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January 2008

Best Management Practices for Wildlife Corridors

I. Practices for roads, canals, and railroads that cross corridors

Impacts of Roads on Wildlife

While the physical footprint of the nearly 4 million miles of roads in the United States is relatively small, the *ecological* footprint of the road network extends much farther. Direct effects of roads include road mortality, habitat fragmentation and loss, and reduced connectivity. The severity of these effects depends on the ecological characteristics of a given species (Table). Direct **roadkill** affects most species, with severe documented impacts on wide-ranging predators such as the cougar in southern California, the Florida panther, the ocelot, the wolf, and the Iberian lynx (Forman et al. 2003). In a 4-year study of 15,000 km of road observations in Organ Pipe Cactus National Monument, Rosen and Lowe (1994) found an average of at least 22.5 snakes per km per year killed due to vehicle collisions. Although we may not often think of roads as causing **habitat loss**, a single freeway (typical width = 50 m, including median and shoulder) crossing diagonally across a 1-mile section of land results in the loss of 4.4% of habitat area for any species that cannot live in the right-of-way. Roads cause **habitat fragmentation** because they break large habitat areas into small, isolated habit patches which support few individuals; these small populations lose genetic diversity and are at risk of local extinction.

In addition to these obvious effects, roads create noise and vibration that interfere with ability of reptiles, birds, and mammals to communicate, detect prey, or avoid predators. Roads also increase the spread of exotic plants, promote erosion, create barriers to fish, and pollute water sources with roadway chemicals (Forman et al. 2003). Recent studies demonstrate that vehicles deposit 300 to 800 exotic seeds per square meter per year to roadside areas, often from several kilometers away (von der Lippe and Kowarik 2007). Highway lighting also has important impacts on animals (Rich and Longcore 2006).

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Characteristics making a species vulnerable to road effects (from Forman et al. 2003)	Effect of roads		
	Road mortality	Habitat loss	Reduced connectivity
Attraction to road habitat	★		
High intrinsic mobility	★		
Habitat generalist	★		
Multiple-resource needs	★		★
Large area requirement/low density	★	★	★
Low reproductive rate	★	★	★
Behavioral avoidance of roads			★

Mitigation for Roads

Clearly the most corridor-friendly road policy is avoid building any new roads in a wildlife corridor. Where there are over-riding reasons to build or expand roads in corridors, wildlife crossing structures can facilitate wildlife movement across roads; these structures include wildlife overpasses & green bridges, bridges, culverts, and pipes. While many of these structures were not originally constructed with ecological connectivity in mind, many species benefit from them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use pipes and small culverts, while bighorn sheep prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a mountain lion or bear, but not by a deer or bighorn sheep. Small mammals, such as deer mice and voles, prefer small culverts to wildlife overpasses (McDonald & St Clair 2004). Some mammals avoid crossing 2-lane roads with less than 100 vehicles per day (McGregor et al. 2008); thus crossing structures are needed to provide connectivity even on lightly-used small roads.

Wildlife overpasses are most often designed to improve opportunities for large mammals to cross busy highways. Approximately 50 overpasses have been built in the world, with only 6 of these occurring in North America (Forman et al. 2003). Overpasses are typically 30 to 50 m wide, but can be as large as 200 m wide. In Banff National Park, Alberta, grizzly bears, wolves, and all ungulates (including bighorn sheep, deer, elk, and moose) prefer overpasses to underpasses, while species such as mountain lions prefer underpasses (Clevenger & Waltho 2005).

Wildlife underpasses include viaducts, bridges, culverts, and pipes, and are often designed to ensure adequate drainage beneath highways. For ungulates such as deer that prefer open crossing structures, tall, wide bridges are best. Mule deer in southern California only used underpasses below large spanning bridges (Ng et al. 2004), and the average size of underpasses used by white-tailed deer in Pennsylvania was 15 ft wide by 8 ft high (Brudin 2003). Because most small mammals, amphibians, reptiles, and insects need vegetative cover for security, bridged undercrossings should extend to uplands beyond the scour zone of the stream, and should be high enough to allow enough light for vegetation to grow underneath. In the Netherlands, rows of stumps or branches under crossing structures have increased connectivity for smaller species crossing bridges on floodplains (Forman et al. 2003). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). A bridge is a road supported on piers or abutments above a watercourse, while a culvert is a round or rectangular tube under a road. The most important difference is that the streambed under a bridge is mostly native rock and soil (instead of concrete or corrugated metal in a culvert) and the area under the bridge is large enough that a semblance of a natural stream channel returns a few years after construction. Even when rip-rap or other scour protection is installed to protect bridge piers or abutments, stream morphology and hydrology usually return to near-natural conditions in bridged streams, and vegetation often grows under bridges. In contrast, vegetation does not grow inside a culvert, and hydrology and stream morphology are permanently altered not only within the culvert, but for some distance upstream and downstream from it.

Despite their disadvantages, well-designed and located *culverts* can mitigate the effects of busy roads for small and medium sized mammals (Clevenger et al. 2001; McDonald & St Clair 2004). Culverts and concrete box structures are used by many species, including mice, shrews, foxes,

rabbits, armadillos, river otters, opossums, raccoons, ground squirrels, skunks, coyotes, bobcats, mountain lions, black bear, great blue heron, long-tailed weasel, amphibians, lizards, snakes, and southern leopard frogs (Yanes et al. 1995; Brudin 2003; Dodd et al. 2004; Ng et al. 2004). Black bear and mountain lion prefer less-open structures (Clevenger & Waltho 2005). In south Texas, bobcats often used 1.85 m x 1.85 m box culverts to cross highways, preferred structures near suitable scrub habitat, and sometimes used culverts to rest and avoid high temperatures (Cain et al. 2003). Culvert usage can be enhanced by providing a natural substrate bottom, and in locations where the floor of a culvert is persistently covered with water, a concrete ledge established above water level can provide terrestrial species with a dry path through the structure (Cain et al. 2003). It is important for the lower end of the culvert to be flush with the surrounding terrain. Some cases located in fill dirt have openings far above the natural stream bottom. Many culverts are built with a concrete pour-off of 8-12 inches, and others develop a pour-off lip due to scouring action of water. A sheer pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert.

Based on the small but increasing number of scientific studies on wildlife use of highway crossing structures, we offer these standards and guidelines for *all* existing and future crossing structures intended to facilitate wildlife passage across highways, railroads, and canals. These recommendations apply with equal force to crossing structures across canals (see Section IV).

1) **Multiple crossing structures should be constructed at a crossing point to provide connectivity for all species likely to use a given area** (Little 2003). Different species prefer different types of structures (Clevenger et al. 2001; McDonald & St Clair 2004; Clevenger & Waltho 2005; Mata et al. 2005). For deer or other ungulates, an open structure such as a bridge is crucial. For medium-sized mammals, black bear, and mountain lions, large box culverts with natural earthen substrate flooring are optimal (Evink 2002). For small mammals, pipe culverts from 0.3m – 1 m in diameter are preferable (Clevenger et al. 2001; McDonald & St Clair 2004).

2) **At least one crossing structure should be located within an individual's home range**. Because most reptiles, small mammals, and amphibians have small home ranges, metal or cement box culverts should be installed at intervals of 150-300 m (Clevenger et al. 2001). For ungulates (deer, pronghorn, bighorn) and large carnivores, larger crossing structures such as bridges, viaducts, or overpasses should be located no more than 1.5 km (0.94 miles) apart (Mata et al. 2005; Clevenger and Wierzchowski 2006). Inadequate size and insufficient number of crossings are two primary causes of poor use by wildlife (Ruediger 2001).

3) **Suitable habitat for species should occur on both sides of the crossing structure** (Ruediger 2001; Barnum 2003; Cain et al. 2003; Ng et al. 2004). This applies to both *local* and *landscape* scales. On a local scale, vegetative cover should be present near entrances to give animals security, and reduce negative effects of lighting and noise (Clevenger et al. 2001; McDonald & St Clair 2004). A lack of suitable habitat adjacent to culverts originally built for hydrologic function may prevent their use as potential wildlife crossing structures (Cain et al. 2003). On the landscape scale, "Crossing structures will only be as effective as the land and resource management strategies around them" (Clevenger et al. 2005). Suitable habitat must be present throughout the linkage for animals to use a crossing structure.

4) **Whenever possible, suitable habitat should occur *within* the crossing structure.** This can best be achieved by having a bridge high enough to allow enough light for vegetation to grow under the bridge, and by making sure that the bridge spans upland habitat that is not regularly scoured by floods. Where this is not possible, rows of stumps or branches under large span bridges can provide cover for smaller animals such as reptiles, amphibians, rodents, and invertebrates; regular visits are needed to replace artificial cover removed by flood. Within culverts, mammals and reptiles prefer earthen to concrete or metal floors.

5) **Structures should be monitored for, and cleared of, obstructions such as detritus or silt blockages that impede movement.** Small mammals, carnivores, and reptiles avoid crossing structures with significant detritus blockages (Yanes et al. 1995; Cain et al. 2003; Dodd et al. 2004). In the southwest, over half of box culverts less than 8 x 8 ft have large accumulations of branches, Russian thistle, sand, or garbage that impede animal movement (Beier, personal observation). Bridged undercrossings rarely have similar problems.

6) **Fencing should never block entrances to crossing structures, and instead should direct animals towards crossing structures** (Yanes et al. 1995, Gagnon et al. 2007). In Florida, construction of a barrier wall to guide animals into a culvert system resulted in 93.5% reduction in roadkill, and also increased the total number of species using the culvert from 28 to 42 (Dodd et al. 2004). Fences, guard rails, and embankments at least 2 m high discourage animals from crossing roads (Barnum 2003; Cain et al. 2003; Malo et al. 2004). One-way ramps on roadside fencing can allow an animal to escape if it is trapped on a road (Forman et al. 2003).

7) **Raised sections of road discourage animals from crossing roads, and should be used when possible to encourage animals to use crossing structures**. Clevenger et al. (2003) found that vertebrates were 93% less susceptible to road-kills on sections of road raised on embankments, compared to road segments at the natural grade of the surrounding terrain.

8) **Manage human activity near each crossing structure**. Clevenger & Waltho (2000) suggest that human use of crossing structures should be restricted and foot trails relocated away from structures intended for wildlife movement. However, a large crossing structure (viaduct or long, high bridge) should be able to accommodate both recreational and wildlife use. Furthermore, if recreational users are educated to maintain utility of the structure for wildlife, they can be allies in conserving wildlife corridors. At a minimum, nighttime human use of crossing structures should be restricted.

9) **Design crossing structures specifically to provide for animal movement**. Recent research shows that traffic noise within an undercrossing can discourage passage by wildlife, suggesting that new designs are needed to minimize vehicle noise in underpasses (Gagnon et al. 2007). Ungulates prefer undercrossings with sloped earthen sides to vertical concrete sides (Dodd et al. 2007). High openness ratio (height x width divided by length) promote animal travel, and perhaps the best way to achieve this is to minimize the distance an animal must travel within the structure (Dodd et al. 2007). Most culverts are designed to carry water under a road and minimize erosion hazard to the road. Culvert designs adequate for transporting

water often have pour-offs at the downstream ends that prevent wildlife usage. At least 1 culvert every 150-300m of road should have both upstream and downstream openings flush with the surrounding terrain, and with native land cover up to both culvert openings, as noted above.

II. Practices for streams in corridors

1) **Retain natural fluvial processes** – Maintaining or restoring natural timing, magnitude, frequency, and duration of surface flows is essential for sustaining functional riparian ecosystems (Shafroth et al. 2002, Wissmar 2004).
   - Urban development contributes to a "flashier" (more flood-prone) system. Check dams and settling basins should be required in all upstream urban areas of the watershed to increase infiltration and reduce the impact of intense flooding (Stromberg 2000).
   - Maintain natural channel-floodplain connectivity—do not harden riverbanks and do not build in the floodplain (Wissmar 2004).
   - Release of treated municipal waste water in some riparian corridors has been effective at restoring reaches of cottonwood and willow ecosystems. Habitat quality is generally low directly below the release point but improves downstream (Stromberg et al. 1993). However in an intermittent reach with native amphibians or fishes, water releases should not create perennial (year-round) flows. Bullfrogs can and do displace native amphibians from perennial waters (Kiesecker and Blaustin 1998, Maret et al. 2006).

2) **Promote base flows and maintain groundwater levels within the natural tolerance ranges of native plant species** – Subsurface water is important for riparian community health, and can be sustained more efficiently by reducing ground water pumping near the river, providing municipal water sources to homes, and reducing agricultural water use through use of low-water-use crops, and routing return flows to the channel (Stromberg 1997, Colby and Wishart 2002). Cottonwood/willow habitat requires maintaining water levels within 9 feet (2.6 m) below ground level (Lite and Stromberg 2005).

3) **Maintain or improve native riparian vegetation** – Moist surface conditions in spring and flooding in summer after germination of tamarisk will favor native cottonwood/willow stands over the invasive tamarisk (Stromberg 1997). Pumps within ½ mile of a river or near springs should cease pumping in early April through May, or, if this is impossible, some pumped water should be spilled on to the floodplain in early April to create shallow pools through May (Wilbor 2005). Large mesquite *bosques* should receive highest priority for conservation protection because of their rarity in the region; mesquite, netleaf hackberry, elderberry, and velvet ash trees should not be cut (Stromberg 1992, Wilbor 2005).

4) **Maintain biotic interactions within evolved tolerance ranges**. Arid Southwest riparian systems evolved under grazing and browsing pressure from deer and pronghorn antelope—highly mobile grazers and browsers. High intensity livestock grazing is a major stressor for riparian systems in hot Southwest deserts; livestock should thus be excluded from stressed or degraded riparian areas (Belsky et al. 1999, National Academy of Sciences 2002). In healthy riparian zones, grazing pressure should not exceed the historic grazing intensity of native ungulates (Stromberg 2000).

5) **Eradicate non-native invasive plants and animals** – Hundreds of exotic species have become naturalized in riparian corridors, and a few, such as tamarisk and Russian olive, are significant problems. Removing stressors and reestablishing natural flow regimes can help restore riparian communities, but physical eradication of some persistent exotics is necessary

(Stromberg 2000, Savage 2004, but see D'Antonio and Meyerson 2002). Elimination of unnatural perennial surface pools can eradicate water-dependent invasives like bullfrogs, crayfish, and mosquitofish.

6) **Where possible, protect or restore a continuous strip of native vegetation at least 200 m wide along each side of the channel**. Buffer strips can protect and improve water quality, provide habitat and connectivity for many species, improve quality of life for human neighbors, and increase nearby property values (Fisher and Fischenich 2000, Parkyn 2004, Lee et al. 2004). Recommended buffer widths to sustain riparian plant and animal communities vary from 30 to 500 m (Wenger 1999, Fisher and Fischenich 2000, Wenger and Fowler 2000, Environmental Law Institute 2003). At a minimum, buffers should capture the stream channel and the terrestrial landscape affected by flooding and elevated water tables (Naiman et al. 1993). Wider buffers are needed to protect edge sensitive bird species from nest predation and parasitism. We recommend delineating a buffer that extends 200 m beyond the annual high water mark on each side of the channel.

7) **Enforce existing regulations**. We recommend aggressive enforcement of existing regulations restricting dumping of soil, agricultural waste, and trash in streams, and restricting farming, gravel mining, and building in streams and floodplains. OHV travel in streams disturbs soils, damages vegetation, and disturbs wildlife (Webb and Wilshire 1983).

III. Practices for urban development in corridors

Impacts of urbanization on wildlife habitat and connectivity

Urbanization includes not only factories, gravel mines, shopping centers, and high-density residential, but also low-density ranchette development. These diverse types of land use impact wildlife movement in several ways. In particular, urbanization causes:

- development of the local road network. Rural subdivisions require more road length per dwelling unit than more compact residential areas. Many wild animals are killed on roads. Some reptiles (which "hear" ground-transmitted vibrations through their jaw (Heatherington 2005) are repelled even from low-speed 2-lane roads, resulting in reduced species richness (Findlay and Houlihan 1997). This reduces road kill but fragments their habitat.

- removal and fragmentation of natural vegetation. CBI (2005) evaluated 4 measures of habitat fragmentation in rural San Diego County, namely percent natural habitat, mean patch size of natural vegetation, percent core areas (natural vegetation > 30m or 96 ft from non-natural land cover), and mean core area per patch at 7 housing densities (Figure). Fragmentation effects were negligible in areas with <1 dwelling unit per 80 acres, and severe in areas with > 1 dwelling unit per 40 acres (CBI 2005). Similar patterns, with a dramatic threshold at 1 unit per 40 acres, were evident in 4 measures of fragmentation measured in 60 landscapes in rural San Diego County, California (CBI 2005).

% Natural Vegetation

80

60

40

20

0

0   80   160   240   320

Acres per dwelling unit
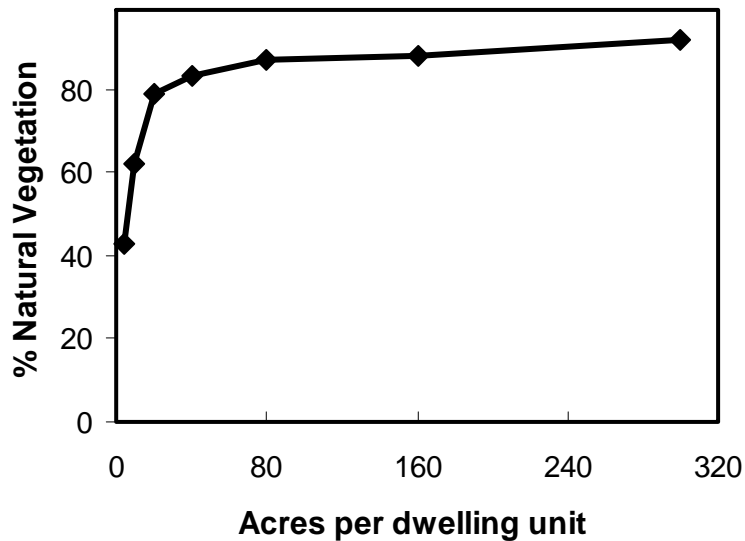
- decreased abundance and diversity of native species, and replacement by non-native species. In Arizona, some species of birds (Germaine et al. 1998) and lizards (Germaine and Wakeling 2001) were absent as housing density increased. Similar patterns were observed for birds and butterflies in California (Blair 1996, Blair and Launer 1997, Blair 1999, Rottenborn 1999, Strahlberg and Williams 2002), birds in Washington state (Donnelly and Marzluff 2004), mammals and forest birds in Colorado (Odell and Knight 2001), and migratory birds in Ontario (Friesen et al. 1995). The negative effects of urbanization were evident at housing densities as low as 1 dwelling unit per 40-50 acres. In general, housing densities below this threshold had little impact on birds and small mammals.
- increased vehicle traffic in potential linkage areas, increasing the mortality and repellent effect of the road system (van der Zee et. al 1992, Marsh 2007).
- increased numbers of dogs, cats, and other pets that act as subsidized predators, killing millions of wild animals each year (Courchamp and Sugihara 1999, May and Norton 1996).
- increased numbers of wild predators removed for killing pets or hobby animals. Rural residents often are emotionally attached to their animals, and prompt to notice loss or injury. Thus although residential development may bring little or increase in the number of the depredation incidents per unit area, each incident is more likely to lead to death of predators, and eventual elimination of the population (Woodroffe and Frank 2005).
- subsidized "suburban native predators" such as raccoons, foxes, and crows, that exploit garbage and other human artifacts to reach unnaturally high density, outcompeting and preying on other native species (Crooks and Soulé 1999).
- spread of some exotic (non-native) plants, namely those that thrive on roadsides and other disturbed ground, or that are deliberately introduced by humans.
- perennial water in formerly ephemeral streams, making them more hospitable to bullfrogs and other non-native aquatic organisms that displace natives and reduce species richness (Forman et al. 2003).

- mortality of native plants and animals via pesticides and rodenticides, which kill not only their target species (e.g., domestic rats), but also secondary victims (e.g., raccoons and coyotes that feed on poisoned rats) and tertiary victims (mountain lions that feed on raccoons and coyotes – Riley et al. 2007).
- artificial night lighting, which can impair the ability of nocturnal animals to navigate through a corridor (Beier 2006) and has been implicated in decline of reptile populations (Perry and Fisher 2006).
- conflicts with native herbivores that feed on ornamental plants.
- noise, which may disturb or repel some animals and present a barrier to movement (Minton 1968, Liddle 1997).
- disruption of natural fire regime by (a) increasing the number of wildfire ignitions, especially those outside the natural burning season (Viegas et. al 2003), (b) increasing the need to suppress what might otherwise be beneficial fires that maintain natural ecosystem structure, and (c) requiring firebreaks and vegetation manipulation, sometimes at considerable distance from human-occupied sites (Oregon Department of Forestry 2006, Syphard et al. 2007).

Unlike road barriers (which can be modified with fencing and crossing structures), urban and industrial developments create barriers to movement which cannot easily be removed, restored, or otherwise mitigated. For instance, it is unrealistic to think that local government will stop a homeowner from clearing fire-prone vegetation force a landowner to remove overly bright artificial night lighting, or require a homeowners association to kill crows and raccoons. Avoidance is the best way to manage urban impacts in a wildlife linkage. Although some lizards and small mammals occupy residential areas, most large carnivores, small mammals, and reptiles cannot occupy or even move through urban areas. While mapped urban areas currently accounts for less than 1% of the land cover, residential development may increase rapidly in parts of the Linkage Design.

Mitigation for Urban Barriers
1) Integrate the Linkage Design into local land use plans. Specifically, use zoning and other tools to retain open space and natural habitat and discourage urbanization of natural areas in the Linkage Design.
2) Where development is permitted within the linkage design, encourage small building footprints on large (> 40 acre) parcels with a minimal road network.
3) Integrate this Linkage Design into county general plans, and conservation plans of governments and nongovernmental organizations.
4) Encourage conservation easements or acquisition of conservation land from willing land owners in the Linkage Design. Recognizing that there may never be enough money to buy easements or land for the entire Linkage Design, encourage innovative cooperative agreements with landowners that may be less expensive (Main et al. 1999, Wilcove and Lee 2004).
5) Combine habitat conservation with compatible public goals such as recreation and protection of water quality.
6) Each strand of the linkage design must be broad (typically 1-2 km for most of its length) to allow a designated trail system without compromising the usefulness of the linkage for wildlife. Because of the high potential for human access, the trail system should be carefully

planned to minimize resource damage and disturbance of wildlife. People should be encouraged to stay on trails, keep dogs on leashes, and discouraged from collecting reptiles and harassing wildlife. Traveling in groups should be encourage in areas frequented by mountain lions or bears.

7) Where human residences or other low-density urban development occurs within the linkage design or immediately adjacent to it, encourage landowners to be proud stewards of the linkage. Specifically, encourage them to landscape with natural vegetation, minimize water runoff into streams, manage fire risk with minimal alteration of natural vegetation, keep pets indoors or in enclosures (especially at night), accept depredation on domestic animals as part of the price of a rural lifestyle, maximize personal safety with respect to large carnivores by appropriate behaviors, use pesticides and rodenticides carefully or not at all, and direct outdoor lighting toward houses and walkways and away from the linkage area.

8) When permitting new urban development in the linkage area, stipulate as many of the above conditions as possible as part of the code of covenants and restrictions for individual landowners whose lots abut or are surrounded by natural linkage land. Even if some clauses are not rigorously enforced, such stipulations can promote awareness of how to live in harmony with wildlife movement.

9) Develop a public education campaign to inform those living and working within the linkage area about living with wildlife, and the importance of maintaining ecological connectivity.

10) Discourage residents and visitors from feeding or providing water for wild mammals, or otherwise allowing wildlife to lose their fear of people.

11) Install wildlife-proof trash and recycling receptacles, and encourage people to store their garbage securely.

12) Do not install artificial night lighting on rural roads that pass through the linkage design. Reduce vehicle traffic speeds in sensitive locations by speed bumps, curves, artificial constrictions, and other traffic calming devices.

13) Encourage the use of wildlife-friendly fencing on property and pasture boundaries, and wildlife-proof fencing around gardens and other potential wildlife attractants.

14) Discourage the killing of 'threat' species such as rattlesnakes.

15) Reduce or restrict the use of pesticides, insecticides, herbicides, and rodenticides, and educate the public about the effects these chemicals have throughout the ecosystem.

16) Pursue specific management protections for threatened, endangered, and sensitive species and their habitats.

IV.   Practices for canals in corridors

In deserts, some species may use canals as a water source, but canals have more negative than positive impacts on wildlife. Desert mule deer, bighorn sheep, and Sonoran pronghorn have drowned in canals (Rautenstrauch & Krausman 1989). Canals serve as significant barriers to movement.

1) **Ensure opportunities for wildlife to cross every canal in the linkage area**. The most permeable method is to bury these segments of the canal below ground. For narrow canals, such as those irrigating fields, it may be cheaper to cover the canal with metal or concrete slabs, and cover these plates with soil and vegetation. Larger canals are typically elevated on

levees that are hard for animals to climb. On such canals, underground siphons should be used to create gaps that follow the natural contour of the land. <u>Siphon gaps intended for wildlife use should at least 40-50 m wide, have natural vegetation, and follow natural grade of the surrounding landscape</u>.

2) **Install fencing on all areas of the canal which do not have crossing structures.** This fencing must keep animals away from canals where they are likely to drown (Rautenstrauch & Krausman 1989). They should be high enough that deer can't jump over the fence (Peris & Morales 2004).

3) **Provide alternative water sources adjacent to crossing structures** (Rautenstrauch & Krausman 1989). To discourage use of the canals as a water supply by deer and other species, some canal water should be diverted to catchments where wildlife can drink without risk of drowning.

4) **Provide escape structures for deer and other species along any area of the canal which does not have a crossing structure or fencing.** Cable-and-float directors in conjunction with stairs or ramps should be installed in the canal to direct deer to provide deer and other species means of escaping the canal. In a study of desert mule deer use of the Mohawk Canal, Rautenstrauch and Krausman (1989) found that deer swim an average distance of 947 meters before escaping via escape structures. They recommend escape structures should be spaced 2 km apart or less and every section with a dam, siphon, or other hazard should have more than 1 escape structure, with at least 1 structure upstream from the hazard.

References

Barnes, T. and Adams, L. 1999. A Guide to Urban Habitat Conservation Planning: University of Kentucky Cooperative Extension Service.

Barnum, S.A. 2003. Identifying the best locations along highways to provide safe crossing opportunities for wildlife: a handbook for highway planners and designers. Colorado Department of Transportation.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. Conservation Biology 7: 94-108.

Beier, P. 2006. Effects of artificial night lighting on terrestrial mammals. Pages 19-42 In C. Rich and T. Longcore, editors, Ecological consequences of artificial night lighting. Island Press, Covelo, California.

Beier, P., and S. Loe. 1992. A checklist for evaluating impacts to wildlife corridors. Wildlife Society Bulletin 20: 434-40.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54:419-431.

Blair, R.B. 1996. Land use and avian species diversity along an urban gradient. Ecological Applications 6:506-519.

Blair, R.B. 1999. Birds and butterflies along an urban gradient: surrogate taxa for assessing biodiversity? Ecological Applications 9:164-170.

Blair, R.B., and A.E. Launer. 1997. Butterfly diversity and human land use: species assemblages along an urban gradient. Biological Conservation 80:113-125.

Brooks, M.L., and B. Lair. 2005. Ecological effects of vehicular routes in a desert ecosystem. Report prepared for the United States Geological Survey, Recoverability and Vulnerability of Desert Ecosystems Program.

Brudin III, C.O. 2003. Wildlife use of existing culverts and bridges in north central Pennsylvania. ICOET 2003.

Cain, A.T., V.R. Tuovila, D.G. Hewitt, and M.E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in Southern Texas. Biological Conservation 114: 189-197.

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., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38: 1340-1349.

Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109: 15-26.

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

Colby, B., and S. Wishart. 2002. Riparian areas generate property value premium for landowners. Agiculatural and Resource Economics, Arizona State University, Tucson, AZ. 15p. Available online: http://ag.arizona.edu/arec/pubs/riparianreportweb.pdf.

Conservation Biology Institute. 2005. Analysis of General Plan-2020 San Diego County. Encinitas, Ca. 27pp.

Courchamp, F., G. Sugihara. 1999 .Biological control of introduced predator populations to protect native island species from extinction. Ecological Applications, 9(10), pp.112-123

Crooks K.R., M.E. Soule. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400:563–566

D'Antonio, C. and L.A. Meyerson. 2002. Exotic plant species as problems and solutions in ecological restoration: a synthesis. Restoration Ecology 10: 703-713.

Dodd, C.K, W.J. Barichivich, and L.L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118: 619-631.

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

Donnelly, R., and J.M. Marzluff. 2004. Importance of reserve size and landscape context to urban bird conservation. Conservation Biology 18:733-745.

Environmental Law Institute. 2003. Conservation thresholds for land use planners. Environmental Law Institute. Washington D.C. Available online: www.elistore.org.

Evink, G.L. 2002. Interaction between roadways and wildlife ecology. National Academy Press, Washington, D.C.

Findlay C.S., and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation biology 11:1000-1009.

Fisher, R. A. and J. C. Fischenich. 2000. Design recommendations for riparian corridors and vegetated buffer strips. U.S. Army Engineer Research and Development Center. ERDC-TN-EMRRPSR-24. Available online

Forman, R.T.T., et al. 2003. Road ecology: science and solutions. Island Press: Washington, D.C.

Friesen, L.E., P.F.J. Eagles, and R.J. Mackay. 1995. Effects of residential development on forest-dwelling neotropical migrant songbirds. Conservation Biology 9:1408-1414.

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

Germaine, S.S., and B.F. Wakeling. 2001. Lizard species distributions and habitat occupation along an urban gradient in Tucson, Arizona, USA. Biological Conservation 97:229-237.

Germaine, S.S., S.S. Rosenstock, R.E. Schweinsburg, and W.S. Richardson. 1998. Relationships among breeding birds, habitat, and residential development in greater Tucson, Arizona. Ecological Applications 8:680-691.

Hetherington, T. 2005. Role of the opercularis muscle in seismic sensitivity in the bullfron Rana catesbeiana. Journal of Experimental Zoology 235:27-34

Kiesecker, J. M. and A. R. Blaustein. 1998. Effects of introduced Bullfrogs and smallmouth bass on microhabitat use, growth, and survival of native red-legged frogs (*Rana aurora*). Conservation Biology 12:776-787.

Lee, P., C. Smyth, and S. Boutin. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. Journal of Environmental Management 70:165-180.

Liddle, M. 1997. Recreation ecology: The ecological impact of outdoor recreation and ecotourism. 639 pp. Chapman and Hall: New York.

Lite, S.J., and J.C. Stromberg. 2005. Surface water and ground-water thresholds for maintaining Populus - Salix forests, San Pedro River, Arizona. Biological Conservation 125:153–167.

Little, S.J. 2003. The influence of predator-prey relationships on wildlife passage evaluation. ICOET 2003.

Main MB, FM Roka, and RF Noss. 1999 Evaluating the costs of conservation. Conservation Biology 13:1262-1272.

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.

Maret T.J., J.D. Snyder, and J.P. Collins.2006. Altered drying regime controls distribution of endangered salamanders and introduced predators. BiologicalConservation 127:129-138.

Marsh, D. 2007. Edge effects of gated and ungated roads on terrestrial salamanders. Journal of Wildlife Management 71:389-394.

Mata, C., I. Hervas, J. Herranz, F. Suarez, and J.E. Malo. 2005. Complementary use by vertebrates of crossing structures along a fences Spanish motorway. Biological Conservation 124: 397-405.

May, S. A., and T. W. Norton. 1996. Influence of fragmentation and disturbance on the potential impact of feral predators on native fauna in Australian forest ecosystems. Wildlife Research 15:387–400.

McDonald, W., and C.C. St Clair. 2004. Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology 41: 82-93.

McGregor, R. L., D. J. Bender, and L Fahrig. 2008. Do small mammals avoid roads because of the traffic? Journal of Applied Ecology: in press.

Minton, Jr. S.A. 1968. The fate of amphibians and reptiles in a suburban area. Journal of Herpetology 2:113-116.

Naiman, R. J., H. Decamps and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209-212.

National Academy of Sciences. 2002. Riparian areas: functions and strategies for management. National Academy Press. Washington D. C. 436 p.

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

Odell, E.A., and R.L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology 15:1143-1150.

Oregon Department of Forestry. 2006. The Oregon Forestland-Urban Interface Fire Protection Act; Property Evaluation and Self-Certification Guide. 32pp. Oregon Department of Forestry, Salem

Parkyn, S. 2004. Review of riparian buffer zone effectiveness. MAF Technical Paper No: 2004/05. Available online: www.maf.govt.nz/publications.

Peris, S., and J. Morales. 2004. Use of passages across a canal by wild mammals and related mortality. European Journal of Wildlife Research. 50: 67-72.

Perry, G.,and R.N. Fisher. 2006. Night Lights and Reptiles: Observed and Potential Effects. Pp 169-191 In C. Rich and T. Longcore, editors, Ecological consequences of artificial night lighting. Island Press, Covelo, California.

Rich, C., and T. Longcore. 2006. Ecological effects of artificial night lighting. Island Press.

Riley et al. 2007. Anticoagulant exposure and notoedric mange in bobcats and mountain lions in urban Southern California. Journal of Wildlife Management 71:1874-1884.

Rautenstrauch, K. R., and P. R. Krausman. 1989. Preventing mule deer drowning in the Mohawk canal, Arizona. Wildlife Society Bulletin 17:281–286

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

Rottenborn, S.C. 1999. Predicting impacts of urbanization on riparian bird communities. Biological Conservation 88:289-299.

Rubin, E.S., W.M. Boyce, C.J. Stermer, and S.G. Torres. 2002. Bighorn sheep habitat use and selection near an urban environment. Biological Conservation 104: 251-263.

Ruediger, B. 2001. High, wide, and handsome: designing more effective wildlife and fish crossings for roads and highways. ICOET 2001.

Savage, M. 2004. Community monitoring for restoration projects in Southwestern riparian communities. National Community Forestry Center Southwest Working Paper No. 16. Forest Guild. Santa Fe, NM

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications 12: 107-123.

Springer, A. E., J. M. Wright, P. B. Shafroth, J. C. Stromberg, and D. T. Patten 1999. Coupling ground-water and riparian vegetation models to simulate riparian vegetation changes due to a reservoir release. Water Resources Research 35: 3621-3630.

Stralberg, D., and B. Williams. 2002. Effects of residential development and landscape composition on the breeding birds of Placer County's foothill oak woodlands. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184.

Stromberg, J. 2000. Parts 1-3: Restoration of riparian vegetation in the arid Southwest: challenges and opportunities. Arizona Riparian Council Newsletter vol. 13 no. 1-3. Arizona Riparian Council. Tempe, Arizona. Available online: http://azriparian.asu.edu/newsletters.htm.

Stromberg, J.C., M.R. Sommerfield, D.T. Patten, J. Fry, C. Kramer, F. Amalfi, and C. Christian. 1993. Release of effluent into the Upper Santa Cruz River, Southern Arizona: ecological considerations. Pp. 81-92 in M. G. Wallace, ed. Proceedings of the Symposium on Effluent Use Management. American Water Resources Association, Tucson, AZ.

Sullivan T.L., and T.A. Messmer. 2003. Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. Wildlife Society Bulletin 31:163-173.

Syphard, A. D., V. C. Radeloff, J. Keeley, et al. 2007. Human influence on California fire regimes. Ecological Applications 17:1388-1402.

Turner et al. 1995. Preserve Design for maintaining biodiversity in the Sky Island region. *In*: De Bano, Leonard F., Peter F. Ffolliott, Alfredo Ortega-Rubio, Gerald J. Gottfried, Robert H. Hamre, and Carleton B. Edminster (tech. cords.). 1995. Biodiversity and Management of the Madrean Archipelago: the sky islands of southwestern United States and northwestern Mexico. Gen. Tech. Report RM-GTR-264. Ft. Collins, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountatin Forest and Range Experiment Station. pp. 524-530.

van der Zee, F.F., J. Wiertz, C.J.F. Ter Braak, and R.C. van Apeldoorn. 1992. Landscape change as a possible cause of the badger (Meles meles) decline in the Netherlands. Biological Conservation 61:17-22

van Wieren, S.E., and P.B. Worm. 2001. The use of a motorway wildlife overpass by large mammals. Netherlands Journal of Zoology 51: 97-105.

Viegas, D.X., B. Allgöwer, N. Koutsias, and G. Eftichidis. 2003. Fire spread and the wildland urban interface problem. Ch. 12 In Proceedings of the International Scientific Workshop on Forest Fires in the Wildland-Urban Interface and Rural Areas in Europe: an integral planning and management challenge.

von der Lippe, M., and I. Kowarik. 2007. Long-distance dispersal of plants by vehicles as a driver of plant

invasions. Conservation Biology 21:986-996.

Webb, R.H. and H.G. Wilshire. 1983. Environmental effects of off-road vehicles: impacts and management in arid regions. New York : Springer-Verlag.

Wenger, S.J. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Athens, GA: University of Georgia, Public Service & Outreach, Institute of Ecology. 59 p.

Wenger, S.J., and L. Fowler. 2000. Protecting stream and river corridors. Policy Notes, Public Policy Research Series vol 1, no. 1. Carl Vinson Institute of Government, University of Georgia, Athens, GA. Available online: http://www.cviog.uga.edu/publications/pprs/96.pdf.

Wilbor, S. 2005. Audubon's important bird areas program's avian habitat conservation plan: U.S. Upper Santa Cruz River Riparian Corridor, Santa Cruz County, Arizona. Audubon Society, Tucson, AZ. Available online: http://www.tucsonaudubon.org/azibaprogram/UpperSantaCruzRiverAvianHabitatConsPlan.doc.

Wilcove, D.S., and J. Lee. 2004. Using economic and regulatory incentives to restore endangered species: lessons learned from three new programs. Conservation Biology 18:639-645.

Wildlands Project. 2005. Threats to Cross-Border Wildlife Linkages in the Sky Islands Wildlands Network. In: Gottfried, Gerald J.; Gebow, Brooke S.; Eskew, Lane G.; Edminster, Carleton B., comps. Connecting mountain islands and desert seas: biodiversity and management of the Madrean Archipelago II. Proc. RMRS-P-36. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 353-356.

Wissmar, R.C. 2004. Riparian corridors of Eastern Oregon and Washington: Functions and sustainability along lowland-arid to mountain gradients. Aquatic Sciences 66: 373-387.

Woodroffe and Frank 2005

Yanes, M., J.M. Velasco, and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71: 217-222.