RESEARCH ARTICLE

# Mitigating Continental Scale Bottlenecks: How Small-Scale Highway Mitigation Has Large-Scale Impacts

*Anthony P. Clevenger*


## ABSTRACT

Roads are a primary contributor to habitat destruction and fragmentation yet have only recently become a major focus of conservation efforts. Road ecology originated from the realization that sprawling road systems can have substantial effects on species and ecosystems. Understanding these effects and developing science-based solutions to mitigate them will be central to large-scale landscape connectivity efforts. North American transportation agencies have been slow to adopt ecosystem and landscape-based approaches to planning. Large-landscape connectivity efforts focus on mitigating habitat fragmentation and increasing ecological connectivity at the landscape scale; however, local scale mitigation is equally important. Wildlife crossing structures are an increasingly popular strategy for restoring connectivity across highways but are only as effective as the management strategies developed around them. Coordination is needed between land management and transportation agencies for local scale mitigation to be of value to landscape scale conservation planning. Because population viability is rarely threatened by transportation alone, cumulative human impacts need to be assessed and mitigated for connectivity conservation efforts to be successful at local scales. Here I provide an example where a multi-criteria decision-making process was used to assess potential transportation mitigation opportunities at a local scale but within a regional connectivity context. More work is required to assess the role of crossing structures in allowing animals to adapt and population to redistribute in response to changing climate.




**Keywords:** Connectivity, crossing structures, habitat fragmentation, highways, mitigation, planning, scale, wildlife conservation

Ecological connectivity is a fundamental principle in the conservation of wildlife, ecosystems and biodiversity (Crooks and Sanjayan 2006). In a general sense, all animal and plant populations are shaped by, and persist because of, spatial connections. Habitat connections are needed for mobile animals to move through and survive within resident home ranges. At broader scales, landscape linkages allow individuals to move among core habitat areas, providing stability to regional populations and allowing range peripheries to be occupied through periodic or continual augmentation (Taylor et al. 1993). The resulting genetic flow across large connected populations also contributes to localized adaptability to a changing environment and helps to ensure that only genes beneficial to individual fitness are expressed (Broquet et al. 2010). Although ecological connectivity is nebulous and without definition as it pertains to species, habitats, spatial and temporal scales, thresholds, and risk, the notion of connectivity is nonetheless central to effective conservation planning (Beier et al. 2011, Theobald et al. 2012).

Habitat loss and fragmentation are the leading causes of extinction (Wilcove et al. 1998), and the negative effects of fragmentation are predicted to increase as organisms attempt to track changing climates (Thomas et al. 2004). Maintaining and restoring landscape connectivity is therefore a central priority for wildlife conservation (Soulé and Orians 2001). Roads are a primary contributor to habitat destruction and fragmentation (Forman and Alexander 1998, Forman et al. 2003), yet they have only recently become a major focus of conservation efforts (Beckmann et al. 2010).

Roads and their networks are one of the most prominent human-made features on the landscape today (Sanderson et al. 2002, Ritters and Wickham 2003). Busy roads can block or disrupt animal movement (Hels and Buchwald 2001, Rondini and Doncaster 2002, Chruszcz et al. 2003) and in some cases are the leading cause of animal mortality (Maehr et al. 1991, Jones 2000, Kaczensky et al. 2003).

Compared to other sources of habitat fragmentation, roads not only fragment habitat and sever wildlife populations (genetic consequences) but are also an important source of

*Ecological Restoration* Vol. 30, No. 4, 2012
ISSN 1522-4740 E-ISSN 1543-4079

wildlife mortality (demographic consequences). Understanding these 2 forces and developing science-based solutions to mitigate them will be central to large-scale landscape connectivity efforts in landscapes impacted by a growing transportation network.

Conservation measures at regional and landscape scales are critical in conserving and promoting connectivity of wildlife populations (Beier and Noss 1998, Bennett 1999, Epps et al. 2005, Crooks and Sanjayan 2006). At the landscape scale, this has occurred through land acquisition and managing existing lands for regional scale connectivity. However, securing local-scale connections will be equally important for mitigating continental-scale bottlenecks. All the critical corridors and habitat connections, large and small, must be functional for the entire system to be effective and viable over the long term. In this paper, I describe the importance of local-scale connections in restoring large landscape-scale bottlenecks. I present examples of some of the advances made in mitigating perhaps the most widespread and contentious threat to regional corridor networks and a planning approach for mitigating highway effects at multiple scales.

## Road Ecology: History and Advancement

Historically, roads followed natural landscape contours and ran parallel and adjacent to rivers and streams. However, post-war transportation planning and road building diverged from the sinuous landscape form of roads and became more angular and rectilinear in order to provide efficient travel between population centers. As a result, today many roads and highways cut across landscapes, severing ecosystems and local habitats and blocking or radically altering many terrestrial and aquatic flows.

The field of road ecology originated from the realization that sprawling road systems can have substantial effects on the function of ecosystems and their parts (Forman and Alexander 1998, Spellerberg 1998). This realization occurred less than 2 decades ago, reflecting the recent emergence of this new interdisciplinary field of applied conservation biology (Spellerberg 1998, Forman et al. 2003, Davenport and Davenport 2006). As recent as 15 yr ago, there was little, if any, communication between transportation agencies and natural resource agencies (National Research Council 1997). Transportation agencies planned and executed projects, rarely consulting with stakeholder agencies. Of concern to land managers responsible for mitigating road impacts was the discovery that transportation practitioners were largely unaware of road effects beyond the right-of-way and how roads fit into the natural landscape (National Research Council 2005).

In the U.S., passage of successive Transportation Equity Act bills (ISTEA, TEA-21, SAFETEA-LU) helped raise agency awareness of the more terrestrial concerns of roads on the environment (Evink 2002). Along with that discovery came the emerging concept that the transportation network is very similar to the ecological (or habitat) networks across the land—and where these 2 intersect, on-the-ground measures are needed to restore or maintain the important ecological flows (Forman et al. 2003, Beier et al. 2006).

## Thinking Big—Transportation Planning

Europeans had far more experience managing the conservation of natural or semi-natural landscapes within a matrix of transportation infrastructure than in North America (Bekker 1995, Opdam 1997, Iuell 2003). The European method of transportation planning was adopted as the most broad and ecologically comprehensive means of trying to resolve conflicts between transportation and ecological networks. In planning, this consisted of overlaying transportation networks on top of ecological networks, identifying the conflict zones, and prioritizing them in terms of urgency and ecological importance (cites). This is done at the national-level and the Pan-European level using ecological network data from the European Environmental Agency and Natura 2000 mapping (Iuell 2003).

This approach was entirely novel in North America 10 yr ago. Fortunately, it did resonate among biologists and also some transportation agencies (Beier et al. 2006, Giles et al. 2010, Smith and Sullivan 2010). Transportation and land management agencies, universities, and nongovernmental organizations have attempted to address this need by conducting workshops where biologists, academics, and regulatory specialists come together to make decisions on conservation and connectivity needs based on analysis of best available environmental data (Beier et al., 2006, Beckmann et al. 2010). In subsequent years, transportation planning exercises, such as Statewide Transportation Improvement Program (STIP) helped identify key areas for transportation infrastructure investments. Concurrent with STIP, state natural resource agencies developed statewide comprehensive wildlife conservation plans that addressed a full array of wildlife and habitat conservation issues. Coordination of both network plans in a timely and integrated fashion helps streamline environmental concerns in transportation planning (Beckmann et al. 2010).

Ten years ago, no transportation agency in North America had completed a state- or province-wide habitat linkage map. In the U.S. today, many states have initiated or completed statewide maps, while in Canada this approach has not been initiated. The approach has gained traction in Asia as Yunnan Province, China, is contemplating a province-wide map that identifies intersections between areas of ecological importance and the growing highway network.

A significant advance in mitigating transportation impacts at large landscape scales in North America occurred recently when the Western Governors Association (WGA) passed the Wildlife Corridors Initiative (WGA 2008). The initiative protects wildlife migration corridors and crucial wildlife habitat in the West and sets a management directive to coordinate habitat protection and land use management for wildlife across jurisdictional boundaries. Of particular note was the section of the report produced by the Transportation Infrastructure Working Group, which made detailed recommendations on ways to integrate future transportation planning with wildlife habitat conservation at the systems level. The WGA includes Governors from all the western U.S. States and Premiers from British Columbia and Alberta.

## Big Ideas—Continental-Scale Landscape Connectivity

One of the most popular conservation strategies to overcome the impacts of habitat fragmentation has been to increase ecological connectivity, or the degree to which a landscape facilitates the movement of organisms (Crooks and Sanjayan 2006, Hilty et al. 2006). This strategy has been implemented at local scales (Duke et al. 2001, Dixon et al. 2006, Paetkau et al. 2009), regional scales (Beier et al. 2006), and continental scales (Kaiser 2001, Ross 2004, Van der Sluis et al. 2004, Raimer and Ford 2005). The justification to this point has been relatively simple: by increasing connectivity, gene flow and dispersal is increased within and among populations (Tewksbury et al. 2002), increasing biodiversity and reducing extinction (Damschen et al. 2006).

The Yellowstone to Yukon (Y2Y) initiative is a big idea. It is an internationally significant movement corridor that stretches 3000 km from Wyoming to the Northern Yukon territory (Locke and Francis, this volume). Wide-ranging species with trans-boundary movements, such as wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*), are some species that theoretically should benefit from the large-scale, landscape conservation effort. Despite the extensive nature of road systems throughout Y2Y, mitigation of major highways throughout the ecoregion has not received much attention until recently. This is particularly surprising given nearly all the major transportation corridors run east to west, which poses particular problems to the predominantly north-south movement of wildlife.

Recent research documenting high rates of wildlife mortality, reduced mobility and gene flow across highways has helped raise awareness of the severity of highway impacts on species of conservation concern (Apps 1999, Waller and Servheen 2005, Packila et al. 2007, Proctor et al. 2012). While these studies discovered the harmful effects of transportation infrastructure, long-term research was being conducted on potential solutions to mitigate highway impacts and promote cross-highway connectivity in Banff National Park, Alberta (Clevenger and Waltho 2000, 2005, Clevenger et al. 2009). Today there are a growing number of Safe Passage Projects throughout Y2Y that are designed to mitigate the impacts of highways on wildlife populations (Figure 1). Many of these projects have come about through interagency cooperation, nongovernmental organization efforts, and a common understanding of stakeholder needs and capacities (Beier et al. 2006, Beckmann et al. 2010).

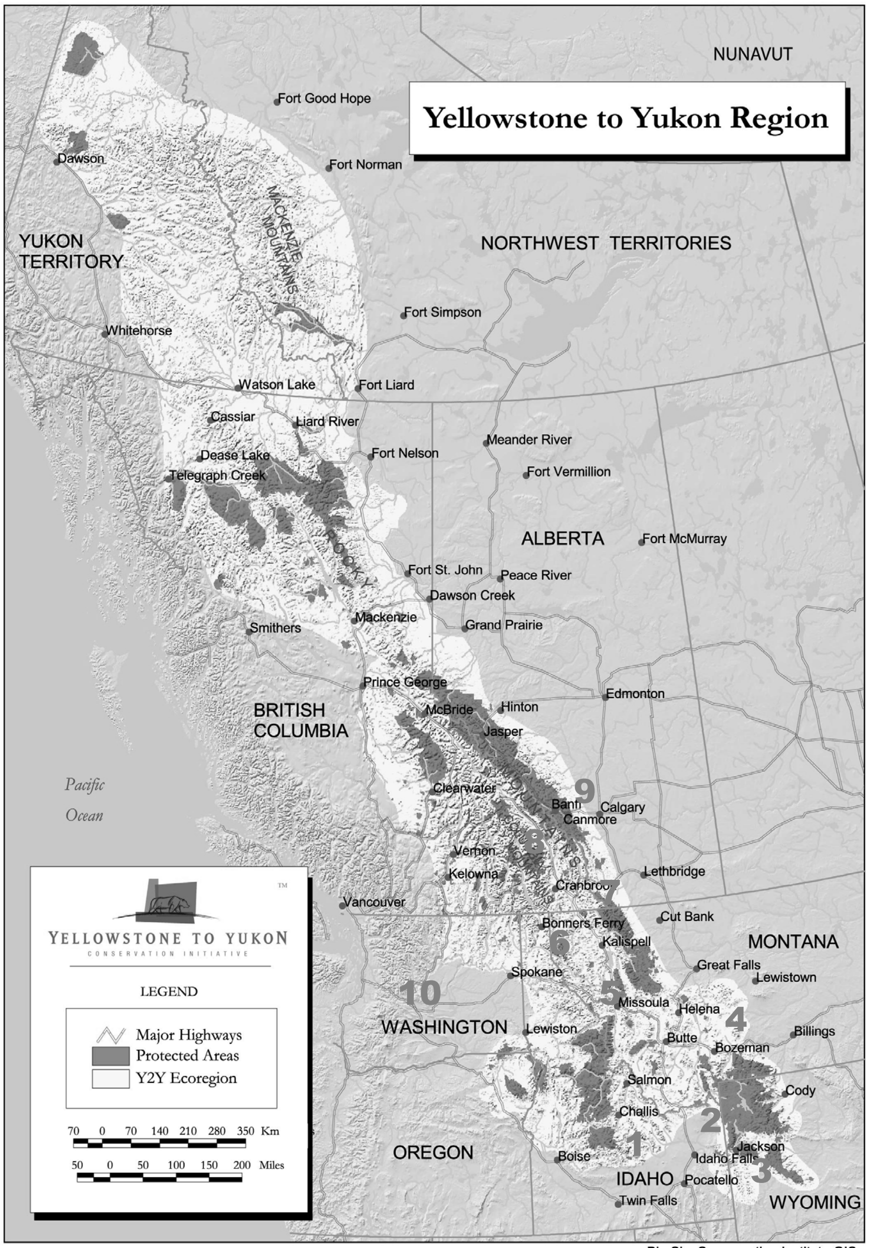


## Local-Scale, Site-Specific Mitigation—The Missing Link

Successfully promoting gene flow and dispersal in large landscape-scale connectivity efforts requires that the sum of all the critical parts (habitat linkages and corridors) be integral and functional at not only regional scales but local as well. Some examples of local-scale, site-specific mitigation efforts that effectively promote connectivity at both scales include the Trans-Canada Highway in Banff National Park, Alberta and Interstate-75 in Florida (Evink 2002, Ford et al. 2010). An ambitious landscape-scale effort to restore ecological connectivity across Interstate-90 in the Washington Cascades (Snoqualmie Pass) is currently underway (Giles et al. 2010). These exemplary projects utilize wildlife crossing structures and fencing to meet the dual needs of reducing wildlife mortality and increasing dispersal across major transportation corridors.

Wildlife crossing structures are only as effective as the management strategies developed around them that incorporate all the key landscape elements (humans, terrain, natural resources, transportation). These engineered passage structures are in essence small, narrow, site-specific habitat corridors. For these conservation measures to fulfill their function as habitat connectors, 2 scales of mitigation strategies must be considered (Clevenger and Huijser 2011). Site-level or local-scale impacts from development or human disturbance adjacent to crossing structures may impede wildlife use (Beier and Loe 1992, Clevenger and Waltho 2000). Similarly, alteration of landscape elements at a broader regional-scale could impede or obstruct movements towards the crossing structures and prevent animals from using them, rendering them ineffective. The larger scale concerns must be recognized and remediated if the local-scale measures are to be effective, and vice-versa.

Coordination between land management and transportation agencies, and in some cases municipal planning organizations, can reconcile the connectivity concerns at both scales (National Research Council 2005). If a transportation agency designs and builds appropriate wildlife crossings, but the land management agency fails to manage adjacent lands, the transportation agency funds will be




Big Sky Conservation Institute GIS

**Figure 1. Safe passage projects mitigating highway impacts on wildlife in the Yellowstone to Yukon (Y2Y) ecoregion. 1: State Highway 75, Ketchum, Idaho, 2: Raynolds Pass, Idaho, 3: Togwotee Pass, Wyoming, 4: Bozman Pass, Montana, 5: US Highway 93 Montana, 6: US Highway 95, Idaho, 7: Highway 3, Alberta-British Columbia, 8: Kootenay National Park, British Columbia, 9: Banff National Park, Alberta. Outside the Y2Y region, 10: Snoqualmie Pass, Washington.** Map provided by Big Sky Conservation Institute, Bozeman, Montana.

wasted and the measures likely ineffective. Similarly, if adjacent lands are managed to ensure regional-scale connectivity across a highway, but the transportation agency fails to provide appropriate wildlife crossing structures, then efforts of the land management agency will be of limited conservation value.

## Highway 3 Crowsnest Pass: A Case Study in Transportation Mitigation for Wildlife and Connectivity

Because the viability of wildlife populations is rarely threatened by transportation systems alone, cumulative human impacts must be assessed and mitigated for connectivity conservation efforts to be successful at local scales. The southern Canadian Rocky Mountains encompass the northern half of the Crown of the Continent Ecosystem and comprise a zone of utmost strategic importance in the securing of connected wild land ecosystems (Apps et al. 2007, Graumlich and Francis 2010). The Highway 3 transportation corridor that bisects the Crown of the Continent Ecosystem from east to west is a stellar example of the challenges of complex land use and large landscape connectivity (Apps et al. 1997, 2007).

Highway 3 is associated with human settlement and development in and around the communities of Sparwood, Fernie and Elko, British Columbia, as well as the Municipality of Crowsnest Pass in Alberta. Given the existing communities, a large proportion of private land ownership and high human accessibility, much of the landscape through which Highway 3 passes is composed of, or is potentially subject to, permanent human development. Considering human demographic and socioeconomic trends, there is obvious potential for the Highway 3 corridor to fracture the north–south contiguity for populations of wide-ranging carnivores and some ungulates.

As a source of high mortality and a constraint to the movements of resident and dispersing animals, the genetic and demographic implications of such a fracture zone can destabilize populations and increase the likelihood of localized extirpation. Addressing cumulative impacts in the Highway 3 area requires research and planning across multiple scales, with strategies tailored not only for transportation, but simultaneously for public land management and the management and development of residential and industrial private lands.

Although conservation measures at regional and landscape scales are critical in maintaining wildlife population connectivity, to address Highway 3 impacts on terrestrial wildlife a project

**Table 1. Five criteria used to assist in ranking sites for mitigation priority. Sites were visited in the field and evaluated for mitigation potential. Each site was assigned a subjective score of mitigation importance from 1 (low) to 5 (high) on the basis of the following criteria.**

| Criteria | Description |
|---|---|
| Local Conservation Value | Captures the importance of maintaining connectivity for the seasonal movement of local herds of ungulates, carnivores or other related fine-scale opportunities for wildlife. For example, elk herds move in the autumn from their summer range at higher elevations in the adjacent mountains down into the valley in winter where highways are located. |
| Regional Conservation Significance | Captures the importance of the site in maintaining connectivity at a regional scale. This relates especially to large mammals that have low population density (e.g. grizzly bears, wolverines [*Gulo gulo*]), but it could also relate to the importance of corridors for more common species. Success for some of these species may be measured by safe passage at highway crossings at very low rates, because effective population levels are so low. |
| Transportation Mitigation Opportunity | Considers the ease of implementing mitigation measures, including consideration of geographical setting and features (i.e., stream crossing, terrain, slope stability), the difficulty or ease for the placement and design of infrastructure (i.e., underpass, overpass), the age, condition and appropriate size of existing infrastructure (i.e., culverts, bridges) and other physical, biological and social (i.e., recreational trails) features. |
| Highway Mortality | The relative rate of wildlife-vehicle collisions at each site was scaled as a proxy for safety risks to motorists and wildlife. |
| Land Security | Evaluates the condition of the lands directly adjacent to the site. Investing in highway infrastructure that provides safe passage for wildlife is often an expensive undertaking, costing a million dollars or more. Therefore, land security (protection from development or land use not conducive to wildlife movement) around the structure is an important consideration. Values for land security were developed based on land ownership, existing conservation easement information, and land development attributes on both sides of the highway at each site. The highest value (5) was very secure and the lowest value (1) had development on lands on both sides of the highway at the MES location. |

was developed to focus on the finest scale necessary—that of site-specific mitigation of the highway (Clevenger et al. 2010). A group of 6 experts was gathered, each with experience in local wildlife conservation, regional scale landscape connectivity, wildlife-vehicle collision severity, and highway mitigation. The group synthesized the existing biological data, analyses, and reports regarding key landscapes, habitat linkages, and wildlife mortality for large mammals to describe the current conflicts with wildlife along a 180-km section of the Highway 3 transportation corridor in southwestern Alberta and southeastern British Columbia.

Based on wildlife conservation, regional habitat connectivity, and motorist safety, 31 sites were identified in the project area as key locales where highway mitigation should be focused. Each site was visited by the group of experts in the field and evaluated using 5 different criteria: local conservation value, level of highway mortality, land-use security, regional conservation significance, and opportunities for highway mitigation (Table 1). Each criterion was assigned a score from 1 (low) to 5 (high) and reached by consensus. The average score of the 5 criteria helped determine the relative importance for mitigation efforts among the 31 sites. At each site, an evaluation of a variety of short- and long-term wildlife mitigation measures was identified and became recommendations.

This multi-criteria decision-making process resulted in an informed assessment of potential transportation mitigation sites and options along Highway 3 in the short and long term. It reflected the best available understanding and options for direct mitigation of highway impacts to local populations of large terrestrial wildlife and larger regional connectivity context. This is the first example I am aware of where site-specific highway mitigation planning has been conducted at a regional scale (=180 km of highway), evaluating 5 elements that are critical for success (Table 1). Because transportation and land management agencies were involved by providing project input from the start, the report and its findings are currently being used by their agencies to help prioritize highway mitigation projects in the short and long term.

This type of approach is particularly valuable, given the need to integrate not only indices of wildlife mortality and regional connectivity across transportation infrastructure, but the juxtaposition of secure lands for local and regional scale connectivity concerns and opportunities for realistic implementation of site-specific mitigation measures. The assessment also relied heavily on a cost-benefit analysis of wildlife-vehicle collisions on Highway 3, helping to pinpoint sections where mitigation would produce cost-benefits over the long term (Huijser et al. 2009). Nearly one-third of the monetary costs for the sites in British Columbia were estimated in excess of the threshold cost per year, while half of the sites in Alberta had estimated annual costs in excess of the threshold.

## Conclusions

The U.S. highway system is the largest public works project in history, and while its 75,317 km of high-capacity highway are critical to the U.S. economy (Button and Hensher 2001, Forman et al. 2003), they also present hard barriers to wildlife movement across North America (Riley et al. 2006). Road systems have been referred to as "the sleeping giant of conservation biology" (Forman 1998), and they have now become a major focus of connectivity research and planning (National Research Council 2005, Beier et al. 2006).

Wildlife crossing structures are an increasingly popular strategy for restoring connectivity across highways. Recent studies have shown that crossing structures can facilitate landscape scale connectivity at the level of individuals and populations (Clevenger and Waltho 2005, Gagnon et al. 2011, Sawaya 2012, Van Manen et al. 2012). Increasing landscape connectivity also has been recognized as an important tool for helping biodiversity respond to climate change (Heller and Zavaleta 2009, Krosby et al. 2010). The role of crossing structures in allowing animals to adapt and respond to a warming climate has received little attention but intuitively should be an important tool for improving species' abilities to respond to a changing climate. Future research should continue to identify attributes of wildlife crossing structures (underpasses and overpasses) that facilitate connectivity and dispersal for fragmentation-sensitive species to ensure local-scale habitat linkages will be able to support landscape-scale connectivity (Crooks and Sanjayan 2006, Hilty et al. 2006).



## References

Apps, C.D. 1997. Identification of grizzly bear linkage zones along the Highway 3 corridor of southeast British Columbia and southwest Alberta. Prepared for Ministry of Environment, Lands and Parks, Victoria, BC and World Wildlife Fund Canada, Toronto, ON.

Apps, C.D. 1999. Space-use, diet, demographics, and topographic associations of lynx in the southern Canadian Rocky Mountains: a study. Pages 351–72 *in* L.F Ruggiero, K.B. Aubry, S.W. Buskirk, G.M. Koehler, C.J. Krebs, K.S. McKelvey and J.R.Squires (eds) *Ecology and conservation of lynx in the United States.* General Technical Report RMRS-GTR-30WWW. Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Apps, C.D., J.L. Weaver, B. Bateman, P.C. Paquet and B.N. McLellan. 2007. Carnivores in the southern Canadian Rocky Mountains: core areas and connectivity across the Crowsnest Highway. Wildlife Conservation Society Canada Conservation Report No. 2, Toronto, Ontario.

Beckmann, J., A.P. Clevenger, M. Huijser, and J Hilty. 2010. *Safe Passages: Highways, Wildlife and Habitat Connectivity.* Washington, DC: Island Press.

Beier, P. and S. Loe. 1992. A checklist for evaluating impacts to wildlife movement corridors. *Wildlife Society Bulletin* 20:434–440.

Beier, P. and R. Noss. 1998. Do habitat corridors provide connectivity? *Conservation Biology* 12:1241–1252.

Beier, P., K.L. Penrod, C. Luke, W.D. Spencer and C. Cabanero. 2006. South Coast missing linkages: restoring connectivity to wildlands in the largest metropolitan area in the USA. Pages 555–586 *in* K. Crooks and M. Sanjayan (eds) *Connectivity Conservation*. Cambridge University Press: Cambridge, UK.

Beier, P., W. Spencer, R. Baldwin and B. McRae. 2011. Towards best practices for developing regional connectivity maps. *Conservation Biology* 25:879–892.

Bekker, G.J., B. van der Hengel and H. van der Sluis. 1995. Natuur over Wegen [Nature over motorways]. Ministry of Transport, Public Works and Water Management, Delft, The Netherlands.

Bennett, A.F. 1999. Linkages in the landscape: the role of corridors and connectivity in wildlife conservation. IUCN, Gland, Switzerland and Cambridge, U.K.

Broquet T, S. Angelone, J. Jaquiéry, P. Joly, J. Léna, T. Lengagne, S. Plénet, E. Luquet and N. Perrin. 2010. Genetic bottlenecks driven by population disconnection. *Conservation Biology* 24:1596–1605.

Button, K. and D.A. Hensher. 2001. *Handbook of transportation systems and traffic control.* New York: Pergamon Press.

Chruszcz, B., A. P. Clevenger, K. Gunson, and M. Gibeau. 2003. Relationships among grizzly bears, highways, and habitat in the Banff-Bow Valley, Alberta, Canada. *Canadian Journal of Zoology* 81:1378–1391.

Clevenger, A.P. and N. Waltho. 2000 Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14:47–56.

Clevenger, A.P. and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121:453–464.

Clevenger, A.P. and M.P. Huijser. 2011. Wildlife Crossing Structure Handbook, Design and Evaluation in North America, Publication No. FHWA-CFL/TD-11-003. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Clevenger, A.P., A.T. Ford and M.A. Sawaya. 2009. Banff wildlife crossings project: Integrating science and education in restoring population connectivity across transportation corridors. Final report to Parks Canada Agency, Radium Hot Springs, British Columbia, Canada.

Clevenger, A.P., C. Apps, T. Lee, M. Quinn, D. Paton, D. Poulton and R. Ament. 2010. Highway 3: Transportation mitigation for wildlife and connectivity in the Crown of the Continent Ecosystem. Report prepared for Woodcock, Wilburforce and Calgary Foundations.

Crooks, K.R. and M. Sanjayan. 2006. *Connectivity Conservation*. Cambridge, UK: Cambridge University Press,

Damschen, E. I., N. M. Haddad, J. L. Orrock, J. J. Tewksbury,and D. J. Levey. 2006. Corridors Increase Plant Species Richness at Large Scales. *Science* 313:1284–1286.

Davenport, J. and J.L. Davenport. 2006. *The ecology of transportation: managing mobility for the environment.* London: Springer.

Dixon, J., M. Oli, M, Wooten, T. Eason, H. McCown, J. Walter and D Paetkau. 2006. Effectiveness of a Regional Corridor in Connecting Two Florida

Black Bear Populations. *Conservation Biology* 20:155–162.

Duke, D.L., M. Hebblewhite, P.C. Paquet, C. Callaghan and M. Percy. 2001. Restoring a large carnivore corridor in Banff National Park. Page 261–275 *in* R.F Maehr, R.F. Noss and J.L. Larkin (eds) *Large mammal restoration: ecological and sociological challenges to the 21st century*. Washington, DC: Island Press.

Epps, C.W., P.J. Palsbøll, J.D. Weyhausen, G.K. Roderick, R.R. Ramey and D.R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. *Ecology Letters* 8:1029–1038.

Evink, G. 2002. Interaction between roadways and wildlife ecology: a synthesis of highway practice. National Cooperative Highway Research Program Synthesis 305. Transportation Research Board, Washington, D.C.

Ford, A.T., A.P. Clevenger, K. Rettie. 2010. Banff Wildlife Crossings, Trans-Canada Highway, Alberta—An international public-private partnership. Pages 157–172 *in* J. Beckmann, A.P. Clevenger, M. Huijser and J. Hilty (eds) *Safe Passages: Highways, Wildlife and Habitat Connectivity.* Washington DC, Island Press.

Forman, R.T.T. 1998. Road ecology: a solution for the giant embracing us. *Landscape Ecology* 13:3–5.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29:207–231.

Forman, R.T.T., D. Sperling, J. Bissonette, A. Clevenger, C. Cutshall, V. Dale, L. Fahrig, R. France, C. Goldman, K. Heanue, J. Jones, F. Swanson, T. Turrentine and T. Winter. 2003. *Road Ecology: Science and Solutions*. Washington, DC: Island Press.

Gagnon, J.W., N.L. Dodd, K.S. Ogren and R.E. Schweinsburg. 2011. Factors associated with use of wildlife underpasses and importance of long-term monitoring. *Journal of Wildlife Management* 75:1477–1487.

Giles, R., S. Golbeck A. Sullivan and J. Wood. 2010. I-90 Snoqualmie Pass East Project's design engineering challenges of integrating transportation needs with landscape-level connectivity and transportation corridor-crossing objectives in Washington State. *Transportation Research Record* 2158:113–121.

Graumlich, L. and W.L. Francis. 2010. Moving Toward Climate Change Adaptation: The Promise of the Yellowstone to Yukon Conservation Initiative foraddressing the Region's Vulnerabilities. Yellowstone to Yukon Conservation Initiative. Canmore, Alberta.

Heller, N.E., and E.S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation* 142:14–32.

Hels, T. and E. Buchwald. 2001. The effect of road kills on amphibian populations. *Biological Conservation* 99:331–340.

Hilty, J., W. Lidicker and A. Merenlender. 2006. *Corridor Ecology: The Science and Practice of Linking Landscapes for Biodiversity Conservation*. Washington, DC: Island Press.

Huijser, M.P, J. W. Duffield, A.P. Clevenger, R.J. Ament and P.T. McGowen. 2009. Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in North America; a decision support tool. *Ecology and Society* 14:15. http://www.ecologyandsociety.org/vol14/issue2/art15/.

Iuell, B. 2003. *Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. Utrecht, The Netherlands: KNNV Publishers.

Jones, M.E. 2000. Road upgrade, road mortality and remedial measures: impacts on a population of eastern quolls and Tasmanian devils. *Wildlife Research* 27:289–296.

Kaczensky, P., F. Knauer, B. Krze, M. Jonosovic, M. Adamic and H. Gossow. 2003. The impact of high speed, high volume traffic axes on brown bears in Slovenia. *Biological Conservation* 111:191–204.

Kaiser, J. 2001. Bold corridor project confronts political reality. *Science* 293:2196–2199.

Krosby, M., J. Tewksbury, N. Haddad and J. Hoekstra. 2010. Ecological connectivity for a changing climate. *Conservation Biology* 24:1686–1689.

Maehr, D.S., E.D. Land, and M.E. Roelke. 1991. Mortality patterns of panthers in southwest Florida. *Proceedings of the Annual Conference of Southeast Game and Fish and Wildlife Agencies* 45:201–207.

National Research Council (NRC). 1997. Towards a sustainable future: Addressing the long-term effects of motor vehicle transportation on climate and ecology. Washington, DC: The National Academies Press.

National Research Council (NRC). 2005. Assessing and managing the ecological impacts of paved roads. Washington, DC: The National Academies Press.

Opdam, P.F.M. 1997. How to choose the right solution for the right fragmentation problem? Pages 55–60 *in* K. Canters (ed) *Habitat fragmentation & Infrastructure.* Delft, The Netherlands: Ministry of Transportation, Public Works & Water Management.

Packila, M., R. Inman, K. Inman and A. McCue. 2007. Wolverine road crossings in western Greater Yellowstone. Pages 103–120 in Greater Yellowstone Wolverine Program, Cumulative Report, May 2007. Wildlife Conservation Society, Ennis, Montana.

Paetkau D., E. Vazquez-Dominguez, N. Tucker and C. Moritz. 2009. Monitoring movement into and through a newly planted rainforest corridor using genetic analysis of natal origin. *Ecological Management and Restoration* 10:210–216.

Proctor, M. et al. 2012. Population fragmentation and inter-ecosystem movements of grizzly bears in western Canada and the northern United States. *Wildlife Monograph* 180:1–46.

Raimer, F. and T. Ford. 2005. Yellowstone to Yukon (Y2Y)—one of the largest international wildlife corridors. *GAIA—Ecological Perspectives for Science and Society* 14:357–360.

Riley, S.P.D., J. Pollinger, R. Sauvajot, E. York, C. Bromley, T. Fuller and R.K. Wayne. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. *Molecular Ecology* 15:1733–41.

Ritters, K.H. and J.D. Wickham. 2003. How far to the nearest road? *Frontiers in Ecology and Environment* 1:125–129.

Rondinini, C. and C. Doncaster. 2002. Roads as barriers to movement for hedgehogs. *Functional Ecology* 16:504–509.

Ross, D. 2004. Analyzing the resistance values of the 401 Highway to wildlife movements in the Thousand Islands Section of the Algonquin to Adirondack Corridor and Thousand Islands Frontenac Arch Biosphere Reserve. Prepared for Algonquin to Adirondack Conservation Association, Ontario.

Sanderson, E.W., M. Jaiteh, M.A. Levy, K.H. Redford, A.V. Wannebo, and G. Woolmer. 2002. The human footprint and the last of the wild. *Bioscience* 52:891–904.

Sawaya, M. 2012. Using noninvasive genetic sampling methods to estimate demographic and genetic parameters for large carnivore populations in the Rocky Mountains. PhD dissertation, Montana State University, Bozeman, Montana.

Smith, J. and A. Sullivan. 2010. Washington State's ecological application of collaborative approach to identify a preferred alternative and mitigation strategy for I-90 Snoqualmie Pass East Project. *Transportation Research Record* 21589:1–9.

Soulé, M.E.,and G.E. Orians. 2001. *Conservation Biology: Research Priorities for the Next Decade*. Washington, DC: Island Press.

Spellerberg, I.F. 1998. Ecological effects of roads and traffic: a literature review. *Global Ecology and Biogeography* 7:317–333.

Taylor, P.D., Fahrig, L., Henein, K. and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68:571–572.

Tewksbury, J.J., D. Levey, N. Haddad, S. Sargent, J. Orrock, A. Weldon, B. Danielson, J. Brinkerhoff, E. Damschen and P. Townsend. 2002. Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences* 99:12923–12926.

Theobald, D., S. Reed, K. Fields and M. Soule. In press. Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States. *Conservation Letters*.

Thomas, C.D., A. Cameron, R. Green, M. Bakkenes, L. Beaumont and Y. Collingham. 2004. Extinction risk from climate change. *Nature* 427:145–148.

Van Manen, F., M. McCollister, J. Nicholson, L. Thompson, J. Kindal and M. Jones. 2012. Short-term impacts of a 4-lane highway on American black bears in Eastern North Carolina. *Wildlife Monograph* 181:1–35.

Van der Sluis, T., M. Bloemmen and I.M. Bouwma. 2004. *European Corridors: Strategies forCcorridor Development for Target Species*. Waginingen University and Research Centre, The Netherlands: Alterra.

Waller, J.S. and C. Servheen. 2005. Effects of transportation infrastructure on grizzly bears in northwestern Montana. *Journal of Wildlife Management* 69:985–1000.

Western Governor's Association (WGA). 2008. Wildlife Corridors Initiative Report. Western Governor's Association, Denver, CO.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips and E. Losos. 1998. Quantifying threats to imperiled species in the United States. *BioScience* 48:607–615.

---

*Anthony P. Clevenger, Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, Montana 59717 USA, apclevenger@gmail.com.*

---