WILDLIFE CONNECTIVITY GUIDANCE
Keeping Landscapes Connected

HIGHWAY IMPACT TO CONNECTIVITY

The recognition and understanding of the impact that highways can have on wildlife populations have increased dramatically in the past decade, as evidenced by the emergence of the growing field of "road ecology" (Forman et al. 2003). In addition to direct mortality from wildlife-vehicle collisions, highways contribute to barrier and fragmentation effects resulting in diminished ***connectivity*** between habitat blocks and populations (Noss and Cooperrider 1994, Forman and Alexander 1998). Highways and their traffic can limit the free movement of animals across highways, or ***permeability***, limiting access to seasonal ranges or other vital habitats. This highway barrier effect can fragment habitats and populations, reduce genetic interchange (Gerlach and Musolf 2000, Epps et al. 2005), and limit dispersal of young (Beier 1995). Though connectivity concerns are great in fast-growing states like Arizona where increased highway traffic associated with the essential movement of people, goods and services necessitates the upgrading of existing highways and construction new ones, such highway construction presents our best opportunity to accommodate wildlife passage to maintain highway permeability and landscape connectivity.

Wildlife highway permeability, and thus connectivity may be influenced by these key factors (in addition to habitat type, season, and others):

Highway standard: highway corridor width, number of lanes (e.g., 2-lane versus 4-lane divided highway), and other highway design characteristics influence wildlife permeability (Jeager et al 2005; Dodd et al. 2007*a*, 2009*a*; Olsson et al. 2008).

Traffic volume: theoretical models suggest that highways averaging 4,000–10,000 vehicles/day present strong barriers to wildlife; at >10,000 vehicles/day, highways become near total barriers to animal passage (Mueller and Berthoud 1997). Traffic can visually impact wildlife attempting to cross highways, as high traffic volume can create a visual "moving fence" (Bellis and Graves 1978). However, increasing noise levels associated with increasing traffic volume has a greater impact on wildlife (Kaseloo and Tyson 2004), with high volumes causing animals to avoid the highway or causing "repels" when attempting to approach and cross (Jaeger et al. 2004). Gagnon (2007*a*) found that increasing vehicular traffic volume decreased the probability of at-grade highway crossings by elk as their distribution shifted away from the highway.

Wildlife species: some species appear more sensitive to highway-associated impact than others. For instance, in Arizona, elk permeability across the 2-lane State Route 260 before reconstruction averaged 0.86 crossings/approach (Dodd et al. 2007*b*). Along a 2-lane stretch of U.S. Highway 89 with similar traffic volume, pronghorn permeability averaged only 0.006 crossings/approach (Dodd et al. 2009*b*). In this instance, elk generally cross highways in the evenings when traffic volume is lowest, while pronghorn are active during the daytime when traffic volume is typically at its highest.

PROMOTING HIGHWAY PERMEABILITY

Structures designed to promote wildlife passage across highways are increasingly being implemented and shown to be effective throughout North America, particularly large bridges (e.g., underpasses or overpasses) designed specifically for large animal passage (Foster and Humphrey 1995; Clevenger and Waltho 2003; Gordon and Anderson 2003; Dodd et al. 2007*a*,*c*, 2009*a*; Bissonette and Cramer 2008). Wildlife passage structures have shown benefit in promoting passage for a variety of species (Farrell et al. 2002; Clevenger and Waltho 2003; Ng et al. 2004; Dodd et al. 2007*a*, *c*, 2009*a*), and in conjunction with fencing, have reduced the incidence of wildlife-vehicle collisions from 85 to 96% (Clevenger et al. 2001; Dodd et al. 2006, 2007*c*, 2009*a*; Gagnon et al. 2009). Whereas early passage structures were typically approached as single-species mitigation measures to address wildlife-vehicle collisions (Reed et al. 1975), their focus today is more on preserving ecosystem integrity and landscape connectivity benefiting multiple species (Clevenger and Waltho 2000). Transportation agencies are increasingly receptive to integrating passage structures on highways to address both safety and ecological needs (Farrell et al. 2002), though there is an expectation that such structures will indeed yield benefit to multiple species and enhance connectivity (Clevenger and Waltho 2000).

Fencing is regarded as an integral component of effective passage structures (Romin and Bissonette 1996, Clevenger et al. 2001, Forman et al. 2003, Bissonette and Cramer 2008). Ungulate-proof fencing ranging in height from 6.5–8 ft has been demonstrated as effective in reducing the incidence of wildlife-vehicle collisions, especially when used in conjunction with passage structures (Romin and Bissonette 1996). Fencing serves to limit at-grade highway crossings by animals and funnel wildlife of all sizes, from lizards to elk, toward passage structures and thus is vital to promoting highway passage (Romin and Bissonette 1996, Forman et al. 2003, Dodd et al. 2009*d*). In fact, the State Route 260 case study below illustrates both the importance of fencing and how its application in conjunction with passage structures can promote highway permeability and habitat connectivity, as well as yield significant highway safety and economic benefit.

State Route 260 Case Study

Reconstruction of a 17-mile stretch of State Route 260 in central Arizona was begun in 2000, with three of five sections now completed, including seven of 11 total planned wildlife underpasses and all six planned bridges in place. One of the five sections, the 5-mile Christopher Creek Section with four underpasses and three bridges, was opened to traffic a year before ungulate-proof fencing was erected, allowing researchers to compare the incidence of wildlife-vehicle collisions, wildlife use of underpasses, and highway permeability before and after the erection of fencing. The results of this comparison (Dodd et al. 2007*d*) underscore the benefit of underpasses and fencing, and along with the other two reconstructed sections also demonstrate the economic benefit associated with these measures.

Wildlife-vehicle collision benefit: After strategically fencing half the section, elk-vehicle collisions ultimately dropped by over 90% from the year before fencing (Dodd et al. 2009*a*); the passage structures and fencing promoted highway safety through reduced wildlife-vehicle collisions.

Wildlife underpass use: At two underpasses where wildlife use was monitored by video surveillance, only 12% of elk and deer that approached the underpasses in the year before fencing successfully passed through; most (81%) crossed up and over the highway at grade, contributing to wildlife-vehicle collisions. After fencing, 56% of elk and deer crossed successfully through underpasses and none crossed the highway at grade. Fencing was instrumental to forcing the deer and elk to alter their behavior and use the passage structures; without it, the effectiveness of the underpasses was limited (Dodd et al. 2007*a*, 2009*a*).

Highway permeability benefit: GPS telemetry was used to measure elk passage rates across the highway (Dodd et al. 2007*b*) and assess elk distribution relative to varying traffic volumes (Gagnon et al. 2007*a*). During reconstruction, the elk passage rate averaged 0.79 crossings/approach. Once reconstruction was completed but before ungulate-proof fencing was erected, the passage rate declined 32% to 0.52 crossings/approach. However, after fencing, permeability increased significantly by 52%, to 0.82 crossings/approach, pointing to the efficacy of underpasses in combination with fencing in promoting permeability (Dodd et al. 2007*d*). Similarly, for white-tailed deer, the passage rate on three reconstructed highway sections with underpasses and fencing averaged 0.16 crossings/approach, or five times higher than the mean passage rate for control sections without underpasses (0.03 crossings/approach; Dodd et al. 2009*a*). This further illustrates the benefit of passage structures in promoting permeability for multiple ungulate species.

The increase in elk permeability with fencing was attributed partly to the funneling of elk to underpasses where traffic passing overhead had no effect on below-grade underpass crossings and passage rate (Figure 1). Conversely, traffic volume strongly affected elk distribution and permeability when they attempted at-grade highway crossings when fencing was not present to funnel them to underpasses (Figure 1; Gagnon et al. 2007*a*, *b*). Passage structures serve to ameliorate the adverse impact that traffic volume has on wildlife permeability.

Economic benefit: The economic benefit from reduced elk-vehicle collisions due to underpasses and fencing on three reconstructed sections totaled $6.5 million from 2001−2008, or nearly $1 million/year based on figures from the Western Transportation Institute (Huijser et al. 2007); the benefit averaged more than $2 million/year over the past three years (Dodd et al. 2009*a*). Over 20 years, the economic benefit from reduced wildlife-vehicle collisions could equal or exceed the cost of wildlife underpasses and fencing necessary to promote highway safety and permeability.

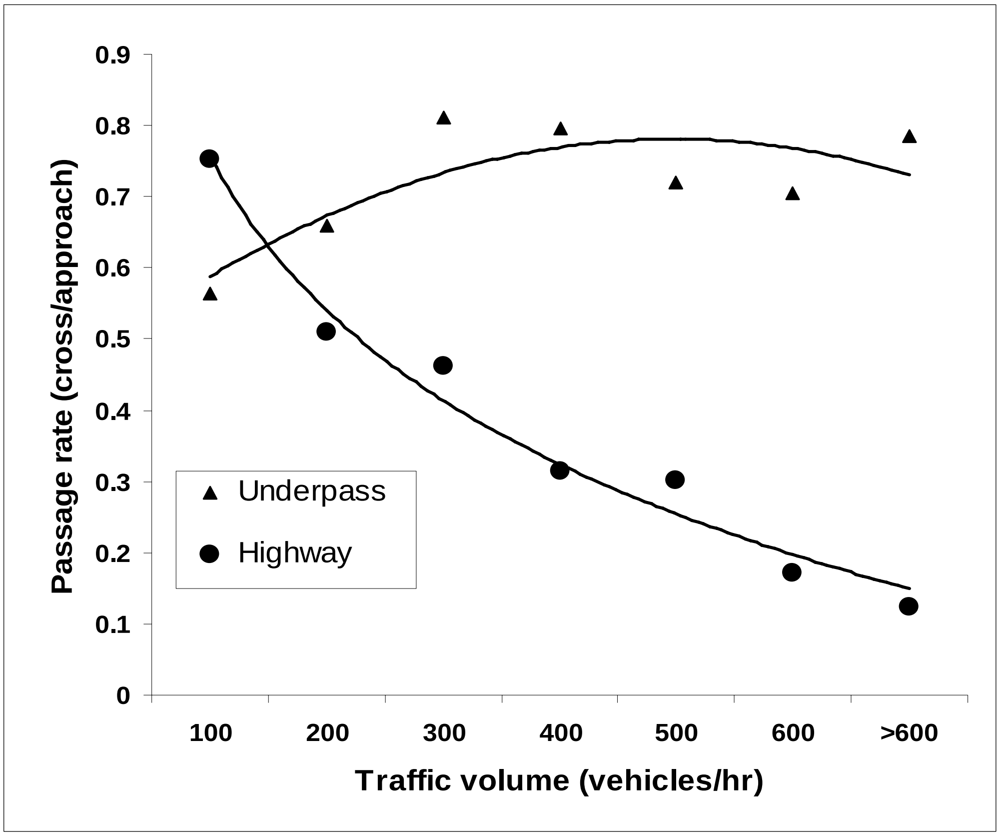

Figure 1. Comparison of elk at-grade highway (from Gagnon et al. 2007*a*) and below-grade underpass (from Gagnon et al. 2007*b*) passage rates at varying traffic volume levels along State Route 260, 2002-2006.

WILDLIFE CONNECTIVITY GUIDANCE

ADOT Environmental Planning Group's *Wildlife Connectivity Guidance* is intended to provide project managers guidance and examples (photos and engineering drawings) of applications of various measures to promote wildlife permeability and connectivity. This guidance focuses on the application of passage structures in promoting permeability, along with funnel fencing that is instrumental to passage structure effectiveness. When funnel fencing is used, animals may breech the fence and become trapped, necessitating the application of various escape measures to allow animals to escape from the fenced corridor. The organization of the *Wildlife Connectivity Guidance* is as follows:

WILDLIFE CONNECTIVITY BACKGROUND

WILDLIFE PASSAGE STRUCTURES

- **Types of structures**
- **New construction versus retrofit applications**
- **Passage structure spacing**
- **General implementation considerations**
- **Literature cited**

WILDLIFE FUNNEL FENCING

Link to Full Text document

- **Types of fencing and alternatives**
- **Implementation considerations**
- **Literature cited**
- **Engineer drawings/plan sheets**

WILDLIFE ESCAPE MEASURES

Link to Full Text document

- **Types of escape measures**
- **Implementation considerations**
- **Literature cited**
- **Engineer drawings/plan sheets**

DETERMINING LOCATIONS FOR CONNECTIVITY MEASURES

There are various tools and approaches to determining where measures are needed to promote highway permeability and thus maintain landscape connectivity, ranging from large-scale landscape connectivity analysis, to more- refined analysis to identify locations for passage structures such as relatively simple GIS-based "rapid assessment" of linkage needs (Ruediger and Lloyd 2003) to more complex modeling of wildlife permeability (Singleton et al. 2002) and identification of linkages (Clevenger et al. 2002), to the analysis of wildlife-vehicle collision patterns (Barnum 2003, Malo et al. 2004, Dodd et al. 2006).

Arizona's foremost connectivity tool is the landmark 2006 *Arizona's Wildlife Linkages Assessment* (http://www.azdot.gov/Inside_ADOT/OES/AZ_Wildlife_Linkages/index.asp). This comprehensive effort identified and described 152 different landscape-scale linkages across the state, and prioritized them in terms of their respective biological value and threat and opportunity ratings (Figure 2). Linkages that exhibit high biological value and threat and opportunity (including future highway construction) scores were prioritized for further refined analysis. To date, 16 linkages have undergone refined analysis by Dr. Paul Beier of Northern Arizona University and his colleagues using various species-specific GIS-based habitat models for least-cost path determination of corridors between wildland blocks (Figure 2). The reports and GIS data for these linkages can be found at http://corridordesign.org/linkages/arizona. The *Arizona's Wildlife Linkages Assessment* and the refined corridor analyses completed to date represent invaluable tools in identifying the need and locations for measures to promote wildlife connectivity in future highway projects.

The application of GPS telemetry to identify wildlife highway crossing patterns constitutes an ideal tool to determine data-driven locations for passage structures and fencing (McKinney and Smith 2007; Dodd et al. 2009*b*), though such an approach can be costly. Such GPS telemetry assessments are currently ongoing on Interstates 17 and 40, State Route 64, and U.S. Highway 191. Dodd et al. (2006, 2007*a*) did find strong relationships between elk-vehicle collisions and GPS telemetry-determined highway crossings at various scales. The relationship was optimized at the 0.6-mile scale indicating that available roadkill data (e.g.,"hotspots") can serve as a useful surrogate for costly GPS data to plan and locate passage structures. However, for species such as pronghorn that seldom cross highways and for which little roadkill data exist, GPS telemetry may constitute the only means to determine the best locations for passage structures based on distribution data to maintain habitat and population connectivity (Dodd et al. 2009*a*). Lastly, ADOT has commissioned wildlife accident reduction studies, such as that for State Route 64 in 2006, that utilize available roadkill and wildlife-vehicle collision/accident records to determine potential locations for passage structures for consideration in planned future highway reconstruction; this accident reduction study was followed up with a GPS telemetry study to refine and prioritize locations for passage structures.

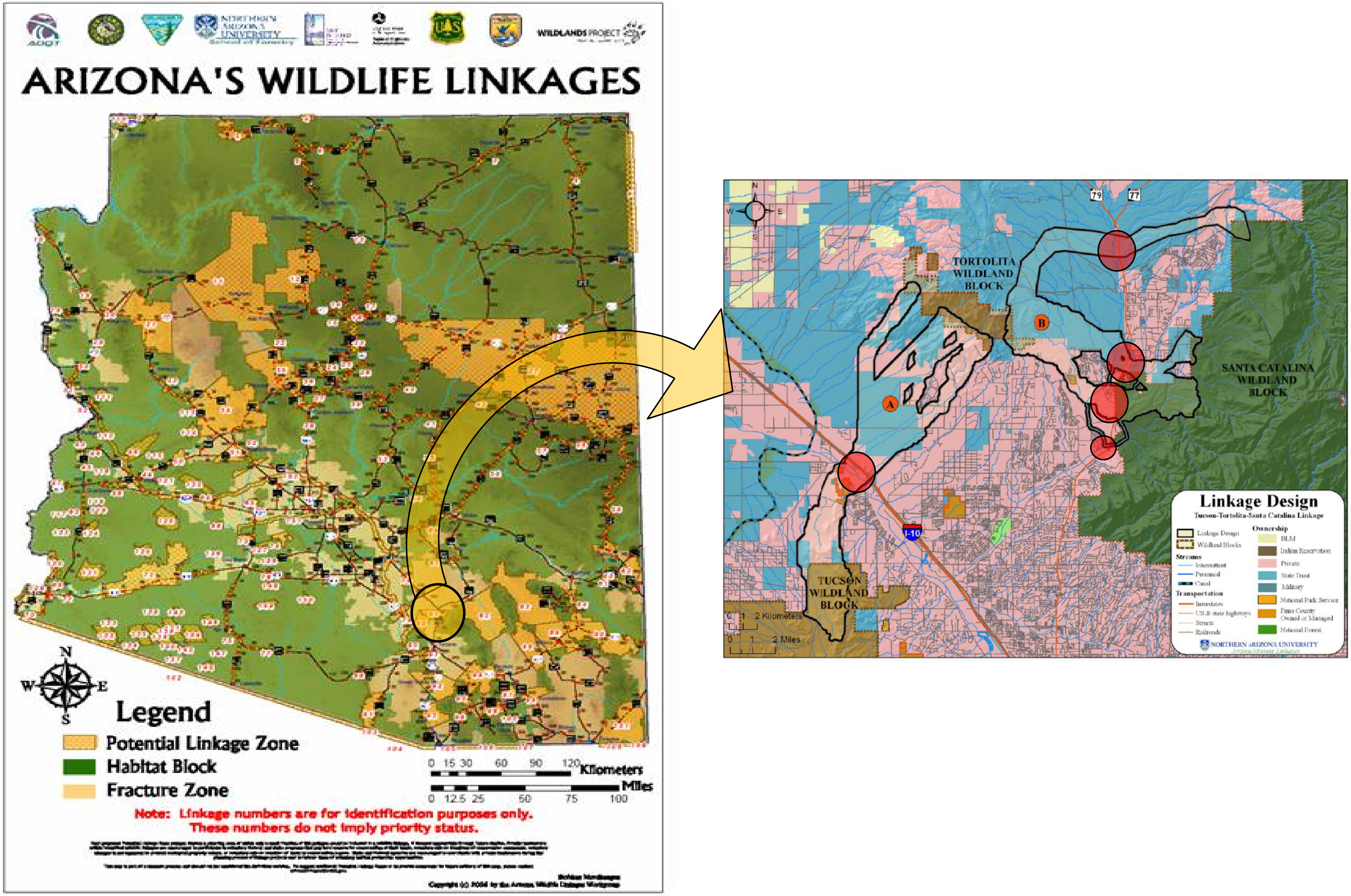

Figure 2. Arizona's Wildlife Linkages Assessment map (left) identifying 152 linkages across the state, including Linkage 81 (Santa Catalina – Tortolita, circled) and the refined corridor design for this linkage (right) with two modeled corridors between wildland blocks (Beier et al. 2006). Passage structures and fencing should be considered where corridors cross highways (red circles, right)

LITERATURE CITED

Barnum, S. A. 2003. Identifying the best locations to provide safe highway crossing opportunities for wildlife. Pages 246-259 *in* 2003 Proceedings of the International Conference on Ecology and Transportation. C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Beier, P. 1995. Dispersal of juvenile cougars in fragmented habitat. *Journal of Wildlife Management* 59:228−237.

Beier, P., E. Garding, and D. Majka. 2006. Arizona missing linkages: Tucson - Tortolita - Santa Cantalina Mountains linkage design. Report to Arizona Game and Fish Department. School of Forestry, Northern Arizona University, Flagstaff, USA.

Bellis, E. D., and H. B. Graves. 1978. Highway fences as deterrents to vehicle-deer collisions. *Transportation Research Record* 674: 53–58.

Bissonette, J. A. and P. Cramer. 2008. Evaluation of the use and effectiveness of wildlife crossings. NCHRP Report 615. National Cooperative Research Program, Transportation Research Board, Washington, DC, USA.

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. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. Pages 293−302 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. 2003 Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Clevenger A. P., B. Chruszcz, and K. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin* 29:646−653.

Clevenger, A. P., P. J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated expert based models for identifying wildlife habitat linkages and mitigation passage planning. Conservation Biology 16:503−514.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2006. Characteristics of elk-vehicle collisions and comparison to GPS-determined highway crossing patterns. Pages 461−477 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. 2005 Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Dodd, N. L., J. W. Gagnon, S. Boe, A. Manzo, and R. E. Schweinsburg. 2007*a*. Evaluation of measures to minimize wildlife-vehicle collisions and maintain wildlife permeability across highways – State Route 260, Arizona, USA. Final report 540 (2002−2006). Arizona Transportation Research Center, Arizona Department of Transportation, Phoenix, Arizona, USA. http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ540.pdf

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007*b*. Assessment of elk highway permeability by Global Positioning System telemetry. *Journal of Wildlife Management* 71:1107−1117.

Dodd, N. L., J. W. Gagnon, A. L. Manzo, and R. E. Schweinsburg. 2007*c*. Video surveillance to assess highway underpasses by elk in Arizona. *Journal of Wildlife Management* 71:637−645.

Dodd, N. L., W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007*d*. Role of fencing in promoting wildlife underpass use and highway permeability. Pages 475−487 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. 2007 Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Dodd, N. L., J. W. Gagnon, S. Boe, K. Ogren, and R. E. Schweinsburg. 2009*a*. Effectiveness of wildlife underpasses in minimizing wildlife-vehicle collisions and promoting wildlife permeability across highways: Arizona Route 260. Final project report 603, Arizona Transportation Research Center, Arizona Department of Transportation, Phoenix, Arizona, USA.

Dodd, N. L., J. W. Gagnon, S. Sprague, S. Boe, and R. E. Schweinsburg. 2009*b*. Assessment of pronghorn movements and strategies to promote highway permeability - U.S. Highway 89. Final project report 619, Arizona Transportation Research Center, Arizona Department of Transportation, Phoenix, Arizona, USA.

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

Farrell, J. E., L. R. Irby, and P. T. McGowen. 2002. Strategies for ungulate-vehicle collision mitigation. *Intermountain Journal of Sciences* 8:1−18.

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

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road ecology: science and solutions. Island Press, Washington, DC, USA.

Foster, M. L., and S. R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23:95−100.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, and R. E. Schweinsburg. 2007*a*. Traffic volume alters elk distribution and highway crossings in Arizona. *Journal of Wildlife Management* 71:2318−2323.

Gagnon, J. W., T. C. Theimer, N. L. Dodd, A. Manazo, and R. E. Schweinsburg. 2007*b*. Effects of traffic on elk use of wildlife highway underpasses Arizona. *Journal of Wildlife Management* 71:2324−2328.

Gagnon, J. W., N. L. Dodd, S. Sprague, K. Ogren, and R. E. Schweinsburg. 2009. Preacher Canyon wildlife fence and crosswalk enhancement project evaluation- State Route 260. Final project report submitted to Arizona Department of Transportation, Phoenix, Arizona, USA.

Gerlach, G., and K. Musolf. 2000. Fragmentation of landscape as a cause for genetic subdivision in bank voles. *Conservation Biology* 14:1066–1074.

Gordon, K. M., and S. H. Anderson. 2003. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309−318 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. 2003 Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Hanski, I., and M. E. Gilpin. 1997. *Metapopulation biology*. Academic Press, New York, New York, USA.

Huijser, M. P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A. P. Clevenger, D. Smith, and R. Ament. 2007. Wildlife-vehicle collision reduction study. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., USA.

Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* 185:329−348.

Kaseloo, P. A., and K. O. Tyson. 2004. Synthesis of noise effects on wildlife. Publication FHWA-HEP-06-016, Office of Research and Technology Services, Federal Highway Administration, McLean, Virginia, USA.

Malo, J. E., F. Suarez, and A. Diez. 2004. Can we mitigate animal-vehicle accidents using predictive models? *Journal of Applied Ecology* 41:701-710.

McKinney, T., and T. Smith. 2007. US 93 bighorn sheep study: distribution and trans-highway movements of desert bighorn sheep in northwestern Arizona. Final project report 576, Arizona Transportation Research Center, Arizona Department of Transportation, Phoenix, Arizona, USA. http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ576/AZ576.pdf

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway underpasses by wildlife in southern California. *Biological Conservation* 115:499−507.

Noss, R. F., and A. Y. Cooperrider. 1994. Saving nature's legacy. Island Press, Washington, D.C., USA.

Olsson, M. P. O., P. Widén, and J. L. Larkin. 2008. Effectiveness of a highway overpass to promote landscape connectivity and movement of moose and roe deer in Sweden. *Landscape and Urban Planning* 85:133–139.

Parker, I. D., A. W. Braden, R. R. Lopez, N. J. Silvy, D. S. Davis, and C. B. Owen. 2008. Effects of US 1 project on Florida key deer mortality. *Journal of Wildlife Management* 72:354–359.

Reed, D. F., T. N. Woodward, and T. M. Pojar. 1975. Behavioral response to mule deer to a highway underpass. *Journal of Wildlife Management* 39:361-367.

Romin, L. A., and J. A. Bissonette. 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24:276–283.

Reudiger, B., and J. Lloyd. 2003. A rapid assessment process for determining potential wildlife, fish and plant linkages for highways. Pages 205-225 *in* 2003 Proceedings of the International Conference on Ecology and Transportation. C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Singleton, P. H., W. L. Gaines, and J. F. Lehmkuhl. 2002. Landscape permeability for large carnivores in Washington: a geographic information system weighted-distance and least-cost corridor assessment. USDA Forest Service Research Paper PNW-RP-549, Portland, Oregon, USA.