Effects of Roads on Wildlife in Arizona: How Far Have We Traveled?

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Abstract—*Roads are conspicuous and pervasive features of landscapes and represent one of the most significant anthropogenic impacts on natural areas and wildlife. The Madrean Archipelago is defined by natural levels of fragmentation due to geography; however, human population growth and transportation needs threaten to exacerbate levels of isolation in the region. Scientists, as well as transportation and resource management agencies, have increased their concern about road impacts on wildlife. To identify needs of future research and managements, we reviewed 29 road-ecology-related, peer-reviewed publications and governmental research in Arizona and compiled geography, focal species, and topic. A taxonomic bias toward large mammals (72%) is evident. Study areas are concentrated along highways and state routes (76%). Despite a prevalence of studies on wildlife road crossing, most research focuses on distribution and movements, whereas impacts at the population and community level are rarely described.*

Introduction

Roads are conspicuous and pervasive features of landscapes and represent one of the most significant anthropogenic impacts on natural areas and wildlife (Forman and Alexander 1998). Over 20% of the land in the United States is affected by roads and traffic (Forman 2000). Road construction causes destruction of habitat and habitat loss directly and facilitates deforestation and landscape fragmentation (Coffin 2007). Roads and traffic can cause mortality, impede and alter movements of animals, influence population density (Fuentes-Montemayor and others 2009; Roedenbeck and Voser 2008; Rytwinski and Fahrig 2007; Trombulak and Frissell 2000), and change community structure (Bissonette and Rosa 2009; Goosem 2000).

The Madrean Archipelago is defined by natural levels of fragmentation due to geography; however, increase of human population and transportation needs threaten to exacerbate levels of isolation in the region (ADOT 2006). The human population has increased 24.6% in Arizona, from 5.1 million in 2000 to 6.4 million in 2010 (U.S. Census Bureau 2012). The road system in Arizona has expanded dramatically from two rough roads in the 1800s to around 92,800 km of roads nowadays (ADOT 2012). With the increase in wildlife-vehicle collisions in Arizona, transportation and resource management agencies have elevated their concern about road impacts on wildlife and recognize the need to develop effective mitigation (Ruediger and others 2005). In this paper, we search road-ecology-related, peer-reviewed publications and governmental research reports and determine geography as well as species and study focus to assess diversity and identify gaps in publications and research projects related to road impacts on wildlife in Arizona.

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Materials and Methods

Literature Search

We used the *Web of Science* literature search tool that includes publications from 1945 to April 22, 2012 to search publications related to roads and wildlife in Arizona. We selected the "Topic" search option and used search terms "road and Arizona" and "highway and Arizona." We browsed titles and abstracts in the search results and included publications related to wildlife in our analysis. For governmental research reports, we focused on research projects conducted by Arizona Department of Transportation (ADOT) and Arizona Game and Fish Deportment (AZGFD). To search project reports about road impacts on wildlife, we browsed ADOT research projects (SPR reports) from 1968 to 2012 in the website (http://www.azdot.gov/TPD/ATRC/Publications/project_reports/index.asp), AZGFD technical reports from 1990 to 1999 (http://www.azgfd.gov/w_c/Technical_Reports.shtml), and AZGFD wildlife and conservation research webpage (http://www.azgfd.gov/w_c/research.shtml). We also used the following internet resources to search other research reports not under ADOT and AGFD, including Wildlife and Roads Search Engine (http://www.wildlifeandroads.org/search/), Transportation Research Board (http://www.trb.org/Main/Home.aspx), TRID database (http://trid.trb.org/), and Google Scholar (http://scholar.google.com/). We realize that some peer-reviewed articles and governmental reports might be missed because of lack of congruence between keywords that we used and publications and the availability of governmental works to public.

Variables

We recorded year of publication, focal species, research location, and the main topic for each peer-reviewed literature and governmental research project. To analyze the taxonomy of the focal species, we recorded the number of publications for each vertebrate animal class. For publications with mammals as focal species, we recorded the number of publications for each Order. We categorized the focal mammalian species as small mammals if body mass was less than 5 kg (Merritt 2010). We used the midpoint of adult body masses; female body mass was used in sexually dimorphic species (Hoffmeister 1986).

Results and Discussions

Do We Have Progress?

We found a total of 30 studies related to road impacts on wildlife, with 10 peer-reviewed articles, and 20 governmental research projects conducted by ADOT, AZGFD and U.S. Geological Survey. We excluded projects that are in-progress or unpublished because information on research is not consistently accessible. With rapid development of the subdiscipline of road ecology since 2000, the number of publications has increased considerably (1900%) in the past 16 years, from 1 publication by Rosen (1994) in 1994-2000 to 19 publications in 2006-2011 (fig. 1). The increased interest from governmental agencies in the integration of scientific research with decision making on transportation planning had positive impacts on the accumulation of knowledge of road-wildlife interactions and likely enhanced the publication of peer-review literature.

What Species Are Underrepresented? Does the Size Have Influence?

Among 30 studies, the most common taxon of study is the mammals (77%; fig. 2) with few studies on reptiles (10%), birds (3%), or general survey on multiple taxonomic groups (10%). No case study examines amphibians; however, road kill is a major source of amphibian mortality and may contribute to global decline of amphibians (Glista and others 2008). Our effort to understand road effects on mammals in Arizona does not extend equally to all Orders. Order Artiodactyla (ungulates) is the most frequently studied group and elk (*Cervus elaphus*) and desert bighorn sheep (*Ovis canadensis*) are the two most common studied species. When we look at the number of studies against the proportion of total species for each order of mammals in Arizona, a taxonomic bias toward ungulates is evident (fig. 3). Ungulates represent 4% of total mammalian species in Arizona, but were the subject of 96% of the studies. Compared to large and medium mammals, small mammals, which constitute 85% of the state's mammalian species, received a disproportionately small amount of attention in these studies (fig. 4). Of course, vehicle collisions or evasive driving maneuvers focused on small mammals

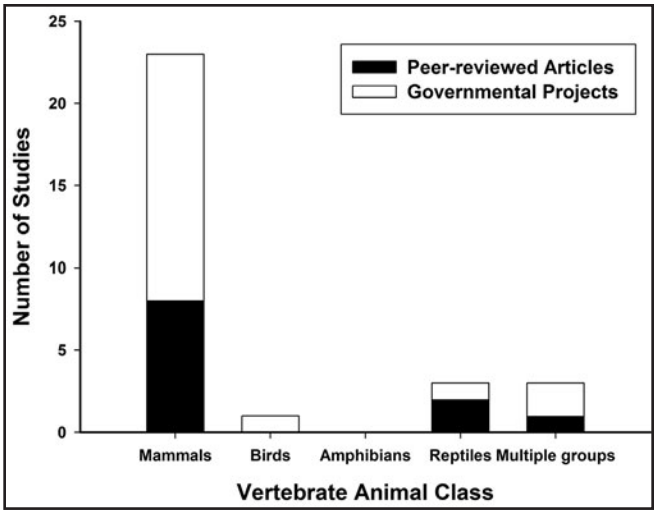

Figure 2—Number of studies related to road impacts on wildlife in Arizona by vertebrate class from 1994 to 2011.

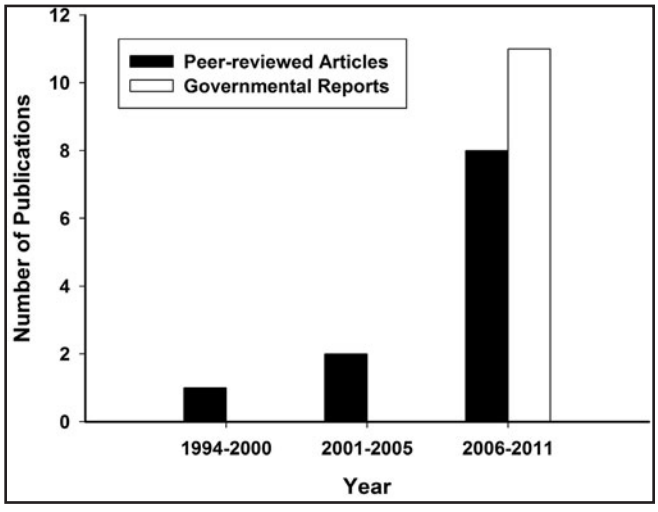

Figure 1—Number of publications related to road impacts on wildlife in Arizona by year from 1994 to 2011.

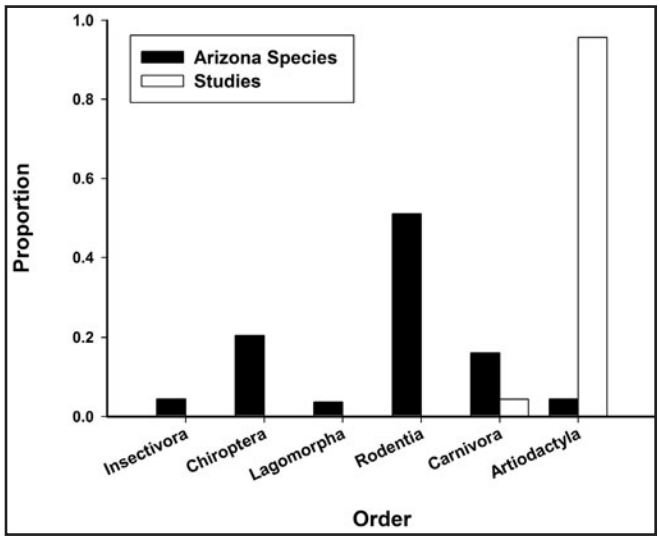

Figure 3—Relative proportions of Arizona mammalian species by order compared with representation of those orders in studies related to road impacts on wildlife from 1994 to 2011.

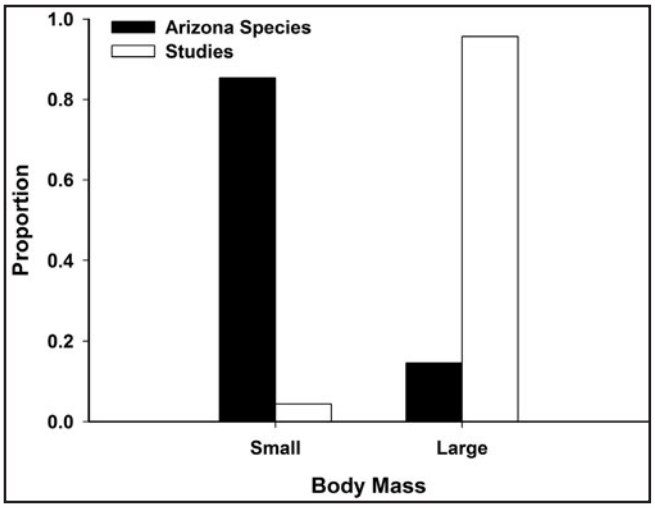

Figure 4—Relative proportions of Arizona mammallian species by size compared with representation of those size classes in studies related to road impacts on wildlife from 1994 to 2011.

do not generally cause property damage or injury to humans, factors that, in part, drive this disproportionate distribution of publications.

Where Are We On the Road?

Current road and wildlife related research in Arizona mainly focuses on the barrier effect of roads on animal movements and efforts to improve motorists' safety. Road type is biased in research location with most efforts focused on highways and state routes (77%). Research topics are aimed at improved road permeability, reduced wildlife-vehicle collisions, and evaluating effectiveness of wildlife passages. Arizona has taken a leadership role in mitigation measures to minimize barrier effects of roads and to restore connectivity by designing and installing wildlife underpasses, overpasses, wildlife-proof fencing, and alert systems along highways and state routes (Reuer 2007). Besides wildlife passages, governmental agencies and scientists also continue to investigate the efficacy of currently installed structures (for example, culverts) as road crossing structures (Mikele and Michael 2007). With this amount of effort, the frequency of wildlife-vehicle collisions has declined and highway permeability for elk has been improved (Dodd and others 2007).

Where Is the Gap?

Our analyses suggest that a gap in knowledge of road impacts on wildlife exists in Arizona. Most importantly, we know very little about the impacts of roads on wildlife in Arizona and in unique biomes such as the Sonoran Desert. If we acknowledge a general dearth of literature on road impacts, we can examine if there are important areas where additional studies are required and prioritize our needs. We have already addressed the paucity of studies on groups beyond large mammals. Large mammals are important focal species because these animals are highly vulnerable to roads in part because they are more likely to encounter roads due to extended movement and ranges, and populations are more susceptible to road mortality because of low reproductive rates and low natural density (Fahrig and Rytwinski 2009). However, negative effects of roads occur across a wide range of vertebrates (Laurance and others 2009; Wisdom and others 2000), and abundant evidence suggests that response to roads and traffic likely vary considerably across species (Goosem 2001; Laurance and others 2004; Taylor and Goldingay 2010). For example, roads restrict movements of forest-dependent species of birds but not frugivorous and edge and gap species (Laurance and others 2004). Whereas large mammals tend to avoid roads, response of small mammals to roads is more complicated (Fahrig and Rytwinski 2009). Despite the extensive size of forest road networks (Coghlan and Sown 1998), forest roads are relatively ignored. Several studies have demonstrated that even narrow roads less than 10 m wide can have barrier effects (Forman and Alexander 1998; Swihart and Slade 1984; Wilson and others 2007). Environmental changes associated with edges created by forest roads may impact species composition within the forest ecosystem, especially for species, such as tree squirrels, that are sensitive to forest fragmentation (Koprowski 2005; Murcia 1995).

Besides a taxonomic and geographic bias toward large mammals and highways in current studies, we need to develop research questions at different levels and scales. Despite several calls for needs and increased attention to research at population and community levels (Fahrig and Rytwinski 2009; van der Ree and others 2011; Underhill and Anhold (2000), these kinds of research are scarce in Arizona. We have gained important knowledge of barrier effects on individual animal movements, but we know less about effects of roads on populations. Does the magnitude of population fragmentation caused by barrier effects of roads affect population persistence? How do roads affect social structure and reproductive success within populations? Most road ecology studies focus on single species, and few assess community level impacts or address species interactions near roads. The danger of this is that we might miss important pieces of a complex system. For example, abundance of rodents often increased at areas near roads, potentially due to the negative effects of roads on predator populations, which cannot be known if we only investigate a single taxon or closely related species (Bissonette and Rosa 2009; Rytwinski and Fahrig 2007). We tend to have focused on patterns but do not fully understand the causes and mechanisms. For example, we know that roads have barrier effects on several species such as desert bighorn sheep, pronghorn (*Antilocapra americana*), and species of snakes, but do not know why (Dodd and others 2010; Jones and others 2011; McKinney and Smith 2007). Do animals avoid roads because of a gap in cover, or environmental changes along road edges, or traffic disturbance? Studies that address the relative importance of different mechanisms of the effects of roads on wildlife are needed (Roedenbeck and others 2007).

Our Roads Ahead

The Madrean Archipelago is a region that exhibits high levels of diversity and is fortunately less disturbed compared to many other places in the United States. Although the transportation system has expanded in recent decades, road density remains relatively low (World Bank 2008), so that ample opportunities exist to minimize road impacts in this region. One substantial challenge in management of road network systems is that no attempt has been made to synthesize piecemeal information from individual studies into a substantial, comprehensive picture about how road networks function in broader scale within the Southwest (Gucinski and others 2001). The need for increased cooperation between governmental departments and agencies is clear. Comprehensive planning that would minimize road effects requires collaboration among academia, public interest groups, and local, state, and federal agencies. We encourage enhanced multi-disciplinary, inter-agency supported events such as the International Conference

on Ecology and Transportation (ICOET) and Infra Eco Network Europe Meetings (IENE) as well as projects that address large scale landscape management. We believe that large scale efforts such as The Wildlands Projects (McDonnell 2002) and Arizona's Wildlife Linkages Assessment (ADOT 2006) as well as increased interest by university scientists and the history of a firm commitment to collaborative research among agencies provide the scaffolding for such a region-wide approach in Arizona. With continued expansion of the human population predicted for Arizona on the order of 7.4 million people by 2020 (ADOT 2006), as well as long term projections of significant redistribution and fragmentation due to climate change (Opdam and Wascher 2004; Weiss and Overpeck 2005), construction of a comprehensive and collaborative long-term plan is necessary.

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References

ADOT. 2006. Arizona's wildlife linkages assessment. Arizona Department of Transportation, Phoenix, AZ. Online: http://www.azdot.gov/inside_adot/OES/AZ_Wildlife_Linkages/assessment.asp [April 26, 2012].

ADOT. 2012. Arizona Department of Transportation, Phoenix, AZ. [Online]. Available: http://www.azdot.gov/Highways/AboutITD.asp [April 26, 2012].

Bissonette, J. A.; and Rosa S.A. 2009. Road zone effects in small-mammal communities. Ecology and Society. 14 (1). Online: http://www.ecologyandsociety.org/vol14/iss1/art27/ [April 26, 2012].

Bouchard, J.A.; Ford T.; Eigenbrod F. E.; Fahrig L. 2009. Behavioral responses of northern leopard frogs (*Rana pipiens*) to roads and traffic: implications for population persistence. Ecology and Society. 14(2). Online: http://www.ecologyandsociety.org/vol14/iss2art23 [April 26, 2012].

Coffin, A. W. 2007. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography. 15(5):396-406.

Coghlan. G.; and Sown R. 1998. National forest road system and use (Draft Report, 1-30-98, Engineering Staff). Washington, DC: U.S. Department of Agriculture, Forest Service.

Dodd, N. L.; Gagnon J. W.; Boe S.; Manzo A.; Schweinsburg R. E. 2007. Evaluation of measures to minimize wildlife-vehicle collisions and maintain wildlife permeability across highways: State Route 260, Arizona, USA. Final project report 540. Phoenix, AZ: Arizona Department of Transportation, Arizona Transportation Research Center.

Dodd, N. L.; Gagnon J. W.; Sprague S.; Boe S.; Schweinsburg R. E. 2010. Assessment of pronghorn movements and strategies to promote highway permeability: U.S. Highway 89. Final project report 619. Phoenix, AZ: Arizona Department of Transportation, Arizona Transportation Research Center.

Fahrig, L.; and Rytwinski, T. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society. 14(1). Online: http://www.ecologyandsociety.org/vol14/iss1/art21/ [April 26, 2012].

Forman, R. T. T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology. 14:31-35.

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

Fuentes-Montemayor, E.; Cuaron, A. D.; Vazquez-Dominguez, E.; Benitez-Malvido, J.; Valenzuela-Galvan, D.; Andresen, E. 2009. Living on the edge: roads and edge effects on small mammal populations. Journal of Animal Ecology. 78: 857-865.

Glista, D. J.; DeVault, T. L.; DeWoody, J. A. 2008. Vertebrate road mortality predominatly impacts amphibians. Herpetological Conservation and Biology. 3(1): 77-87.

Goosem, M. 2000. Effects of tropical rainforest roads on small mammals: edge changes in community composition. Wildlife Research. 27: 151-163.

Goosem, M. 2001. Effects of tropical rainforest roads on small mammals: inhibition of crossing movements. Wildlife Research. 28(4): 351-364.

Gucinski,H.; Furniss, M. J.; Ziemer R. R.; M.H. Brookes. 2001. Forest roads: a synthesis of scientific information. Gen. Tech. Rep. PNW-GTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 103 p.

Hoffmeister, D. F. 1986. Mammals of Arizona. Tucson:University of Arizona Press. 602 p.

Jones, T. R.; Babb, R. D.; Hensley, F. R.; LiWanPo, C.; Sullivan, B. K. 2011. Sonran desert snake communities at two sites: Concordance and effects of increased road traffic. Herpetological Conservation and Biology. 6(1): 61-71.

Koprowski, J. L. 2005. The response of tree squirrels to fragmentation: A review and synthesis. Animal Conservation. 8: 369-376.

Laurance, S. G. W.; Stouffer, P. C.; Laurance, W. E. 2004. Effects of road clearings on movement patterns of understory rainforest birds in central Amazonia. Conservation Biology. 18(4): 1099-1109.

Laurance, W. F.; Goosem, M.; Laurance, S. G. W. 2009. Impacts of roads and linear clearings on tropical forests. Trends in Ecology and Evolution. 24(12): 659-669.

McDonnell, T. 2002. Technical review of the wildlands projects and how it is affecting the management of state, federal and private lands in the United States. Sequim, Washington: North Western Research Institute. Online: http://nwri.org/2011/07/technical-review-of-the-wildlands-project-2002/#more-93. [April 29, 2012].

McKinney, T.; and Smith, T. 2007. US93 bighorn sheep study: Distribution and trans-highway movements of desert bighorn sheep in northwestern Arizona. Final Report 576. Phoenix, AZ: Arizona Department of Transportation, Arizona Transportation Research Center.

Merritt, J.F. 2010. The biology of small mammals. Baltimore: Johns Hopkins University Press. 336 p.

Mikele, L. P.; and Michael, F. I. 2007. Use of simulated highway underpass crossing structures by flat-tailed horned lizards (*Phrynosoma Mcallii*). Final project report 594. Phoenix, AZ: Arizona Department of Transportation, Arizona Transportation Research Center.

Marcia, C. 1995. Edge effects in fragmented forests: Implications for conservation. Trends in Ecology and Evolution. 10(2): 58-62.

Opam, P.; Wascher, D. 2004. Climate change meets habitat fragmentation: Linking landscape and biogeographical scale levels in research and conservation. Biological Conservation. 117(3): 285-297.

Reuer, C. 2007. Synthesis of animal-vehicle collision mitigation measures. Final project report 612. Phoenix, AZ: Arizona Department of Transportation, Arizona Transportation Research Center.

Roedenbeck, I. A.; Fahrig, L.; Findlay, C. S.; Houlahan, J. E.; Jaeger, J. A. G.; Klar, N.; and others. 2007. The Rauischholzhausen agenda for road ecology. Ecology and Society. 12(1). Online: http://www.ecologyandsociety.org/vol12/iss1/art11/ [April 29, 2012].

Roedenbeck, I. A.; and Voser, P. 2008. Effects of roads on spatial distribution, abundance and mortality of brown hare (*Lepus europaeus*) in Switzerland. European Journal of Wildlife Research. 54: 425-437.

Rosen, P. C.; and Lowe, C. H. 1994. Highway mortality of snakes in the Sonoran desert of southern Arizona. Biological Conservation. 68(2): 143-148.

Ruediger W.; Wall, K.; Wall, R. 2005. Effects of Highways on Elk Habitat in the Western United States and Proposed Mitigation Approaches: International Conference on Ecology and Transportation; 2005 August 29- September 2; San Diego, CA. Proceedings. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University: 269-278.

Rytwinski, T.; and Fahrig, L. 2007. Effect of road density on abundance of white-footed mice. Landscape Ecology. 22(10): 1501-1512.

Swihart, R. K.; and Slade, N. A. 1984. Road crossing in *Sigmodon hispidus* and *Microtus ochrogaster*. Journal of Mammalogy. 65(2): 357-360.

Taylor, B. D.; and Goldingay, R. L. 2010. Roads and wildlife: impacts, mitigation and implications for wildlife management in Australia. Wildlife Research. 37(4): 320-331.

Trombulak, S. C.; and Frissell, C. A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14(1): 18-30.

Underhill, J.E.; and Angold, P.E. 2000. Effects of roads on wildlife in an intensely modified landscape. Environmental Review. 8: 21-39.

U.S. Census Bureau. 2012. State and County Quick Facts. U.S.A. Online: http://quickfacts.census.gov/qfd/states/04000.html.[April 28, 2012]

van der Ree, R.; Jaeger, J. A. G.; van der Grift, E. A.; Clevenger, A. P. 2011. Effects of roads and traffic on wildlife populations and landscape function: road ecology is moving toward larger scales. Ecology and Society. Online: http://www.ecologyandsociety.org/vol16/iss1/art48/.[April 28, 2012]

Weiss, J. L.; Overpeck, J. T. 2005. Is the Sonoran Desert losing its cool? Global Change Biology.11(12): 2065-2077.

Wilson, R. F.; Marsh, H.; Winter, J. 2007. Importance of canopy connectivity for home range and movements of the rainforest arboreal ringtail possum (*Hemibelideus lemuroides*). Wildlife Research. 34(3): 177-184.

Wisdom, M.J.; Holthausen, R.S.; Wales, B. K. 2000. Source habitats for terrestrial vertebrates of focus in the interior Columbia basin: Broad-scale trends and management implications. Gen. Tech. Repo. PNW GTR-485. Portland, OR: USDA Forest Service, Pacific Northwest Research Station.

World Bank. 2008. World Bank Indicators – United States – Transportation. Online: http://www.worldbank.org/ [April 28, 2012].

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