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Scaling roads and wildlife: the Cinderella principle

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1 Introduction

Anthropogenically created infrastructure has directly impacted 2 million km^2 or about 1.4% of the Earth's surface (VIROUSEK et al., 1986). While this may not seem like a large percentage, it would be incorrect to imagine that ecological impacts are restricted to the physical footprint of the built infrastructure. FORMAN (2000) has estimated, for example, that 20% of the land surface in the United States is impacted by roads alone. In other words, built infrastructure, and especially roads and road networks have large indirect effects that are not obvious. To gain perspective and context, one can imagine indirect effects as equivalent to a virtual footprint much larger than its causative physical footprint. The resulting impacts of roaded landscapes include habitat fragmentation and loss, reduced habitat quality, loss of habitat connectivity, and barrier effects that impact the diverse communities of species that occupy the landscape. In other words, roads and road networks tend to reduce the permeability of the landscape, impacting movement dynamics of species populations, and resulting in smaller, isolated populations that may exhibit complicated dynamics and have a greater probability of local extinction. Typically, departments of transportation in the United States and elsewhere have not considered these kinds of expanded, indirect, and virtual effects. Yet as road building continues, the virtual footprint is already too large and is still increasing. Mitigation to diminish both direct and indirect effects of roads is what I term the Cinderella Principle, namely, shrinking the virtual footprint to more closely match its physical presence. It is essential to 'make the shoe fit' in order to restore ecological health and integrity.

2 The nature of nature without roads

The defining element of nature is its heterogeneously nature. Ecological processes and ecosystem continuity occur in spatially structured ecosystems. Given spatial heterogeneity across landscapes, it follows that resources needed for species existence are distributed similarly in a non-continuous pattern. Movement across some landscape extent is thus required for species existence, maintenance, and successful reproduction. Small populations require linkages across spatially divided patches if they are to survive. MERRIAM (1998, p. 525) clearly enunciated a critical principle when he stated: "There is a fundamental linkage between demographic success of a population and the spatial structure of its resource base". When movement across a landscape, i.e., for foraging, migration, and finding mates is hindered, then populations of different sizes living in spatially structured habitats across an array of different patch sizes will decline. In roaded landscapes, both direct and indirect effects have the potential to disrupt movement between resource patches and result in population declines of once abundant species.

3 Impacts of roads

Direct Effects
Roads have profound impacts on the abundance of wildlife species, community diversity, and on ecosystem health and integrity. The most direct effect is animal mortality or road kill on roads. Large animals are probably most noticed by the public when they are hit on roads, but are by no means the animals most frequently hit. For example in the U.S., data tend to be better for large animal road mortality, thus skewing our perception. Data for both white-tailed deer (*Odocoileus virginianus*) and mule deer (*Odocoileus hemionus*) suggest an estimated 720,000 animals killed on U.S. roads each year (CONOVER et al., 1995). Not all animals remain visible after being hit. ROMIN (1994) estimated that as many as 50% of deer hit on the road leave the area and may never be counted. DECKER et al. (1990) suggested that only 1/6 of deer hit were counted. Additionally, ALLEN and MCCULLOUGH (1976) estimated that 92% of deer hit die as a result. Assuming the generality of these results, conservatively more than 1.2 million deer may die annually on U. S. roads. However, many smaller species are killed on roads. Data for these species tend to be much more limited in area coverage. Additionally no concerted or organized attempt has been made to extrapolate existing values nationwide. Nonetheless, the number of smaller, less noticed species killed on roads is formidable. For example, FOWLE (1990) reported 207 painted turtles (*Chrysemys picta*) killed along a 7 km stretch of road in Montana during a 4-month period. An estimated 32,000 vertebrates along 3.6 km Long Point Causeway near a wetland near Lake Erie, Canada were reported killed by ASHLEY and ROBINSON (1996) over a 24-month period. EHMANN and COGGER (1985) report an estimated 5.48 million reptiles and frogs killed on Australia roads each year. FAHRIG et al. (1995) reported that 73% of 1,172 snakes found on roads in the Everglades National Park, Florida were a result of road kills. Similarly, ROSEN and LOWE (1994) reported that, based on 15,000 km of road observation over a 4 year period, 22.5 snakes per km per year were killed on average in Organ Pipe National Monument, Arizona (FORMAN et al., 2002, in press) It is not difficult to imagine that direct effects of roaded landscapes is widespread across almost all taxa. When one looks at the historic record of road mortality, 65% were birds; mammals comprised 25%, and reptiles and amphibians about 8% (STARRETT,1938).

Indirect Effects
Direct effects, i.e., effects of the physical footprint of roads may be much less important than the indirect effects associated with roads and road networks (Fig. 1). FORMAN (2000) estimated that in the U.S., roads impacted 20% of the land surface both directly and indirectly. VITOUSEK et al. (1997) stated that between one third and one half of the land surface of the world has been transformed by human activities and actions. As roads bisect the landscape, once connected landscapes become fragmented and less permeable. By permeability is meant the ability of animals to move across the landscape without being significantly affected by the presence of roads and road networks.

Habitat loss and reduced habitat quality, increases in landscape fragmentation with associated increases in edge density and habitat disconnectedness, as well as barrier and cumulative effects are important but little recognized effects of roads. Few indirect effects are independent, making it difficult if not impossible to ascribe responsibility for species responses to a single cause. However, some general patterns are clear.

As fragmentation increases, so also is the absolute amount of edge habitat increased, with subsequent negative effects on so called 'core' species; i.e., those who are seriously impacted by increased anthropogenically-caused disturbance (RANNEY et al., 1981). Edge effects reduce

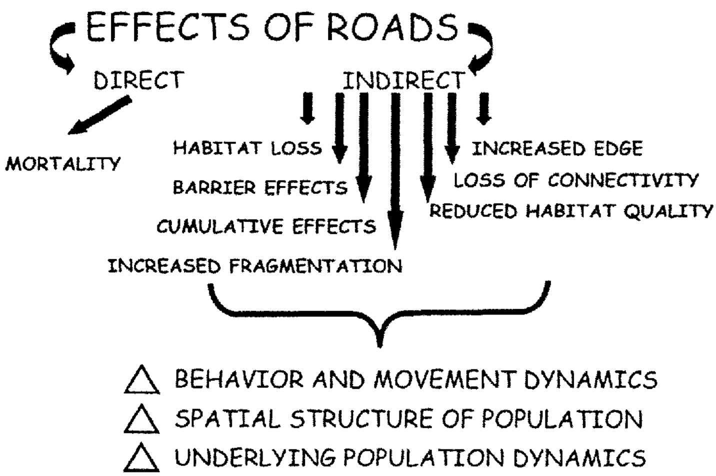

Fig. 1 Roads influence populations and landscapes in both direct and indirect ways resulting in changes in wildlife populations

core habitat areas (FAHRIG, 1997; BENDER et al., 1998). As the absolute mileage of roads increase, so too does the corresponding edge effect.

Perhaps as a direct result of edge effect, habitat quality for many species is diminished near roads. For example, woodland breeding birds in the Netherlands (REIJNEN et al., 1995,1996; REIJNEN and FOPPEN, 1994; FOPPEN and REIJNEN, 1994), geese (KELLER, 1991), and spotted owls (*Strix occidentalis caurina*) densities decreased as distance to roads decreased. ROBITAILLE and AUBRY, (2000) demonstrated that evidence of marten (*Martes americana*) activity was significantly less near roads.

Barrier effects have been documented for several species. Specifically, roads appear to decrease permeability of the landscape and hinder normal species movements. ROST and BAILEY (1979) showed that high volume traffic appeared to decrease mule deer and elk (*Cervus elaphus*) use near roads. BRODY and PELTON (1989) showed similar responses with black bears (*Ursus americanus*) in North Carolina.

Loss of connectivity hinders circadian movements as well as seasonal migrations. Further, given the putatively small population sizes caused by habitat fragmentation, loss of connectivity as well as the associated barrier effects decreases movement across the landscape and hence the repopulation of areas that may have suffered declines (VENIER and FAHRIG, 1996; JAEGER, 2000).

4 Population consequences of road effects

Three general population consequences result from both direct and indirect effects of roaded landscapes. First, behavior and movement dynamics of species are altered, often significantly. Second, as the landscape becomes increasingly fragmented, populations tend to become more isolated and show a spatial structure related to the pattern of habitat occurrence (or density) across the landscape. Third, given the degree of permeability of the landscape, underlying population structure may range from being (almost) panmictic, to spatially structured but with simple, averaging dynamics (RITCHIE, 1997), to spatially complicated, i.e., with source-sink or metapopulation characteristics. The key to understanding the kind of dynamics at work is to understand the nature of the operational demographic unit (MERRIAM, 1998).

In conceptual terms, the operational demographic unit (ODU) is best understood as spatial extent, amount (density), and arrangement of habitat occupied by the interbreeding population. For management purposes and study, the ODU is the sample of the population that must be included in the analysis so that the data can be scaled to the population, i.e., "interpretable in deterministic demographic terms" (MERRIAM, 1998, p. 527). If the landscape is permeable to the population, allowing something close to an ideal free distribution of animals, then regardless of whether spatial structure exists, the population dynamics are simple and panmictic (RITCHIE,1997). If however, roads present significant barrier effects with resulting loss of connectivity, then the spatially structured population may indeed show spatial complications in its dynamics. The consequences are often smaller, more isolated populations, living in habitat patches of varying sizes, and with a higher probability of local extinction. Fragmented populations are certainly more prone to wider fluctuations from year to year and appear to be less resilient to stochastic-induced declines.

Summary

It is clear that a reduction in both direct and indirect effects of roads and road networks must be the goal of management agencies. However, increased permeability of roaded landscapes can only be achieved by up-front planning and subsequent mitigative actions. The key is to understand that roads must be made permeable to the movement of animals. More profoundly, ecosystem services, i.e., clean water, clean air, uncontaminated soil, natural landscapes, recreation opportunities, abundant wildlife, and life sustaining ecological processes must not be seriously impacted. In other words, quality of life as measured by ecosystem services should be a major component of the planning process when roads are constructed or improved.

Mitigative structures exist to increase permeability of roads. Wildlife overpasses and underpasses, often referred to as ecoducts or green bridges, with associated structures to enable larger animals to exit the road right of way, e.g., earthen escape ramps (BISSONETTE and HAMMER, 2001), various culvert designs for smaller animals including badger pipes and amphibian and reptile tunnels, and fish ladders are but a small sampling of the structures already in place around the world. What is needed is attention to the big picture. Landscapes need to be reconnected and made more permeable. Responsible agencies and organizations need to be aggressive about promoting mitigations and a conservation ethic into road planning. Only with a broad based effort between a concerned public, a database to work from, and a willingness of responsible agencies, will the now very large virtual footprint of roads and road networks be reduced to more closely approximate the physical footprint. By embracing the Cinderella Principle of making the virtual shoe fit more closely the actual physical footprint of roads, we will be able to achieve a closer connection with ecological harmony with its resultant effect of abundant wildlife.

Keywords: highway mortality, landscapes, populations, roads, road-kill, scale, wildlife mortality

Zusammenfassung

Straßendurchlässigkeit und das Aschenputtel-Prinzip

Ein Ziel des Wildtier-Managements muss die Verringerung der direkten und indirekten Auswirkungen des Straßen- und Wegenetzes sein. Eine verbesserte Durchlässigkeit der von Straßen durchzogenen Landschaft kann nur durch Planung vor Ort und anschließende Verbesserungsmaßnahmen erreicht werden. Straßen müssen für Tiere passierbar sein. Weiterhin dürfen ökosystemare Dienstleistungen wie die Bereitstellung von sauberem Wasser, sauberer Luft, unbelastetem Boden, natürlichen Landschaften, Erholungsmöglichkeiten, viel Wild, und vitalen ökologischen Funktionen nicht gravierend beeinträchtigt werden. In anderen Worten, bei der Planung von neuen und der Verbesserung von vorhandenen Straßen müssen die Ökosystem-Funktionen als entscheidende Größe berücksichtigt werden.

Verschiedene Hilfsstrukturen verbessern die Durchlässigkeit der Straßen. Überführungen und Unterführungen für Wild, oft als grüne Brücken bezeichnet, und mit ihnen verbundene Strukturen, wie zum Beispiel Erdrampen, ermöglichen größerem Wild eine Überquerung der Fahrbahn (BISSONETTE und HAMMER, 2001). Verschiedene Arten von Durchlässen für kleinere Tiere, darunter Dachsröhren, Tunnel für Amphibien und Reptilien und Fischtreppen sind nur einige der weltweit vorhandenen Strukturen. Notwendig ist jetzt eine Betrachtung des Gesamtbildes. Landschaften müssen wieder vernetzt und durchlässiger werden. Die verantwortlichen Behörden und Organisationen sollten derartige Verbesserungen fördern und eine Naturschutz-Ethik in die Straßenplanung einführen. Nur durch das Zusammenwirken einer interessierten Öffentlichkeit, einer nutzbaren Datengrundlage und der Bereitschaft der verantwortlichen Behörden kann der gegenwärtig große virtuelle Einfluss des Straßen-und Wegenetzes auf den tatsaächlichen, physischen Einfluss reduziert werden. Wenn man gemäß dem Aschenputtel-Prinzip der Anpassung des virtuellen Schuhs auf die tatsächliche Fußgröße, den Einfluss des Straßensystem verringern könnte, würde dies zu einem verbesserten ökologischen Wirkungsgefüge und in der Folge zu einem erhöhtem Wildreichtum führen.

Schlüsselwörter: Straßenverkehrstod, Landschaften, Populationen, Straßen, Maßstab, Wildverkehrstod

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