impact wildlife through direct mortality and habitat fragmentation.³⁶

Approximately 1-2 million wildlife-vehicle collisions occur annually in the United States, with an additional 45,000 collisions in Canada, and these numbers are rising.³⁷ Compared to other agents of habitat fragmentation, roads cause changes to wildlife habitat that are more extreme and permanent.³⁸

Road ecology is an interdisciplinary field of science and engineering that studies the myriad impacts of surface

transportation infrastructure on the environment.³⁹ Wildlife crossing structures (such as overpasses and underpasses) have recently been shown to effectively reduce or eliminate wildlife-vehicle collisions. These structures not only enable wildlife to cross roads safely,⁴⁰ thereby improving landscape permeability for wildlife, but also provide safety and monetary benefits for people.⁴¹

An increasing variety of institutions and researchers provide technical expertise to construct wildlife crossing structures, while others, such as ARC Solutions, a multi-disciplinary partnership (www.arc-solutions.org), work to build wildlife crossings wherever they are needed across North America. Citizen organizations, such as Montanans for Safe Wildlife Passage (www.montanans4wildlife.org/), are important advocates for incorporating road crossing structures in critical corridor areas and work with state departments of transportation and other groups to put them in place.



A black bear uses a wildlife underpass on US Highway 93 south of Polson, Montana.

CONFEDERATED SALISH AND KOOTENAI TRIBES





WILD NORTH PHOTOGRAPHY

Methods, Tools, and Applications

While corridor conservation is now widely agreed to be a key strategy for maintaining biodiversity and ecological processes, and corridor definitions and concepts abound, identification of areas serving as corridors in complex landscapes can often be a challenging task. Early work focused on monitoring the effectiveness of *de facto* corridors such as fencerows, roadside vegetation, and linear remnants of logged forests,⁴² treating the landscape as discrete island-like patches of habitat connected by sharply defined corridors in a sea of uniformly inhospitable land commonly referred to as the “matrix.” The advancement of geographic information system (GIS) software, computing power, availability of remote sensing data, and understanding of species-specific responses to heterogeneous landscapes now allow researchers and practitioners to map and analyze the combined, species-specific effects of diverse habitat factors on movement through continuous landscapes at increasingly high spatial resolution and extent.

A bewildering array of connectivity analysis methods and tools has now been created, and all are (in theory) capable of predicting locations of corridors in complex landscapes. The goal of this section is to introduce some of the most prominently used methods. For each, we provide a general

Throughout the literature, definitions of the “matrix” are generally vague. Most commonly, the *matrix* is defined as “non-habitat” or “the portion of the landscape in which habitat patches and corridors are embedded.”⁴³ This very black-and-white interpretation fails to capture the myriad land cover types and functional continuum that exist in the matrix. Some studies acknowledge the heterogeneity of the matrix and examine the effects of variable matrix quality on connectivity, or movement among habitat patches by a focal species.⁴⁴ Ultimately, the *matrix* may consist of anything from urban development to agricultural land to grassland or forest. High-quality matrix lands have the potential to support movement (such as areas with vegetation that provides cover), while poor-quality matrix lands may be absolute barriers to movement (such as bodies of water, roads, walls, or fences). The range of this quality gradient and associated degree of movement supported is species-specific. Just as with connectivity, the role of the matrix will depend both on its composition and on the unique behavioral response of the species considered.



Chief Mountain (pictured above), on the border of Glacier National Park and the Blackfoot Indian Reservation, is part of a sacred landscape for Native Americans and First Nations in Canada. Traditional knowledge and values of landscapes are important to consider in any conservation planning, including wildlife corridors.

description of the approach along with its strengths and weaknesses as important considerations in selecting the most appropriate method for a given application. We provide a summary of currently available tools for implementing the described methods. We conclude with a discussion of Crucial Habitat Assessment Tools (CHATs) initiated by the Western Governors' Association (WGA) as the largest-scale example of institutionalized use of these methods, and potentially as a key data product for corridor conservation practitioners.

There is no single method that is best in every context, and empirical validation of methods has been sorely lacking, though this is an increasingly active area of research interest. Ultimately, the method used to identify a wildlife corridor for planning purposes is just one of many considerations in designing and managing effective corridors, and the selected method must be appropriate to the project-specific social, economic, and political environment. An informed choice of methods grounded in good conservation science is crucial.

Traditional Knowledge and Expert Opinion

Early approaches to identifying corridor areas relied heavily on the experiential knowledge of those working closely with the landscape and its wildlife (e.g., tribal leaders, hunters and trappers, local wildlife biologists). Direct familiarity with areas of prime habitat and patterns of animal movement was a crucial source of information prior to the widespread use of remotely sensed habitat data and telemetry of animal locations. Today, traditional knowledge continues to be an important resource when working in areas or with species for which data are still unavailable, insufficient, or difficult to obtain. In some cases, social and political considerations may call for the use of traditional or expert knowledge to identify corridors rather than, or in addition to, data-based models.

Traditional knowledge or expert opinion may be incorporated into the corridor identification process in one of three ways. First, corridor locations may be mapped directly by experts. For example, in an effort to identify crucial zones of connectivity in the Cabinet-Purcell conservation area of northern Montana and Idaho, American Wildlands' staff asked wildlife experts from state, tribal, and federal agencies, along with independent biologists within the region, to circle locations on a map serving as habitat linkages for a variety of species and to rank the ecological quality of each location. Second, experts may be consulted to parameterize the corridor models described below. Expert knowledge was used to assign weights to each of nine variables included in a predictive model of black bear corridors in the Bow River Valley of Banff National Park, which captured impacts of topography, hydrology, and vegetation on habitat selection.⁴⁵ In that example, expert knowledge was obtained from expert interviews as well as from published literature. Lastly, expert and traditional knowledge may be called upon to ground-truth the predictions of corridor models, a practice that has not seen extensive use to date, but has potential for future refinement of models.

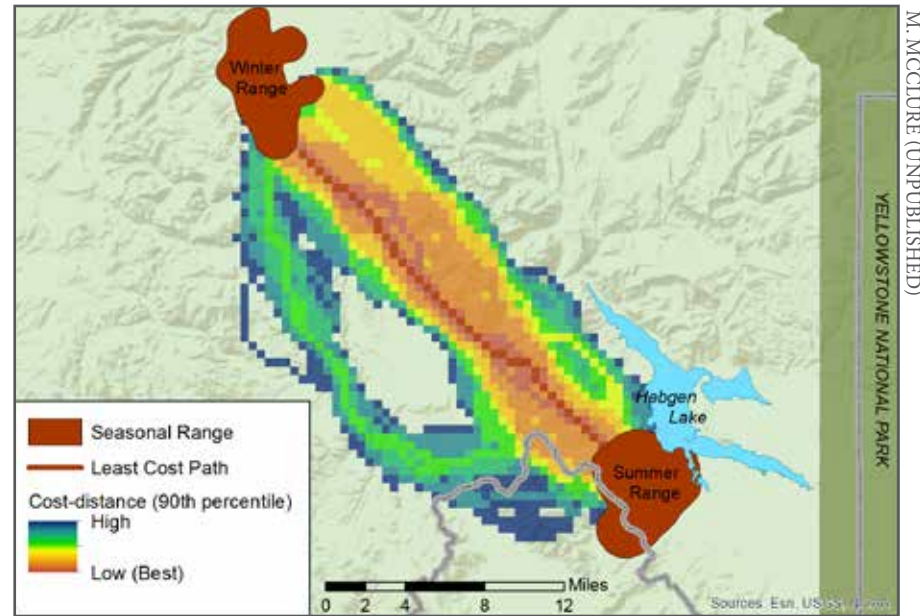
Corridor Models

Spatially explicit, data-based methods of modeling corridors have exploded in recent years.⁴⁶ It is beyond the scope of this primer to comprehensively review and compare all of these approaches; rather, we aim to provide a brief introduction to the most prominent methods that have been applied to on-the-ground conservation efforts. All methods follow a similar underlying process. First, a map of habitat suitability (or, conversely, resistance to movement) is created. This map may be derived from expert knowledge as described above or a data-based statistical model (e.g., resource selection functions,⁴⁷ resource utilization functions,⁴⁸ step selection functions⁴⁹). Corridor models then quantify the relative probability of movement, or relative ease of movement, through each map cell across the landscape. These models have generally been used to predict corridors between patches of “core” habitat, but have more recently been adapted to move beyond the limitations of fixed patches to capture connectivity at multiple scales. We discuss the core patch-based methods first, followed by their scale-free extensions.

Patch-based Models

In patch-based models, patches of high-quality habitat are designated, and models are used to predict corridors between pairs of these patches.

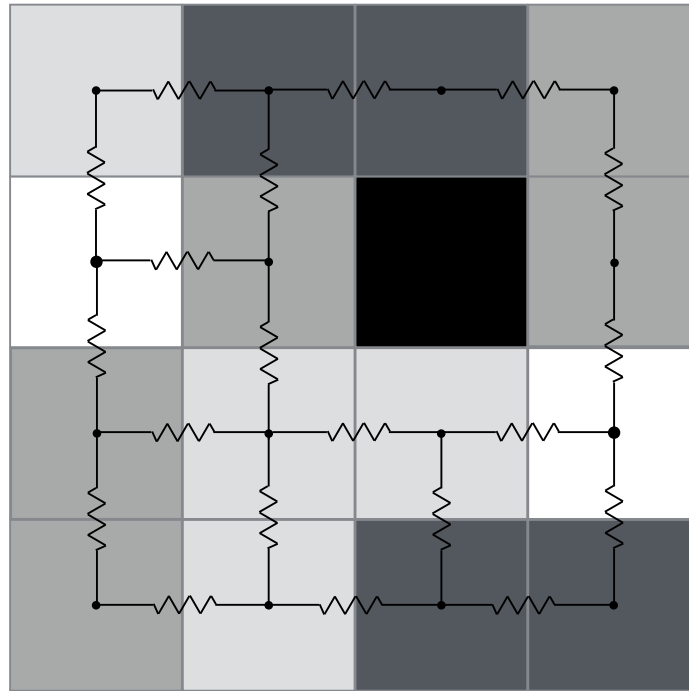
Cost-distance models. Cost-distance (or least cost corridor) models calculate the cost-weighted distance between a source and destination for each map cell in the landscape. The path that minimizes the tradeoff between travel distance and difficulty of travel—the *least cost path*—is predicted to be the optimal route presenting the least total resistance to movement. Other low-cost routes may provide alternative travel paths, and the creation of a *least cost corridor* that includes all paths with cost-distance values below a user-defined cutoff can help to better visualize shape and width of potential corridors.



It is important to note that cost-distance models assume that animals have perfect knowledge of the entire landscape, thus allowing them to select the optimal or near-optimal path. This assumption may be reasonable for movements among frequently visited patches or for repeat annual migration movements, but not for dispersal through novel landscapes. Cost-distance models also do not assume that cost-distance values are proportional to the probability of use by a focal species. Rather, paths with lower cost-weighted distance are simply predicted to offer the best chance for successful movement from the source patch to the destination. Model outputs must be interpreted with some caution as this approach does not account for focal species’ movement capabilities; for example, even least cost paths may be too long to provide connectivity for poor dispersers, and long, yet low-resistance, routes may be overlooked even when they fall within a species’ dispersal range.

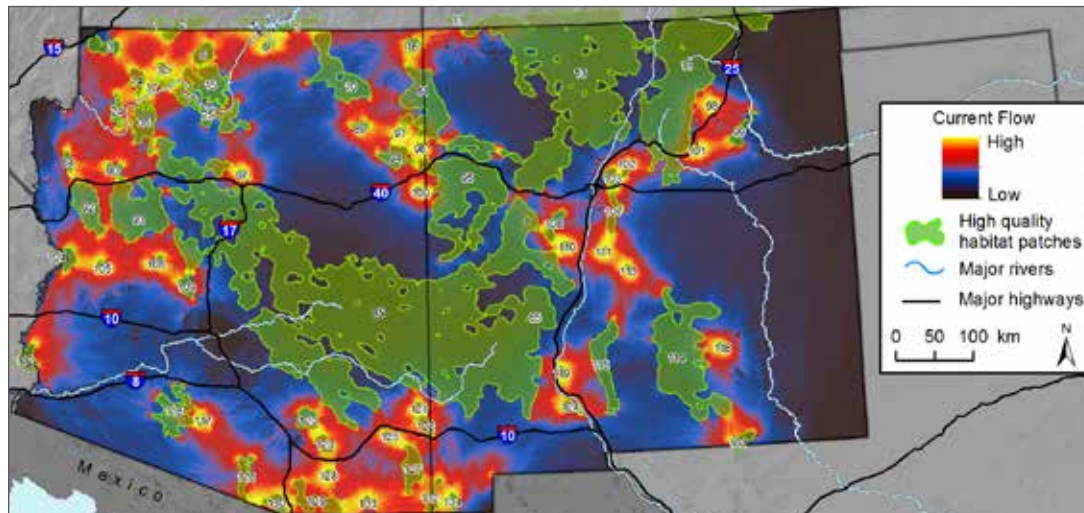
An example of a least-cost corridor between individual summer and winter elk ranges in the Madison Valley of southwest Montana.

Circuit theory models treat each cell as a node (shown by dots) connected to its neighbors by electrical resistors. Here, lighter-shaded cells have lower resistance to movement. The cell shown in black has infinite resistance and is a total barrier to connectivity. (Adapted from McRae et al. 2008).⁵¹



Circuit theory models. Circuit theory models are based on electrical circuit theory, relying on the intuitive analogy between movement of individuals through a landscape and movement of charge through an electrical circuit. Each cell in the landscape is treated as an electrical node connected to neighboring cells by resistors, with resistance values determined by the cells' landscape resistance values. Consecutive resistors can be linked in series to create a path between two patches, and each route's total resistance is equivalent to its cost-weighted distance (as in cost-distance models).⁵⁰ Circuit theory models are unique in that when all possible paths among patches are treated as resistors connected in parallel, a measure of effective cumulative resistance is obtained that decreases with increasing numbers of paths. In this way, circuit theory models account for the positive effects of path redundancy on connectivity.

Map cell values of current flow across the landscape reflect the probability of movement of individual random walkers through the cell. This is an important distinction from cost-distance models: while cost-distance models identify complete paths from a source to a destination, circuit theory models assign values on a cell-by-cell basis, and the most likely routes from one point to another may not be obvious. Circuit theory models are highly useful for understanding landscape-wide patterns of connectivity and for identifying potential pinch-points, or bottlenecks, to movement; however, they may also underestimate the importance of broad swaths of highly suitable habitat because current passing through any particular cell is low. Unlike cost-distance models, circuit theory models assume that animals only perceive the landscape within a one-cell radius of their current location; and therefore this tool may be better suited to modeling dispersal processes. Like cost-distance methods, however, circuit theory does not incorporate any limits on dispersal ability.



Circuit theory model used to estimate connectivity for pumas (*Puma concolor*) in the southwest United States.⁵²

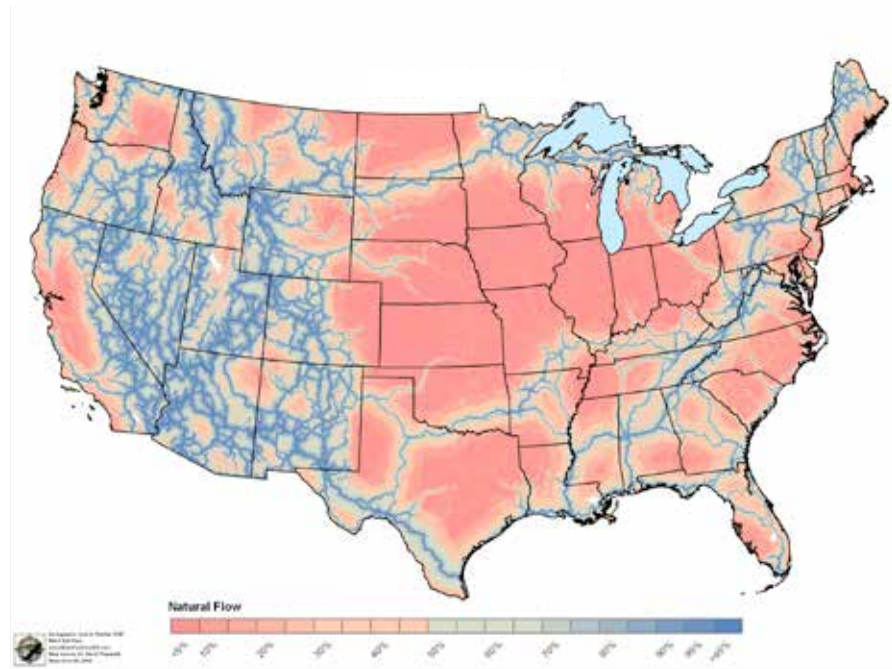
Patch-free Extensions of Models

Delineation of core habitat patches is almost always an inherently subjective process, requiring assumptions about species-specific needs for habitat quality and quantity. Some recent applications of cost-distance and circuit theory models have bypassed these assumptions.

One approach is to use cost-distance or circuit theory models to connect one edge of a map to the other. In a study to predict important movement routes for black bears between Yellowstone National Park and Canadian forest habitat to the north, researchers designated points at two-kilometer intervals along a defined portion of the Canadian border, which they connected with least cost path analysis to points likewise placed along the northern border of Yellowstone.⁵³ Overlaying these paths revealed primary routes that may be crucial to keeping Yellowstone bears connected to more stable Canadian populations.

Circuit theory models have recently been adapted in a similar way.⁵⁴ In order to apply circuit theory analysis to regional scales containing a potentially prohibitive number of patch pairs, omnidirectional, patch-free connectivity surfaces are constructed by multiplying outputs of models run from north-south edges and east-west edges of the study landscape. These models account for the importance of high-quality habitat patches in that those areas are assigned low resistance to movement and thus tend to “attract” low cost routes (or high probabilities of movement, in the case of circuit theory). Their freedom from defined patch boundaries makes them suitable for answering questions about flow between one broad region and another, for species with diverse patch size needs and diverse scales of movement.

A similar approach is based on concepts of hydrologic flow. This approach was pioneered in the development of Wild LifeLines,⁵⁵ which captures major arteries of potential wildlife



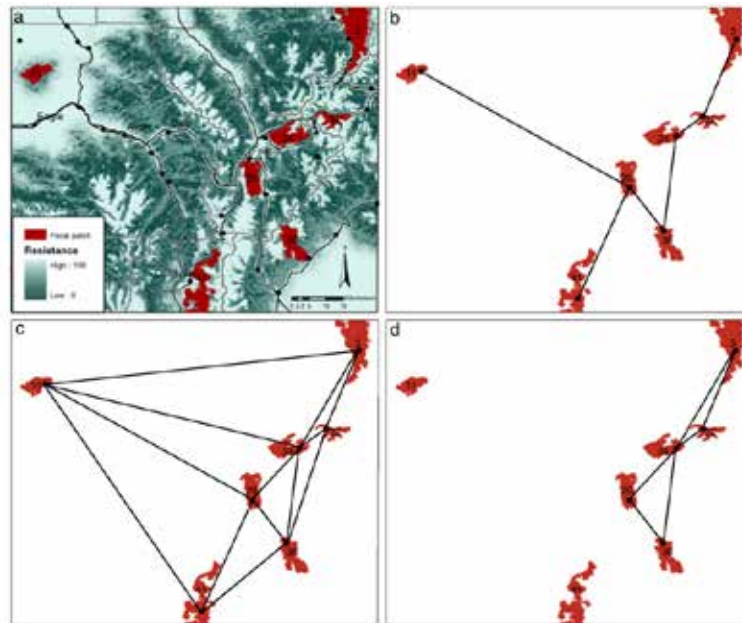
movement across the U.S. In this case, rather than calculating cost-distance (or resistance) between defined source-destination pairs, cost-distance is calculated between many points throughout the landscape and all other points in the landscape, then “flow lines” are identified where many low-cost or low-resistance routes flow together. This can be conceptualized as raindrops falling across a landscape and accumulating along ravines and valleys to form streams and then rivers. These flow lines represent major corridors expected to offer the lowest resistance to movement. The Western Governors’ Association Wildlife Corridors and Crucial Habitat Initiative adopted a similar approach to model connectivity across the western U.S. as a component of the newly released Crucial Habitat Assessment Tool.

Wild LifeLines models the connectivity of U.S. natural landscapes using flow “routes.” The areas overlain by thicker “arteries” are predicted to contribute most to national-scale connectivity, factoring in both local natural values and their position within the broader landscape.⁵⁶

A Note on Graph Theory

Graph theory models, which have been adopted by landscape ecologists from other fields concerned with connectivity (e.g., computer science, transportation, social network theory), represent potentially complex networks very simply as nodes (points) connected by edges (lines). The simplicity of graph representations not only helps to visualize complex networks, but also supports the use of highly efficient network algorithms quantifying higher-level network properties.

In their most typical application to landscape connectivity, graph theory models simplify a landscape down to a network of patches (nodes) and corridors (edges).⁵⁷ While ecologically meaningful quantities can be incorporated into these graphs, (e.g., node size can represent patch size, and edge length can represent cost-weighted distance derived from cost-distance models or cumulative current derived from circuit theory), graph networks are not spatially explicit and offer limited information for locating, designing, and conserving corridors on the ground.



Still, the calculation of graph-based network properties can provide valuable information for prioritizing corridor conservation efforts and assessing risk to connected landscapes.⁵⁸ For example, *node degree* measures the number of neighbors to which a given patch is connected; *characteristic path length* measures how “reachable” patches tend to be from elsewhere in the network; and *centrality* measures the importance of a given patch or corridor to maintaining connectivity of the network as a whole. *Pruning* processes, or removal of one or more patches or corridors, can help practitioners to assess the impact of loss of a portion of the network (e.g., to a housing development) on the rest of the landscape.

Graph theory need not be used as a standalone modeling tool, and, in fact, underlies some of the methods previously described. Circuit theory treats each map cell as a node connected to each of its neighboring cells by edges, thus making use of the efficiency of graph algorithms. The scale-free applications of cost-distance models used in Wild LifeLines.⁵⁹ and the Western Governors’ Association West-wide connectivity assessment incorporate graph theory metrics, assigning graph-based centrality values to flow lines—that is, small “tributaries” have relatively low centrality, while major “rivers” have high centrality.

Example of graph representations of connectivity based on (a) landscape resistance to movement among focal patches of lynx habitat in Colorado. (b) The minimum spanning tree gives the set of edges connecting all patches with minimum total cost-distance. (c) A planar graph connecting all adjacent patches. (d) Networks become disconnected when cost-distance between patches exceeds the dispersal capabilities of the focal species.⁶⁰

Tools and Data Products for Practitioners

There are many tools freely available for implementing the previously described methods to identify wildlife corridors. A good source of information and links is Conservation Corridor online at: <http://www.conservationcorridor.org/corridor-toolbox/>. There is overlap or commonalities among these tools, as well as differences in the range of capabilities.

Although not intended to be all inclusive, the following table provides a brief description and introduction to some available tools. This is a starting point for comparison to help practitioners choose the most appropriate toolset for their needs.

CASE STUDY



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Connectivity Modeling in Practice and in Context

The Western Governors' Association (WGA) Crucial Habitat Assessment Tool (CHAT) was developed cooperatively by the WGA states to “provide the public and industry a high-level overview of crucial habitat” across the West. *Crucial habitats* are defined as places that are likely to provide the natural resources important to aquatic and terrestrial wildlife, including species of concern, as well as hunting and fishing species. The CHAT is intended to be used throughout the West in the planning of energy corridors and transmission routes and to anticipate their impacts on wildlife and recreational values.

The crucial habitat values mapped in the CHATs are composites of many factors, including presence of species of concern, species of recreational or economic importance, natural and unfragmented habitat, and landscape

connectivity. The landscape connectivity layer was modeled for the entire western U.S. using a scale-free extension of cost distance models, though some member states used their own methodology to map connectivity. While landscape connectivity is not currently a visible map layer for most states in the online CHAT tool, due to individual states' discretion, it was nonetheless a key component contributing to final crucial habitat scores that will serve as a guide to land-use decision making across the West. This is perhaps the most ambitious effort yet to formally integrate connectivity into mainstream wildlife habitat conservation efforts. The use of CHAT data has already begun or is being encouraged by the Bureau of Land Management, U.S. Forest Service, and the Federal Highway Administration. These and similar future efforts offer great potential to maintain connectivity for wildlife at a regional, large-landscape scale.

Overview of Currently Published Methods for Modeling Wildlife Corridors

Model	Description	Assumptions	Limitations	Tools
Cost-distance ⁶¹ (least cost path/ corridor)	Identifies path(s) that minimize total travel cost (cost-weighted distance) between source and destination.	Individuals have perfect knowledge of entire landscape. No limits on dispersal distance. Least cost paths are most likely to provide for successful movement.	Requires designation of source-destination pairs. Does not account for dispersal distance limitations or effects of path redundancy on connectivity.	ArcGIS Spatial Analyst, Corridor Designer, Linkage Mapper
Circuit Theory ⁶²	Treats landscape as electrical circuit with probability of movement dependent on resistance; accounts for positive effect of path redundancy on connectivity.	Individuals only perceive landscape within 1 cell of current location. No limits on dispersal distance.	Computational intensity increases exponentially with number of cells. Requires designation of source-destination pairs. Does not account for dispersal distance limitations.	CircuitScape, Connectivity Analysis Toolkit (CAT), Linkage Mapper, Connect
Network Flow ⁶³	Optimization problem identifying distribution of movement across landscape that maximizes flow of dispersers between source and destination.	Individuals only perceive landscape within 1 cell of current location. No limits on dispersal distance.	Computational intensity increases exponentially with number of cells. Requires designation of source-destination pairs. Does not account for dispersal distance limitations.	Connectivity Analysis Toolkit (CAT)
Graph Theory ⁶⁴	Represents patches and corridors as simple network of nodes and edges, allowing efficient calculation of network properties.	Variable: depends on method of constructing and parameterizing graph network.	Not spatially explicit: cannot identify locations of corridors in landscape. Best in conjunction with other method to supply ecologically meaningful node and edge weights.	Connectivity Analysis Toolkit (CAT), Linkage Mapper, Connect, GRAPHAB
Universal Corridor Network Simulator (UNICOR) ⁶⁵	Applies modified least cost path algorithm to all pairs of species' locations, combines to form density map.	All individuals roughly follow least cost paths smoothed with user-defined probability density function.	Outputs network of (smoothed) paths, not continuous corridor surface.	UNICOR
Resistant Kernel ⁶⁶	Hybrid between kernel density estimator and multidirectional least cost path method on continuous resistance surface.	Probability of successful dispersal decreases with distance from source along Gaussian dispersal curve. All sources contribute equally to dispersal.	Models landscape-wide patterns of connectivity, not appropriate for source-destination pairs.	UNICOR
Cost-benefit Approach ⁶⁷	Iteratively samples pairs of source-destination cells to produce link value map based on cumulative cost-weighted distance values.	Individuals have perfect knowledge of entire landscape. No limits on dispersal distance. Output paths are ecologically efficient.	Simplistic manner of accounting for dispersal distance limits; does not identify multiple alternative paths.	Spatial links tool*
Simulation Models ⁶⁸	Cumulative paths of many simulated random walkers with user-specified movement characteristics produce probabilistic corridor surface.	Individuals only perceive landscape within 1 cell of current location.	Intensive data and computational requirements. Tends to be highly sensitive to model parameterization.	J-walk, PATH tool, Delphi-based model*

* No graphical user interface (GUI) or code available for download; contact author for more information.

Overview of Available Tools Used in Corridor Modeling

Tool	Authors	Website	Freeware	Key Capabilities
ArcGIS Spatial Analyst	ESRI	http://www.esri.com/products	No	Habitat suitability modeling, patch delineation cost-distance corridor modeling
Corridor Designer	Paul Beier, Dan Majka, Jeff Jenness	http://corridordesign.org	Yes, but requires ArcGIS	Habitat suitability modeling, patch delineation cost-distance corridor modeling
CircuitScape	Brad McRae, Viral Shah	https://sites.google.com/a/circuitscape.org/circuitscape/ http://www.circuitscape.org	Yes, but best in conjunction with GIS software	Circuit theory modeling
Connectivity Analysis Toolkit (CAT)	Carlos Carroll	http://www.klamathconservation.org/science_blog/software/	Yes, but best in conjunction with GIS software	Circuit theory modeling, network flow modeling, graph theory analysis, patch-free implementation
Linkage Mapper	Brad McRae	https://code.google.com/p/linkage-mapper/	Yes, but requires ArcGIS	Cost-distance modeling, circuit theory modeling, graph theory analysis, pinch-point and barrier analysis, climate gradient corridor analysis
Connect	Ian Breckheimer, Austin Milt	http://www.unc.edu/depts/geog/lbe/Connect/	Yes, but requires ArcGIS	Circuit theory modeling, graph theory analysis, landscape prioritization
UNICOR	Erin Landguth, Brian Hand, Joe Glassy, Mike Jacobi	http://cel.dbs.umt.edu/cms/index.php/software/unicor	Yes, but best in conjunction with GIS software	UNICOR cost-distance modeling, resistant kernel modeling, small-scale graph theory analysis
GRAPHAB	Jean-Christophe Foltête, Céline Clauzel, Gilles Vuidel, Pierline Tournant	http://thema.univ-fcomte.fr/productions/graphab/en-doc.html	Yes, but best in conjunction with GIS software	Graph theory analysis





WILD NORTH PHOTOGRAPHY

Policy

Ensuring connectivity for wildlife in the face of habitat fragmentation and climate change involves not only the consideration of wide-ranging geographic scales from local to multi-national, but also complex social, political, and economic issues. The complexity of this undertaking transcends traditional political and governmental boundaries, making it challenging for individuals or groups to know how best to use their scarce time and resources most effectively to protect wildlife corridors.

The good news is that there has been a recent groundswell of policies across the United States that are providing new avenues to advance wildlife connectivity. By expressly acknowledging the critical role of corridors, these policies equip citizens and conservation practitioners with a variety of tools and mechanisms for effectively protecting connectivity. This section discusses examples of supportive policies already in place that facilitate corridor conservation, including new governmental policies recently adopted at the federal, regional, and state levels as well as efforts aimed at protecting connectivity on private lands.

Public Lands

There are several new policies aimed at conserving wildlife corridors on public lands, including those at the federal, regional (or multi-state), and state levels. Following are just a few examples of such efforts.

The New Forest Planning Rule

The U.S. Forest Service (USFS), in the Department of Agriculture, finalized new federal regulations for Forest Planning in 2012 and, for the first time since the National Forest Management Act was passed in 1976, regulations now specifically state that connectivity must be incorporated into plans.⁶⁹ The new rule includes a definition of connectivity and states, “the plan must include plan components, including standards or guidelines, to maintain or restore the ecological integrity of terrestrial and aquatic ecosystems and watersheds in the plan area, including plan components to maintain or restore structure, function, composition, and connectivity ...” Several other sections of the rule also address terrestrial and aquatic connectivity.

CASE STUDY

Path of the Pronghorn Protected by the U.S. Forest Service

Individuals, organizations, and U.S. Forest Service employees interested in protecting crucial habitat connectivity for wildlife now have a relatively straightforward example to administratively designate and protect habitat as a migration corridor.

The Path of the Pronghorn is well-defined and well-documented in its annual use by wildlife, confirmed with numerous scientific studies. Pronghorn summer in the area around Jackson, Wyoming, migrating from the Green

River basin wintering areas. The round-trip migration distance is 175-330 miles—the longest known terrestrial animal migration within the contiguous 48 states. Within the Bridger-Teton National Forest (the northern portion of the migration corridor), a narrow strip of land approximately 47 miles in length and encompassing 29,400 acres was protected to maintain pronghorn migration and ensure no new projects or actions impede pronghorn use.

This protection came about as part of the forest planning process; amending forest plans to protect wildlife corridors on federal lands is a process that can be replicated in other places in the country. The U.S. Forest Service did not redraw boundaries of any

existing management areas, but rather overlaid the corridor boundaries on the management areas, checking to ensure there were no internal conflicts in direction, guidelines, or standards. The statement designating the corridor was straightforward language:

All projects, activities, and infrastructure authorized in the designated Pronghorn Migration Corridor will be designed, timed, and located to allow continued successful migration of the pronghorn that summer in Jackson Hole and winter in the Green River basin.

This standard is enforceable by law under the 1982 regulations.

Some key lessons from this example are:

- Build strong local community and political support for the corridor. This can be done through increasing public awareness and having credible scientific information that supports wildlife use of the corridor. It is always better to start with agreement about the value of the corridor.
- If possible, select non-controversial lands that are not being fought over by different user groups or special interests. Work with stakeholders to identify critical areas or uses within the corridor and work together to outline the corridor boundaries and mitigate threats.
- Create an administrative designation that is specific and described in simple language, with clearly defined boundaries. Make sure that protection is leveraged across jurisdictional boundaries so that the U.S. Forest Service designation connects to larger landscape conservation goals. The language should be formulated as a Forest Plan *standard*, so that it is legally enforceable.

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The new rule applies to all national forest management plans written by the USFS. Although the initial roll-out of the new rule will be limited to a handful of pilot forests, eventually all USFS lands will be subject to these new connectivity requirements. One simple way for people to get involved is to ask their local USFS managers to consider wildlife connectivity in their future land management plans. To find out the status of national forests plan in your area, go to: <http://www.fs.fed.us/>.

Federal Policies Responding to Climate Change

In 2009, (then) Department of the Interior Secretary Ken Salazar issued Secretarial Order 3289, known as, *Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources*.⁷⁰ Pursuant to that Order, the U.S. Department of the Interior, which houses both the U.S. Fish and Wildlife Service (USFWS) and the National Park Service (NPS), committed to conserve and manage fish and wildlife, including more than 800 species of migratory birds, in the face of climate change, recognizing that shifting habitat requires investment in new wildlife corridors. In addition, the Department set up new Landscape Conservation Cooperatives to coordinate landscape-level management responses, in part for wildlife migration and related needs for new wildlife corridors.⁷¹

The NPS and USFWS recently released strategies that guide their agencies in responding to climate change. In its *Climate Change Response Strategy*, the NPS seeks to “develop cross-jurisdictional conservation plans to protect and restore connectivity and other landscape-scale components of resilience.”⁷² This effort supports one of the overarching goals of the plan, which focuses on implementing adaptation strategies that promote ecosystem resilience and enhance restoration, conservation, and preservation of park resources. The USFWS’s *Rising to the Urgent Challenge: Strategic Plan*

for Responding to Accelerating Climate Change (2010) seeks to promote habitat connectivity and integrity.⁷³ It was followed by an interagency effort (including the Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and the USFWS) resulting in the *National Fish, Wildlife and Plants Climate Adaptation Strategy* (2012), which outlines specific strategies and actions to increase connectivity and protect wildlife corridors.⁷⁴

In a similar vein, the USFS recently adopted a *National Roadmap to Responding to Climate Change*.⁷⁵ Among other things, the Roadmap recommended that the USFS take steps to immediately connect habitats to improve adaptive capacity by (1) collaborating with partners to develop land management plans that establish priority locations for maintaining and restoring habitat connectivity to mitigate the effects of climate change; (2) seeking partnerships with private landowners to provide migration corridors across private lands; (3) removing or modifying physical impediments to the movement of species most likely to be affected by climate change; (4) managing forest and grassland ecosystems to decrease fragmentation; and (5) continuing to develop and restore important corridors for fish and wildlife.

Wildlife Provisions in the New Transportation Law

In 2012, Congress enacted and President Obama signed into law, the *Moving Ahead for Progress in the 21st Century Act (MAP-21)*.⁷⁶ Funding surface transportation programs at over \$105 billion for fiscal years 2013 and 2014, MAP-21 is the first highway authorization enacted since 2005. A watershed event, MAP-21 is the first national transportation law to weave throughout its programs explicit authority for state, federal, and tribal managers to reduce the number of motorist collisions with wildlife and improve connectivity among

habitats disrupted by roads. Projects to reduce, maintain, or improve habitat connectivity are eligible for funding under the following programs:

- **Surface Transportation Program (§ 1108)** – Mitigation of harm to natural habitat and wetlands caused by roads, including development of conservation and restoration plans.
- **Highway Safety Improvement Program (§ 1112)** – Addition or retrofitting of structures or other measures to eliminate or reduce crashes involving vehicles and wildlife.
- **Federal Lands and Tribal Transportation Programs (§ 1119)** – Environmental mitigation in or adjacent to tribal land to improve public safety and reduce vehicle-caused wildlife mortality while maintaining habitat connectivity; or to mitigate the damage to wildlife,

aquatic organism passage, habitat, and ecosystem connectivity, including the costs of constructing, maintaining, replacing, or removing culverts and bridges, as appropriate.

- **Federal Lands Access Program (§ 1119)** – Environmental mitigation in or adjacent to federal land to improve public safety and reduce vehicle-caused wildlife mortality while maintaining habitat connectivity.
- **Transportation Alternatives (§ 1122)** – Activities to reduce vehicle-caused wildlife mortality or to restore and maintain connectivity among terrestrial or aquatic habitats.

To get involved in providing for connectivity as part of state, municipal, or local highway transportation projects, contact your state department of transportation.

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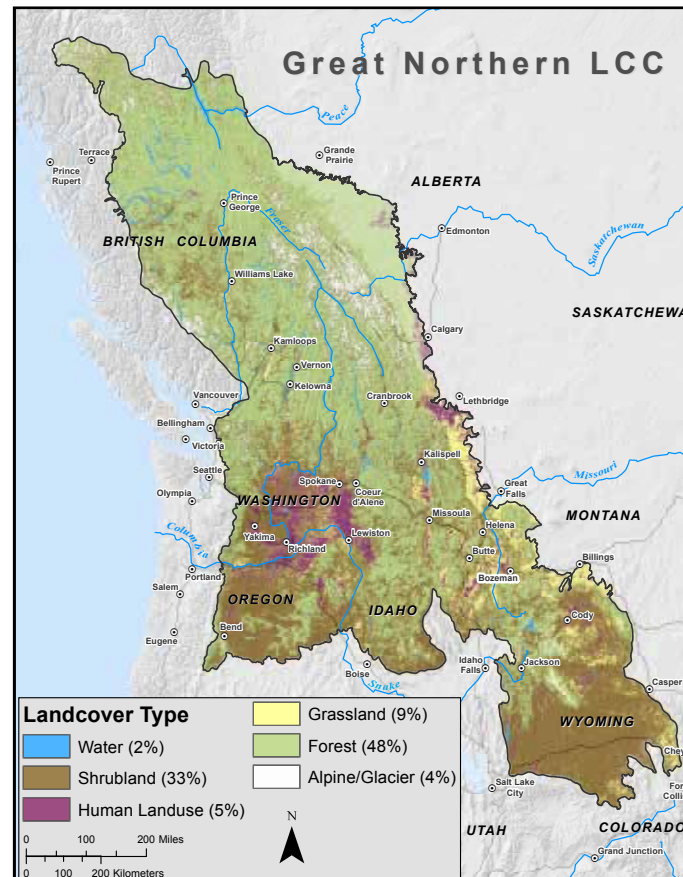
Aerial view of the Trans-Canada Highway overpass wildlife crossing between Banff and Lake Louise, Alberta.

Regional Policy Initiatives

In 2007, the Western Governors' Association (WGA) unanimously approved policy resolution 07-01, *Protecting Wildlife Migration Corridors and Crucial Wildlife Habitat in the West*.⁷⁷ This resolution describes the importance of wildlife corridors and crucial habitat and asks the Western states, in partnership with important stakeholders, to identify key wildlife corridors and crucial wildlife habitats in the West and make recommendations on needed policy options and tools for preserving those landscapes. To implement the resolution, the WGA launched its Wildlife Corridors Initiative, a multi-state collaborative effort charged with developing findings and recommendations on various aspects of wildlife corridors

and crucial habitat. Under the auspices of the Western Governors' Wildlife Council (WGWC), the initiative is developing policies and tools to assist states in identifying and conserving crucial wildlife habitat and corridors across the West. In addition to state-wide data, WGWC is also working with sixteen participating states to compile transboundary habitat and corridor data, the Crucial Habitat Assessment Tool (CHAT). Conservation practitioners can attend online webinars to learn more about how this tool can be used to inform state, regional, and local land-use planning and other decisions affecting wildlife connectivity.

The Great Northern Landscape Conservation Cooperative (GNLCC) is a partnership of federal agencies, five states, two Canadian provinces, Tribes, and citizen groups encompassing an area from the Greater Yellowstone Ecosystem to the Pacific Cascade Mountains to the Canadian Rockies in Alberta and British Columbia. The GNLCC shares data, science, and capacity, working across boundaries and jurisdictions to align and enact a regional response to landscape conservation. The GNLCC plays a critical role in building resource resilience in the face of climate change and other landscape-level stressors. Advancing habitat connectivity is one of its three top priorities.



State Policy

A number of states have adopted policies to improve or maintain connectivity for wildlife, including Colorado, Florida, Maine, New Mexico, and Washington.⁷⁸

Colorado

In 2010, the State of Colorado passed the Wildlife Crossing Zones Act (Colorado House Bill 10-1238).⁷⁹ The act assures that Colorado motorists will see more roadside reminders to slow down and watch for wildlife in specifically designated corridors, with the goal of reducing collisions between motorists and wildlife. It allows the Colorado Department of Transportation (CDOT), in consultation with the Colorado Division of Wildlife, to establish areas within the public highways of the state as wildlife crossing zones. In total, the agencies can identify up to 100 miles of highways in these zones. If CDOT establishes an area as a wildlife crossing zone, it may erect signs identifying the zone and establish a lower speed limit for the portion of the highway that lies within the zone, with corresponding increased penalties for exceeding the speed limit. Although the preliminary analyses suggest that the effect on wildlife-vehicle collisions was not statistically significant, the act provides an example of the types of policy that may be implemented to lessen the barrier effect of roads on wildlife movement.

Florida

In 2013, the Governor and Cabinet of the State of Florida similarly recognized the vital importance of a Florida Wildlife Corridor that would run approximately 1,000 miles from the Everglades to the

Georgia border. Florida officials recognized the initiative's ability to serve multiple purposes, including transcending cultural, political, and geographic boundaries in conserving lands and ultimately helping to reconnect the state's fragmented lands and waters. Among other things, the corridor was identified as vital to protecting and restoring habitat and migration corridors essential for the survival of diverse wildlife, including wide-ranging Florida panthers, Florida black bear, and other native species that represent Florida's natural heritage. In addition, officials recognized that protecting the corridor would provide essential ecosystem services, such as a clean and adequate water supply, storm protection, healthy soils, and clean air for people and wildlife.⁸⁰

Maine

In 2010, the State of Maine enacted the Maine Stream Crossing law (LD 1725 – HP 1224),⁸¹ which requires new culverts to be larger and better situated in streams. Recent studies show that about 90% of the culverts where streams flow under Maine's roads failed to allow fish and other aquatic organisms to pass. The law requires new stream crossings to be designed with a 1.2 times bank full requirement resulting in an estimated 175-325% increase in structure widths for stream crossing projects. The potential benefits to be gained from upsizing stream crossings to meet the 1.2x bank full requirements include, but are not limited to:

- accommodation of increased flows (an anticipated result of climate change);
- reduced maintenance due to increased width (diminished risk of plugging);
- reduced scouring and storm-related damage;
- reduced rate of corrosion for metal pipes;
- reduction in vehicle-wildlife collisions (wildlife may use the culverts as underpasses); and
- added value to Maine's natural resource-based economy, such as sport fishing, commercial fishing, eco-tourism, and habitat creation and restoration.

Florida Wildlife Corridor.
Painting by Mike Reagan;
designed by Carlton
Ward, Jr., Tom Hoyer, and
Richard Hilsenbeck.



Although the law does not require older culverts be redesigned for fish passage, it can be used to ensure that new culverts are built to allow for fish passage.

New Mexico

In April 2009, the New Mexico House of Representatives passed a House Joint Memorial 4 calling for “state agencies, using existing resources, with other agencies, Indian nations, tribes and pueblos, and private groups to share information about key wildlife corridors.”⁸² In so doing, the legislature recognized that better data sharing and mapping of the state’s wildlife corridors would help improve planning for development and roads, reduce collisions between motorists and wildlife, and benefit the state’s economy, which receives billions of dollars each year as a result of wildlife recreational opportunities. The Joint Memorial also advised state agencies to consider “existing and future data about wildlife corridors in the planning decisions,” and encouraged the agencies to convene a workshop among interested stakeholders to share wildlife corridor data and assess needs, including future funding needs.

In 2011, the New Mexico legislature passed House Joint Memorial 10, which advised the New Mexico Department of Transportation, Department of Game and Fish and the State Police to “work together using existing resources to create a pilot traffic safety project in an accident-prone area of the state to save lives by reducing collisions between large animals and vehicles.”⁸³ The Joint Memorial urged the state agencies to consider implementing a pilot safety project that would reduce speeds and double fines in “wildlife crossing zones” in an attempt to reduce wildlife-vehicle collisions and increase motorist safety. The legislature further encouraged the agencies to include information on wildlife-vehicle collisions on their websites and in agency brochures, to better educate citizens about the dangers of such collisions, and called upon the state governor to issue a “proclamation declaring a day to promote slowing down for the safety of drivers and wildlife.”

Washington

In July 2007, the Director of the Washington State Department of Transportation (WSDOT) issued an executive order directing that WSDOT, “in partnership with other agencies, organizations, and the public, . . . assure that road and highway programs recognize, together with other needs, the importance of protecting ecosystem health, the viability of aquatic and terrestrial wildlife species, and the preservation of biodiversity.”⁸⁴ Among its aims, the order provided that “planning should recognize and respond to particular concerns and opportunities for habitat preservation and the need for habitat connections.” It further committed the agency to identify “specific opportunities to restore habitat connectivity already damaged by human transportation corridors. Such opportunities should be prioritized for maximum ecological benefit by taking account of such factors as the multiplicity of benefited species, as well as the opportunity to support recovery of threatened and endangered species, the long-term security and viability of the habitat connection, and the cost-effectiveness of achieving connectivity gains.”

As part of the I-90 Snoqualmie Pass project, the Washington State Department of Transportation rebuilt a 900-foot bridge over Gold Creek near Lake Keechelus for wildlife to pass safely underneath the highway.



WASHINGTON STATE DEPARTMENT OF TRANSPORTATION



Policies that Support Private Land Conservation

Because wildlife do not recognize property boundaries, protecting connectivity on private lands requires a set of tools and methods that complement similar efforts on public lands. Although there is a vast array of legal tools that can be used to promote connectivity, this section focuses on two federal programs that provide funding for improving wildlife connectivity on private lands through the Land and Water Conservation Fund and the Farm Bill's Conservation Reserve Program. The first program provides funding to purchase private lands to supplement public land holdings, while the second offers monetary incentives for promoting connectivity on private lands.

Land and Water Conservation Fund

Established in 1965, the Land and Water Conservation Fund (LWCF) provides funding to federal and state governments in planning, acquiring, and developing land and water facilities to meet the outdoor recreational demands of present and future generations of Americans.⁸⁵ Over the first 35 years of its existence, LWCF funding has enabled the U.S. Forest Service, National Park Service, U.S. Fish and Wildlife Service, and the Bureau of Land Management to acquire over 4.5 million acres of land, and has provided funding to conserve over 2.3 million

acres through 37,000 state-funded projects.⁸⁶ Although a primary focus is improving outdoor recreation opportunities, LWCF funds may be used to purchase important wildlife habitat, including migration corridors. By providing funds for federal and state land managers to purchase lands from willing private sellers, LWCF can be used to create or enhance wildlife corridors that connect core habitat on public lands that might otherwise remain isolated.

Conservation Reserve Program

Although the 2014 Farm Bill reduced the amount of acreage allowed in the Conservation Reserve Program (CRP), it remains the largest private-lands conservation program in the United States.⁸⁷ CRP provides funding for interested landowners to voluntarily retire or convert eligible agricultural lands to a less-intensive use in return for annual rental payments. Similar payments are available for landowners who agree to develop or manage grassland for multiple conservation benefits, including soil, water, air, and wildlife. CRP also provides cost-sharing assistance and incentive payments for landowners who agree to undertake certain practices, such as establishing wildlife habitat buffers or windbreaks, shelterbelts or living snowfences that provide wildlife habitat and travel corridors, among other benefits.⁸⁸



WILD NORTH PHOTOGRAPHY

Taking Action

One of the greatest conservation challenges facing us today is the increasing isolation of wildlife on islands of habitat, restricted by human modifications on the landscape. Protected areas are not large enough to fully conserve biodiversity; in some cases, they may not even be sufficient to prevent species extinction. And the situation is further exacerbated by climate change as shifts in habitat and wildlife distribution will mean new challenges for maintaining terrestrial and aquatic species viability. To address this challenge, here are some actions you can take that encourage landscape connectivity and facilitate the movement of wildlife species.

Engage in federal land management planning efforts and encourage federal agencies to:

- Establish specific wildlife corridor and ecological connectivity goals and objectives for inclusion in land management plans.
- Methodically delineate and assess geographic areas of interest (cores and corridors) under current federal land and water management plans and determine the ability of key wildlife and plants to move under current conditions and their ability to adapt to climate change based on available potential core habitats and corridors.
- Determine species requirements and describe the desired future condition for public lands and waters to ensure requirements for ecological connectivity are met for the planning unit by a network of cores and corridors that ensure latitudinal and altitudinal connectivity is maintained under climate change scenarios.
- Describe management objectives, guidelines, and standards to meet the desired future condition. Include any restrictions on human use or development that are needed to reduce stressors to connectivity.
- Adhere to management plan direction and requirements for ensuing project development and implementation.
- Provide a monitoring plan to evaluate the condition of the cores and corridors and adjust management when necessary.

Engage in transportation planning efforts and encourage transportation agencies to identify wildlife crossing areas and evaluate options for structures that would allow wildlife to cross safely and minimize wildlife-vehicle collisions.

Approximately 20% of the U.S. land base is ecologically affected by road networks. The Federal Highway Administration reports 1-2 million large wild animals are struck by vehicles every year. Wildlife-vehicle collisions have increased 50% over the 15-year period from 1990 to 2005. This is perhaps one of most shocking and neglected impacts to the welfare of wild animals that requires more attention. Identifying wildlife corridors and mitigating road impacts through road design and crossing structures helps wildlife overcome the barrier effect of busy roads, reduces wildlife mortality, and promotes human safety—all at the same time.

Ensure there is cooperation and coordination among federal, tribal, state, and local governments to identify and conserve wildlife corridors and ecological connectivity; where appropriate, work across international borders, so that species that move and migrate between habitats in different countries and in international waters are protected.

- Help establish or join landscape-level conservation partnerships to ensure connectivity protections are developed and implemented at the appropriate scale and across jurisdictions.
- When State Wildlife Comprehensive Strategies (also known as State Wildlife Action Plans) are amended, provide public comments to insure they identify and prioritize the protection of wildlife corridors.
- Comment on and advocate for wildlife corridor identification and conservation in state coastal zone management plans, and other state wildlife species or habitat plans.

- Support county- and local-level open space initiatives that protect habitat and increase connectivity across the landscape.
- Support county-level and local planning efforts that maintain open space, facilitate wildlife movement, and minimize the opportunity for human-wildlife conflicts.

Advocate for incentives for private landowners to manage their lands for the benefit of wildlife.

Support land trusts and advocate for federal funding for private land management incentives through Farm Bill programs, the Land and Water Conservation Fund, and other programs specifically for enhancing ecological connectivity on private lands.

Continue to facilitate the implementation of wildlife corridors and improve landscape connectivity.

- Connect the available science on ecological connectivity and wildlife corridors with natural resource managers and decision makers. Share knowledge and methods for landscape connectivity and corridor conservation through applied practice.
- Create and advocate for the adoption of national wildlife corridors legislation that would support landscape connectivity and conservation across the country.
- Continue research that improves methods for identifying critical landscape linkages and wildlife corridors.
- Expand our knowledge about economic cost/benefit of wildlife crossing structures and the provision of ecosystem services through additional research.

CASE STUDY

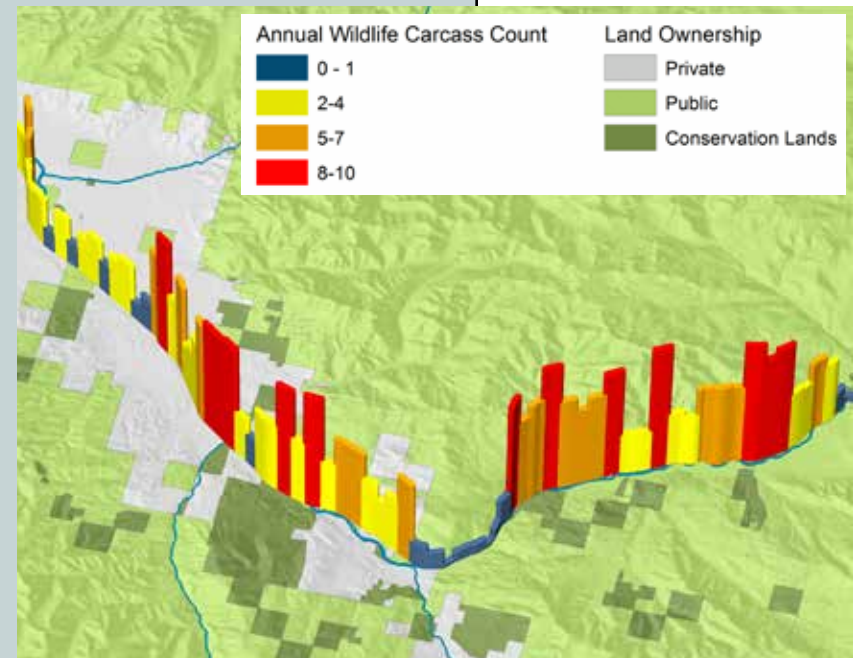
Citizen Involvement in Highway Mitigation Projects for Wildlife Crossing

Many grassroots citizen organizations across the country are getting involved in efforts to mitigate the impacts of roads on wildlife. A variety of mitigation options and techniques are available, depending on the local conditions, that may provide safe passage for both people and wildlife; some mitigation may reduce wildlife-vehicle collisions by 85% or more (e.g., reduce collisions from 100 to 15).⁸⁹ Public safety is the primary mandate of transportation agencies, and because budgets are limited, mitigation for wildlife may not be a top priority if drivers are not also at great risk. Engaging in these projects requires good information and good relationships with state department of transportation (DOT) officials. The following are some tips for engagement:

- Get involved early in the planning process. Look for state DOT highway corridor studies (pre-planning or environmental impact studies) that take a broad look at potential safety and environmental issues along a road segment of concern in order to identify potential projects to improve the roadway for both people and wildlife.
- Look for DOT State Transportation Improvement Programs (STIPs), released annually, that identify the schedule, funding, and location of all upcoming transportation projects over the upcoming four-year period. Compare planned project locales with known priority areas for conservation, submit public comments flagging potential impacts on wildlife early, and work with your state DOT partners to identify opportunities to combine wildlife mitigation measures with already-planned construction projects. Mitigation is typically much cheaper, easier, and more feasible to implement during construction than after.

- Take the initiative to acquire and interpret publicly available information. Wildlife-vehicle collisions and wildlife carcass records help identify “hotspots” where mitigation might make the most sense. Compare these to maps of land ownership and topography to understand where mitigation options may be limited and where they may be feasible. Investment in mitigation will typically only be pursued when the land on either side of the mitigated road section is secure (i.e., public or under conservation easement).
- Attend public meetings on road planning and construction projects. Submit public comments and meet with planning teams to discuss wildlife issues where they exist. Ensure that the issue is flagged early for consideration.
- Seek opportunities to collaborate with DOTs to raise funds to install mitigation measures or conduct further research on wildlife impacts where needed. Budgeting in the face of competing priorities is likely the greatest barrier to wildlife mitigation.

Maps of wildlife carcass records by mile along a highway can be powerful tools to identify hotspots where wildlife and drivers are at risk. Mitigation opportunities should be assessed with adjacent land ownership, topography, and other feasibility issues in mind.



WILD NORTH PHOTOGRAPHY



Notes

Executive Summary

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Taking Action

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