

## Effects of Roads on Elk: Implications for Management in Forested Ecosystems

Mary M. Rowland<sup>1</sup>, Michael J. Wisdom, Bruce K. Johnson, and Mark A. Penninger

The effects of roads on both habitat and population responses of elk (*Cervus elaphus*) have been of keen interest to foresters and ungulate biologists for the last half century. Increased timber harvest in National Forests, beginning in the 1960s, led to a proliferation of road networks in forested ecosystems inhabited by elk (Hieb 1976, Lyon and Christensen 2002). Among disturbances to elk habitat, roads have been viewed as a major factor influencing distributions of elk across the landscape (Leege 1984, Lyon 1984, Lyon et al. 1985, Roloff 1998, Lyon and Christensen 2002, Wertz et al. 2004). Evidence from a variety of studies, such as those conducted at the Starkey Experimental Forest and Range (Starkey) in northeastern Oregon, has corroborated this view (Lyon 1983, 1984; Witmer and deCalesta 1985; Cole et al. 1997; Johnson et al. 2000; Rowland et al. 2000; Ager et al. 2003). (See Rowland et al. [1997] for a general description of the Starkey Project and the Starkey environment.)

Early studies of elk were among the first to address effects of roads on wildlife, establishing a precedent for subsequent research on a wide range of terrestrial and aquatic species. These early elk-roads studies included those reported in a symposium on the topic in 1975 (Hieb 1976), the seminal studies of Jack Lyon in Montana and northern Idaho (Lyon 1979, 1983, 1984), the Montana Cooperative Elk-Logging Study (Lyon et al. 1985), and work by Perry and Overly (1977) in Washington and Rost and Bailey (1979) in Colorado.

As research and analysis techniques have become more sophisticated, particularly with the advent of geographic information systems (GIS) and high-resolution remote imagery, the study of effects of roads on terrestrial and aquatic communities has evolved into a unique discipline of “road ecology” (Forman et al. 2003). Road effects are far more pervasive than originally believed and include such disparate consequences as population and habitat fragmentation, accelerated rates of soil erosion, and invasion of exotic plants along roadways. Indeed, “in public wildlands management, road systems are the largest human investment and the feature most damaging to the environment” (Gucinski et al. 2001:7). Summaries of the effects of roads on wildlife habitats and biological systems in general have been compiled by Forman and Alexander (1998), Trombulak and Frissell (2000), Gucinski et al. (2001), Forman et al. (2003) and Gaines et al. (2003).

Well-designed research that furthers our understanding of road effects and road management on key species, such as elk, and their habitats is critical for enhancing the long-term functioning of ecosystems impacted by the vast network of roads in North America. Moreover, addressing effects of roads on elk and elk habitat often is mandated on public lands, e.g., through standards and guidelines developed for National Forests.

Our goals in this paper are three-fold: (1) to describe current knowledge about effects of roads on elk, emphasizing results of research conducted at Starkey, (2) to describe an example in which a distance-band approach, rather than the traditional road density method, was used to evaluate habitat effectiveness (HE) for elk in relation to roads, and (3) to discuss the broader implications of road-related policies and land management with regard to elk.

---

<sup>1</sup> Suggested citation: M. M. Rowland, M. J. Wisdom, B. K. Johnson, and M. A. Penninger. 2005. Effects of Roads on Elk: Implications for Management in Forested Ecosystems. Pages 42-52 in Wisdom, M. J., technical editor, The Starkey Project: a synthesis of long-term studies of elk and mule deer. Reprinted from the 2004 Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communications Group, Lawrence, Kansas, USA.

## Effects of Roads on Elk in Forested Ecosystems – What do we Know?

Effects of roads on elk can be divided into two broad categories: indirect effects on habitats occupied by elk, and direct effects on individual elk and their populations. Effects of roads in forested ecosystems in general have been well summarized (Gucinski et al. 2001, Gaines et al. 2003). With regard to elk habitat, the primary effect of roads may be habitat fragmentation; heavily roaded areas may contain few patches of forest cover large enough to function effectively as habitat for elk, especially where elk are hunted (Leege 1984, Rowland et al. 2000). The total loss of elk habitat from road construction is unknown; a rough estimate of 5 acres per linear mile (1.4 ha/km) of road is often applied (Forman et al. 2003). Across the United States, the area occupied by public roads and associated corridors is estimated to be 27 million acres (10.9 million ha); these numbers do not include private roads or “unofficial” roads on public lands (Forman et al. 2003). Roads may also exert more subtle influences on habitat, for example by facilitating the spread of exotic vegetation (Gelbard and Belnap 2003) which may subsequently reduce quality and abundance of forage available to elk. Gaines et al. (2003) listed five road-associated factors in relation to elk: hunting, poaching, collisions, displacement or avoidance, and disturbance at a specific site.

The direct impacts of roads and associated traffic on elk, in addition to outright mortality from collisions with motorized vehicles, can be summarized as follows:

1. *Elk avoid areas near open roads.* A plethora of studies have demonstrated an increasing frequency of elk occurrence or indices of elk use, such as pellet groups, at greater distances from open roads (defined here as any road where motorized vehicles are allowed). This response varies in relation to traffic rates (Wisdom 1998, Johnson et al. 2000, Ager et al. 2003), the extent of forest canopy cover adjacent to roads (Perry and Overly 1977, Lyon 1979, Wisdom 1998, Wisdom et al. 2004b), topography (Perry and Overly 1977, Edge and Marcum 1991), and type of road (e.g., improved versus primitive; Perry and Overly 1977, Lyon 1979, Witmer and deCalesta 1985, Marcum and Edge 1991, Rowland et al. 2000, Lyon and Christensen 2002, Benkobi et al. 2004), which also correlates with traffic rates. Responses may also differ between sexes, with bull elk demonstrating a stronger avoidance of areas close to roads than do cow elk (Marcum and Edge 1991). Shifts in distribution of elk away from roads may occur across a range of temporal and spatial scales. For example, elk at Starkey were generally farther from open roads during daytime, but moved closer to roads during nighttime (Wisdom 1998, Ager et al. 2003). This pattern was also observed in South Dakota (Millsbaugh 1999). In addition, both daily movements and size of home ranges of elk may decrease when open road density decreases. These reductions could lead to energetic benefits that translate into increased fat reserves or productivity (Cole et al. 1997). On a larger scale, entire ranges can be abandoned if disturbance from traffic on roads and the associated habitat loss and fragmentation exceed some threshold level. The ultimate effect of displacement of elk, by motorized traffic as well as other disturbances, is a temporary or permanent reduction in effective habitat for elk. Concomitant with loss of effective habitat are reduced local and regional populations (Forman et al. 2003).
2. *Elk vulnerability to mortality from hunter harvest, both legal and illegal, increases as open road density increases.* Many factors affect elk vulnerability to hunter harvest, but the evidence is compelling that survival rates of elk are reduced in areas with higher road density (Leege 1984, Leptich and Zager 1991, Unsworth et al. 1993, Gratson and Whitman 2000a, Weber et al. 2000, Hayes et al. 2002, McCorquodale et al. 2003). Closing roads offers more security to elk and may decrease hunter densities (fewer hunters may be willing to hunt without vehicle access). Also, poaching losses may decrease when roads are closed (Cole et al. 1997).
3. *In areas of higher road density, elk exhibit higher levels of stress and increased movement rates.* Higher levels of physiological indicators of stress, such as fecal glucocorticoids, have been observed in elk exposed to increased road density and traffic on roads (Millsbaugh et al. 2001). In

addition, the energetic costs of moving away from disturbance associated with roads may be substantial (Cole et al. 1997). Research to estimate such costs to elk in relation to recreational use on roads is underway at Starkey (Wisdom et al. 2004a). Conversely, elk may conserve energy by traveling on closed roads to avoid woody debris and downfall (Lyon and Christensen 2002).

Knowledge has been gained not only about elk response to roads, but also about modeling this relationship. Results from research at Starkey suggested that a road-effects model based on distance bands provides a more spatially explicit and biologically meaningful tool than a traditional model based on road density (Rowland et al. 2000). This analysis, based on more than 100,000 radiolocations of cow elk during spring and summer, found no relation between numbers of elk locations and HE scores based on open road density in 15 elk “analysis units.” (We define habitat effectiveness as the “percentage of available habitat that is usable by elk outside the hunting season” [Lyon and Christensen 1992:4].) However, elk preference increased strongly (as measured by selection ratios) as distance to open roads increased. Such distance-to-roads analyses are readily accomplished using widely available spatial data layers in a GIS.

Despite the wealth of information about how roads and motorized traffic affect elk and their habitats, gaps in our knowledge remain. For example, while we know that elk response to roads generally varies depending on the level and type of motorized traffic, we have little knowledge about the precise levels of such disturbance that elicit a response, and the duration of that response. Research at Starkey has demonstrated threshold rates of traffic above which a response by elk is elicited, but below which open roads are functionally equivalent to closed roads (A. A. Ager, personal communication 2003; Wisdom et al. 2004b). Measurements of traffic rates and elk response to these rates are needed in other locations to better understand these thresholds. Though more costly to obtain than maps of roads, information about traffic rates can be used to improve management of roads in elk habitat in ways that are both cost-effective and beneficial to elk. Further research also is needed to better understand the interaction of roads, topography, and forest cover in affecting elk distributions, primarily in relation to providing security for elk.

Also needed is a better understanding of the effectiveness of road closures; examples abound about the lack of effectiveness of closures on public lands, especially when few resources are made available for enforcement (Havlick 2002, Wertz et al. 2004). More than half of 802 road closures inventoried on National Forests in Idaho, Montana, Washington, and Wyoming were found to be ineffective, even after accounting for administrative use (Havlick 2002). In Idaho, elk mortality was positively correlated to densities of both closed roads and open roads, suggesting that road closures were ineffective in reducing mortality from hunting (Hayes et al. 2002). Systematically collected data on use by all motorized vehicles, including off-highway vehicles, of closed roads would benefit management of elk and other resources (e.g., soils) affected by vehicle traffic on roads. And last, HE models for elk, including the roads variable, need further validation. Beyond the Starkey research (Rowland et al. 2000) and a few other studies (e.g., Roloff et al. 2001, Benkobi et al. 2004), such validation has not been conducted, especially of the most commonly applied models (Wisdom et al. 1986, Thomas et al. 1988). Given the continued widespread use of elk HE models in land-use planning on National Forests and other lands occupied by elk, such validation is a critical research need.

A final cautionary note: much of what has been learned about elk and roads to date has resulted from field studies that had no experimental component and thus no sound basis from which to infer cause-effect relations. Experimental studies underway at Starkey, in which road densities and traffic rates are manipulated according to strict sampling protocols, and distributions of elk are closely monitored, will greatly enhance our understanding of elk response to roads (Wisdom et al. 2004b).

## Current Management Approaches to Elk-Roads Issues

In light of the deleterious effects of roads on elk as described above, both ungulate biologists and land managers have developed methods to address their respective concerns. During the 1970s and 1980s, biologists created a suite of models, based on empirical data, to predict effects of land management activities on habitat effectiveness for elk (e.g., Lyon 1979, 1983; Thomas et al. 1979, 1988; Legee 1984; Wisdom et al. 1986). All of these models incorporated a road-density component. In addition to the more general elk HE models, specific habitat guidelines were written related to roads. For example, guidelines developed in Montana specified that elk security areas be located more than 0.5 miles (0.8 km) from open roads (Hillis et al. 1991). Elk habitat models that include a roads component also have been used to evaluate the suitability of sites for restoration of elk populations (Didier and Porter 1999). Further, ungulate biologists have constructed resource selection models that include a roads variable to predict spatial distributions of elk (Cooper and Millspaugh 1999, Johnson et al. 2000).

Land managers in turn have incorporated concerns about elk and roads into formal planning processes through the application of standards and guidelines. How management agencies address elk-roads issues varies widely, however, both within and across agencies. For example, elk are designated as a Management Indicator Species (MIS) within some National Forests but not others. This designation, or lack thereof, subsequently affects how elk habitat is addressed in forest planning and environmental assessment.

Forest plans for many National Forests contain specific standards and guidelines for elk HE, using one or more of the various elk HE models that have been developed. For example, the forest plan for the Wallowa-Whitman National Forest in northeastern Oregon provides direction to maintain HE >0.5 during timber sale planning in management area 1 (MA1; timber production emphasis), but only “where this can be done without reducing timber harvest volumes” (U.S. Department of Agriculture, Forest Service 1990b:4-57). (Habitat effectiveness scores range from 0 to 1.0 in most HE models.) Furthermore, the plan assumes that in the long-term, elk HE will be maintained at 0.62 in MA1. Open road density in this management area is targeted not to exceed 2.5 miles per square mile (1.6 km/km<sup>2</sup>) in general, but no more than 1.5 miles per square mile (0.9 km/km<sup>2</sup>) in selected elk summer and winter ranges. In the adjacent Umatilla National Forest, elk HE is projected to range between 0.67 and 0.70, and open road density from 2.0-2.2 miles per square mile (1.2-1.4 km/km<sup>2</sup>), forest-wide during the five decades beyond 1990 (U.S. Department of Agriculture, Forest Service 1990a). In addition, the standard for elk HE on big game winter range is 0.70 (U.S. Department of Agriculture, Forest Service 1990a). Generally, if habitat for elk is identified as an issue for a proposed management activity, such as timber restoration, or if elk have been identified as a Management Indicator Species, evaluation of elk habitat is mandated during the environmental assessment process. Such evaluation commonly entails the application of an elk HE model to the affected area under the various alternatives, with the results incorporated into an “effects analysis” for evaluation of alternatives.

A more recently developed approach is to incorporate evaluations of habitat effectiveness for elk into the initial stages of forest planning, rather than using HE models to evaluate effects of single management activities, such as timber harvest (Bettinger et al. 1999). This approach incorporates elk HE into the objective function of a mathematical forest-planning model. Various scenarios can be simulated, with maximization of elk HE scores, timber output, or both. Likewise, Roloff et al. (1999) developed a decision support system that allows evaluation of effects of various management strategies on habitat for elk and other wildlife within the context of forest planning models.

## Applying a Distance-band Model of Elk-Road Effects in Forest Planning: A Case Example

A method to evaluate effects of roads on elk using a distance-band approach has been suggested both by Roloff (1998) and by Rowland et al. (2000), as described above. Based on radiolocations of elk at Starkey, Rowland et al. (2000) found no relation between number of elk locations and HE based on open road densities. By contrast, the authors found a strong, linear increase in selection ratios of elk as distance

to roads increased. For this analysis, elk locations were assigned to 109-yard (100-m) wide bands away from open roads. Roloff (1998) also developed a road-effects module in which habitat adjacent to roads was buffered into distance bands in a GIS. Habitat effectiveness in the bands was adjusted according to level of security cover, as well as road use or road type. Regardless of the exact approach selected, ongoing planning efforts within National Forests and other lands that provide habitat for elk may benefit from consideration of a revised, spatially explicit road-effects variable.

The mechanics of calculating HE related to roads ( $HE_R$ ) using distance bands are similar to those for another variable in elk HE models – the size and spacing of cover and forage ( $HE_S$ ). Both variables involve buffering out from a linear feature – either roads, for  $HE_R$ , or the cover:forage edge, for  $HE_S$  – to create distance bands. Each band is assigned a weight, with lower weights corresponding to lower HE. A weighted average is then calculated, based on the proportion of the analysis area in each of the bands and the weight of the appropriate band (see Hitchcock and Ager 1992 for details of calculating  $HE_S$  using this method). The sum of these products yields the final HE value, which cannot exceed 1.0.

To examine how the method of calculation (i.e., the traditional road-density method versus distance bands) might affect  $HE_R$  for elk, we applied both methods in an evaluation of the effects of a timber sale in the Wallowa-Whitman NF in northeastern Oregon. The Dark Meadow Restoration Project was proposed to “restore and enhance ecosystems” within the project area, through thinning, prescribed fire, and mechanical fuels-reduction treatments over the next 10-15 years (U.S. Department of Agriculture, Forest Service 2003). Project goals include reductions in fuel loading, promotion of old-growth habitat, improvement in big game habitat, and initiation of tree regeneration. Under the two “action alternatives” of the project, open road density will be lower than that under the “no action” (existing condition) alternative (Table 1, Figure 1).

The Dark Meadow analysis area encompasses 17,700 acres (7,169 ha) of the Blue Mountains and is completely contained within the Starkey Game Management Unit. The elk population in this unit is estimated to be at the objective (5,300) set by Oregon Department of Fish and Wildlife. The area functions primarily as summer range for elk, with smaller portions used as transitional or winter range. Lack of elk security habitat was identified as a key issue in planning for the Dark Meadow project; thus, roads were a primary consideration in the crafting of alternatives (U.S. Department of Agriculture, Forest Service 2003).

To calculate  $HE_R$  for elk in Dark Meadow, all roads open to motorized vehicles were counted. No traffic rate data were available; thus, roads were not weighted according to level of use. We defined open roads as those officially designated as open, as well as closed roads for which no promulgation was planned. Promulgated road closures are those for which the Code of Federal Regulations is applied; such closures are legal and enforceable. In the Wallowa-Whitman Forest Plan, closed roads were assumed to be physically impassable to full-sized vehicles, and also assumed to be seldom traveled by off-highway vehicles (U.S. Department of Agriculture, Forest Service 1990b). Roads designated as “closed” but not promulgated, however, are often traveled by off-highway vehicles (Havlick 2002).

The  $HE_R$  variable based on open road densities (hereafter referred to as  $HE_{R-ORD}$ ) was then calculated with the equations of Hitchcock and Ager (1992), for the existing condition and the two action alternatives (Table 1). To calculate  $HE_R$  based on distance bands ( $HE_{R-DB}$ ), all open roads were buffered in a GIS. The analysis area was partitioned into five bands, each 394 yards (360 m) wide, with the sixth band containing any area greater than 1,969 yards (1,800 m) from an open road. This distance (i.e., 1,969 yards) is equivalent to that at which elk response to open roads diminished markedly at Starkey (Rowland et al. 2000). Each band was assigned a weight, reflecting a linear increase in elk selection ratios as distance from open roads increased at Starkey: band 1 – 0.17, band 2 – 0.33; band 3 – 0.50; band 4 – 0.67; band 5 – 0.83; and band 6 – 1.0.  $HE_{R-DB}$  was then calculated as a weighted average, with the proportion of the analysis area in each band multiplied by the appropriate weight. Finally, we calculated total HE for the analysis area, based on all four variables of the elk HE model, with only  $HE_R$  differing between the two calculations (Table 1).

Open road density in the Dark Meadow area was relatively high under all three alternatives, and  $HE_{R-DB}$  was consistently lower than  $HE_{R-ORD}$  (Table 1). However, this difference was more

pronounced with lower open road densities; under the “no action” alternative,  $HE_R$ -DB was only 15 percent less than  $HE_R$ -ORD, but under the two action alternatives this difference increased to 32-35 percent (Table 1). Compared to the “no action” alternative, the density of open roads declined 17 and 23 percent, respectively, under Alternatives 1 and 2. Concomitant with this decline in road density were increases in  $HE_R$ -ORD of 40 and 55 percent for the two action alternatives, respectively; however,  $HE_R$ -DB increased only 12 and 18 percent (Table 1). These results suggest that the spatial arrangement of remaining open roads was such that the amount of effective habitat for elk improved only marginally (Figure 1). Thus,  $HE_R$ -ORD may overestimate habitat effectiveness for elk under certain conditions.

Because total HE is the geometric mean of all four input variables, differences in total HE between the two methods were not as substantial as were those for  $HE_R$  alone (Table 1). Among the four variables used to calculate HE, all of which are equally weighted in computing the mean, values for  $HE_R$  were substantially lower than those of the other three variables (Table 1). Thus, in the Dark Meadow project area, the relatively high open road densities were largely responsible for the low total HE scores. These scores exceeded only slightly the recommended standard of 0.5 for total HE in timber planning on the Wallowa-Whitman, and only when  $HE_R$ -ORD was used for the roads variable (Table 1). By contrast, when  $HE_R$ -DB was used, total HE was below the standard for all alternatives (Table 1).

We did not alter band weights, or “back buffer” them, based on the level of security cover in each band (see Roloff 1998). This additional refinement may be warranted in situations where cover quality varies widely across the analysis area, or is predicted to vary under proposed management alternatives. In addition, band weights could be adjusted by accounting for topographic relief, such that areas providing topographic barriers to human disturbance would have weights adjusted upward, or by traffic rates, if such data were available (e.g. Wisdom et al. 2004b).

### Implications for Management and Policy Involving Elk-Roads Issues

Road management inevitably involves tradeoffs between the benefits of increased access that roads provide versus the ecological and economic costs associated with roads (Gucinski et al. 2001, Forman et al. 2003). Because the U.S. Department of Agriculture, Forest Service (Forest Service) manages about 10 percent of the public road system in the United States (Forman et al. 2003), road-management decisions made by that agency strongly influence current road systems. The Forest Service policy regarding road closures and construction continues to engender controversy, exemplified by the multi-year debate over the national Roadless Rule. The rule, first published in the Federal Register in January 2001 (U.S. Government 2001), has been challenged by at least nine lawsuits in federal district courts. Decisions about roads, including construction, reconstruction, closure, obliteration, or decommissioning, are complex because they affect a multitude of resources, not just wildlife. All resource values in a watershed must be evaluated when making decisions about roads; these may include human safety (e.g., access to combat wildfires), soils, recreation, commercial timber harvest, and restoration activities. In addition, decisions about roads are closely tied to available funding. Expenses are involved both in constructing and maintaining roads and in decommissioning roads and enforcing road closures (Forman et al. 2003). Complicating the issue of evaluating effects of roads is that roads in forested ecosystems currently are not well inventoried (Gucinski et al. 2001).

The potential implications of road-related policies for elk management are diverse and complex. Benefits of road closures may include:

- Decreased energy expenditure by elk, a result of less frequent disturbance by motorized vehicles, with potential improvements in animal performance.
- Increases in total amount of effective habitat for elk in the area affected by the closures.
- Increased hunting opportunities on public lands, when roads are closed on public lands adjacent to comparatively less-roaded private lands, thereby enticing elk to remain on public lands rather than moving to private lands where hunting may not be allowed or is prohibitively expensive (Wertz et al. 2004).

- Decreased damage to crops and haystacks from elk on private lands, due to decreased disturbance from traffic on public land, which in turn causes elk to remain on public land longer during the fall and winter seasons.
- Improvements in diet quality when elk are able to forage undisturbed in areas previously avoided due to excessive motorized traffic; these changes may translate into improvements in animal fitness and population performance.
- Increased hunter satisfaction from the opportunity to hunt in a roadless area or the use of all-terrain vehicles on closed roads or other “off-highway” sites (Gratson and Whitman 2000b).
- Decreased vulnerability of elk during hunting seasons, due to fewer hunters willing to hunt without a vehicle or able to access the area.

Road closures alone may not be effective in eliminating effects of roads and traffic on elk because of inadequate enforcement. For this reason, the Forest Service may promulgate road closures in addition to designating roads as closed, as in the Dark Meadow project discussed above. Careful assessment of how roads are being used, rather than their official status, is important to credibly evaluate effects of roads on elk and other wildlife. Likewise, judicious closing of certain road segments, particularly road spurs (Forman et al. 2003), may retain or create blocks of habitat that serve as security areas for elk while allowing sufficient road access for other management needs. Spatially explicit models and tools are currently available to aid in evaluating among road closure alternatives.

Elk continue to exert tremendous impact on local economies, through their status as a premier game species, and on forested ecosystems, through their role as abundant, widespread, large herbivores. Given the indisputable effect of roads on distribution of elk, roads and their management will undoubtedly remain, as stated by Lyon and Christensen (2002:566), “central to elk management on public and private lands.”

## Acknowledgments

We thank J. G. Kie, G. J. Roloff, and B. C. Wales for reviewing earlier drafts of this manuscript. C. Whitlock provided information about the Dark Meadow project and planning for the Wallow-Whitman National Forest and B. Fischer prepared the figures. Funding for the Starkey roads study was provided by the Oregon Department of Fish and Wildlife and the U.S. Department of Agriculture, Forest Service.

## Literature Cited

- Ager, A. A., B. K. Johnson, J. W. Kern, and J. G. Kie. 2003. Daily and seasonal movements and habitat use by female Rocky Mountain elk and mule deer. *Journal of Mammalogy* 84:1076-1088.
- Benkobi, L., M. A. Rumble, G. C. Brundige, and J. J. Millspaugh. 2004. *Refinement of the Arc-Habcap model to predict habitat effectiveness for elk*. U. S. Department of Agriculture, Forest Service, Research Paper RMRS-RP-51, Fort Collins, Colorado.
- Bettinger, P., K. Boston, and J. Sessions. 1999. Combinatorial optimization of elk habitat effectiveness and timber harvest volume. *Environmental Modeling and Assessment* 4:143-153.
- Cole, E. K., M. D. Pope, and R. G. Anthony. 1997. Effects of road management on movement and survival of Roosevelt elk. *Journal of Wildlife Management* 61:1115-1126.
- Cooper, A. B., and J. J. Millspaugh. 1999. The application of discrete choice models to wildlife resource selection studies. *Ecological Applications* 80:566-575.
- Didier, K. A., and W. F. Porter. 1999. Large-scale assessment of potential habitat to restore elk to New York State. *Wildlife Society Bulletin* 27:409-418.
- Edge, W. D., and C. L. Marcum. 1991. Topography ameliorates the effects of roads and human disturbance on elk. In *Proceedings Elk Vulnerability Symposium*, eds. A. G. Christensen, L. J. Lyon, and T. N. Lonner, 132-137. Bozeman: Montana State University.

- Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29:207-231.
- Forman, R. T. T., D. Sperling, J. A. Bissonette et al. 2003. *Road ecology: science and solutions*. Washington, DC: Island Press.
- Gaines, W. L., P. H. Singleton, and R. C. Ross. 2003. *Assessing the cumulative effects of linear recreation routes on wildlife habitats on the Okanogan and Wenatchee National Forests*. U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-586, Portland, Oregon.
- Gelbard, J. L., and J. Belnap. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. *Conservation Biology* 17:420-432.
- Gratson, M. W., and C. Whitman. 2000b. Characteristics of Idaho elk hunters relative to road access on public lands. *Wildlife Society Bulletin* 28:1016-1022.
- Gratson, M. W., and C. Whitman. 2000a. Road closures and density and success of elk hunters in Idaho. *Wildlife Society Bulletin* 28:302-10.
- Gucinski, H., M. H. Brooks, M. J. Furniss, and R. R. Ziemer. 2001. *Forest roads: a synthesis of scientific information*. U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-509, Portland, Oregon.
- Havlick, D. G. 2002. *No place distant: Roads and motorized recreation on America's public lands*. Washington, DC: Island Press.
- Hayes, S. G., D. J. Leptich, and P. Zager. 2002. Proximate factors affecting male elk hunting mortality in northern Idaho. *Journal of Wildlife Management* 66:491-499.
- Hieb, S. R., ed. 1976. *Proceedings of the elk-logging-roads symposium*. Moscow: Forest, Wildlife, and Range Experimental Station, University of Idaho.
- Hillis, J. M., M. J. Thompson, J. E. Canfield, L. J. Lyon, and T. N. Lonner. 1991. Defining elk security: the Hillis paradigm. In *Proceedings Elk Vulnerability Symposium*, eds. A. G. Christensen, L. J. Lyon, and T. N. Lonner, 38-43. Bozeman: Montana State University.
- Hitchcock, M., and A. Ager. 1992. *Microcomputer software for calculating an elk habitat effectiveness index on Blue Mountain winter range*. U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-301, Portland, Oregon.
- Johnson, B. K., J. W. Kern, M. J. Wisdom, S. L. Findholt, and J. G. Kie. 2000. Resource selection and spatial separation of mule deer and elk during spring. *Journal of Wildlife Management* 64:685-697.
- Leege, T. A. 1984. *Guidelines for evaluating and managing summer elk habitat in northern Idaho*. Idaho Department of Fish and Game, Wildlife Bulletin 11, Boise, Idaho.
- Leptich, D. J., and P. Zager. 1991. Road access management effects on elk mortality and population dynamics. In *Proceedings Elk Vulnerability Symposium*, eds. A. G. Christensen, L. J. Lyon, and T. N. Lonner, 126-131. Bozeman: Montana State University.
- Lyon, L. J. 1979. Habitat effectiveness for elk as influenced by roads and cover. *Journal of Forestry* 79:658-660.
- Lyon, L. J. 1983. Road density models for describing habitat effectiveness for elk. *Journal of Forestry* 81:592-595.
- Lyon, L. J. 1984. *Field tests of elk/timber coordination guidelines*. U.S. Department of Agriculture, Forest Service, Research Paper INT-RP-325, Ogden, Utah.
- Lyon, L. J., and A. G. Christensen. 1992. *A partial glossary of elk management terms*. U.S. Department of Agriculture, Forest Service, General Technical Report INT-GTR-288, Portland, Oregon.
- Lyon, L. J., and A. G. Christensen. 2002. Elk and land management. In *North American elk: ecology and management*, eds. D. E. Towell and J. W. Thomas, 557-581. Washington, DC: Smithsonian Institution Press.
- Lyon, L. J., T. N. Lonner, J. P. Weigand, C. L. Marcum, W. D. Edge, J. D. Jones, D. W. McCleerey, and L. L. Hicks. 1985. *Coordinating elk and timber management: Final report of the Montana Cooperative Elk-Logging Study*. Helena: Montana Department of Fish, Wildlife, and Parks.

- Marcum, C. L., and W. D. Edge. 1991. Sexual differences in distribution of elk relative to roads and logged areas in Montana. In *Proceedings Elk Vulnerability Symposium*, eds. A. G. Christensen, L. J. Lyon, and T. N. Lonner, 142-148. Bozeman: Montana State University.
- McCorquodale, S. M., R. Wiseman, and C. L. Marcum. 2003. Survival and harvest vulnerability of elk in the Cascade Range of Washington. *Journal of Wildlife Management* 67:248-257.
- Millspaugh, J. J. 1999. Behavioral and physiological response of elk to human activities in the southern Black Hills, South Dakota. Ph.D. dissertation, University of Washington, Seattle.
- Millspaugh, J. J., R. J. Woods, K. E. Hunt, K. J. Raedeke, G. C. Brundige, B. E. Washburn, and S. K. Wasser. 2001. Fecal glucocorticoid assays and the physiological stress response in elk. *Wildlife Society Bulletin* 29:899-907.
- Perry, C., and R. Overly. 1977. *Impact of roads on big game distribution in portions of the Blue Mountains of Washington*. Washington Game Department, Bulletin No. 11, Olympia, Washington.
- Roloff, G. J. 1998. Habitat potential model for Rocky Mountain elk. In *Proceedings 1997 Deer/Elk Workshop, Rio Rico, Arizona*, ed. J. C. deVos, Jr., 158-175. Phoenix: Arizona Game and Fish Department.
- Roloff, G. J., B. Carroll, and S. Scharosch. 1999. A decision support system for incorporating wildlife habitat quality into forest planning. *Western Journal of Applied Forestry* 14:91-99.
- Roloff, G. J., J. J. Millspaugh, R. A. Gitzen, and G. C. Brundige. 2001. Validation tests of a spatially explicit habitat effectiveness model for elk. *Journal of Wildlife Management* 65:899-914.
- Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* 43:634-641.
- Rowland, M. M., L. D. Bryant, B. K. Johnson, J. H. Noyes, M. J. Wisdom, and J. W. Thomas. 1997. *The Starkey project: History, facilities, and data collection methods for ungulate research*. U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-396, Portland, Oregon.
- Rowland, M. M., M. J. Wisdom, B. K. Johnson, and J. G. Kie. 2000. Elk distribution and modeling in relation to roads. *Journal of Wildlife Management* 64:672-684.
- Thomas, J. W., H. Black, Jr., R. J. Scherzinger, and R. J. Pedersen. 1979. Deer and elk. In *Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington*, ed. J. W. Thomas, 104-127. U.S. Department of Agriculture, Forest Service, Agricultural Handbook No. 553. Portland, Oregon.
- Thomas, J. W., D. A. Leckenby, M. Henjum, R. J. Pedersen, and L. D. Bryant. 1988. *Habitat-effectiveness index for elk on Blue Mountain winter ranges*. U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-218, Portland, Oregon.
- Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.
- Unsworth, J. W., L. Kuck, M. D. Scott, and E. O. Garton. 1993. Elk mortality in the Clearwater drainage of northcentral Idaho. *Journal of Wildlife Management* 57:495-502.
- U.S. Department of Agriculture, Forest Service. 1990a. *Umatilla National Forest Land and Resource Management Plan*. Pendleton, Oregon.
- U.S. Department of Agriculture, Forest Service. 1990b. *Wallowa-Whitman National Forest Land and Resource Management Plan*. Baker City, Oregon.
- U.S. Department of Agriculture, Forest Service. 2003. *Dark Meadow restoration environmental assessment*. La Grande Ranger District, Wallowa-Whitman National Forest, La Grande, Oregon.
- U.S. Government, Office of the Federal Register. 2001. *Rules and regulations*. Federal Register 66: 9 (Jan. 12, 2001): 3244-3273.
- Weber, K. T., C. L. Marcum, M. G. Burcham, and L. J. Lyon. 2000. Landscape influences on elk vulnerability to hunting. *Intermountain Journal of Science* 6:86-94.
- Wertz, T. L., A. Blumton, and L. E. Erickson. 2004. Conflict resolution by adaptive management: moving elk where they want to go. In *Proceedings 2001 Western States and Provinces Deer and Elk*

- Workshop*, ed. J. Mortensen, D. G. Whittaker, E. C. Meslow et al., 59-66. Salem: Oregon Department of Fish and Wildlife.
- Wisdom, M. J. 1998. Assessing life-stage importance and resource selection for conservation of selected vertebrates. Ph.D. dissertation, University of Idaho, Moscow.
- Wisdom, M. J., A. A. Ager, H. K. Preisler, N. J. Cimon, and B. K. Johnson. 2004a. Effects of off-road recreation on mule deer and elk. *Transactions of the North American Wildlife and Natural Resources Conference* 69:531-550.
- Wisdom, M. J., L. R. Bright, C. G. Carey, W. W. Hines, R. J. Pedersen, D. A. Smithey, J. W. Thomas, and G. W. Witmer. 1986. *A model to evaluate elk habitat in western Oregon*. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Publication No. R6-F&WL-216-1986, Portland, Oregon.
- Wisdom, M. J., N. J. Cimon, B. K. Johnson, E. O. Garton, and J. W. Thomas. 2004b. Spatial partitioning by mule deer and elk in relation to traffic. *Transactions of the North American Wildlife and Natural Resources Conference* 69:509-530.
- Witmer, G. W., and D. S. deCalesta. 1985. Effect of forest roads on habitat use by Roosevelt elk. *Northwest Science* 59:122-125.

Table 1. Comparison of two methods for modeling effects of roads on elk habitat effectiveness (HE) under three alternatives in the Dark Meadow Restoration Project, Wallowa-Whitman National Forest, northeastern Oregon.

| Variable                                                      | “No action” alternative <sup>a</sup> | Alternative 1 | Alternative 2 |
|---------------------------------------------------------------|--------------------------------------|---------------|---------------|
| Total miles (km) of open roads in analysis area <sup>b</sup>  | 138.1 (222.2)                        | 114.2 (183.7) | 106.5 (171.4) |
| Open road density in mi/mi <sup>2</sup> (km/km <sup>2</sup> ) | 4.99 (3.09)                          | 4.13 (2.56)   | 3.85 (2.39)   |
| HE <sub>R</sub> -ORD <sup>c</sup>                             | 0.20                                 | 0.28          | 0.31          |
| HE <sub>R</sub> -DB <sup>c</sup>                              | 0.17                                 | 0.19          | 0.20          |
| HE <sub>C</sub> <sup>d</sup>                                  | 0.60                                 | 0.59          | 0.61          |
| HE <sub>S</sub> <sup>e</sup>                                  | 0.84                                 | 0.79          | 0.80          |
| Total HE (ORD method) <sup>f</sup>                            | 0.47                                 | 0.51          | 0.52          |
| Total HE (DB method)                                          | 0.45                                 | 0.46          | 0.47          |

<sup>a</sup> This alternative is the existing condition.

<sup>b</sup> Open roads include any road available to motorized traffic; these are roads officially designated as open as well as closed roads that have no promulgation. See text for details.

<sup>c</sup> Habitat effectiveness for roads (HE<sub>R</sub>) based on open road densities (ORD); HE<sub>R</sub>-DB uses distance bands (DB) to calculate HE<sub>R</sub>. See text for details.

<sup>d</sup> Habitat effectiveness as related to cover quality; see Thomas et al. (1988) for details.

<sup>e</sup> Habitat effectiveness as related to size and spacing of cover and forage areas; see Thomas et al. (1988) for details.

<sup>f</sup> Total habitat effectiveness, which is the geometric mean of HE<sub>R</sub>, HE<sub>C</sub>, HE<sub>S</sub>, and HE<sub>F</sub>. HE<sub>F</sub> (habitat effectiveness as related to forage quality and quantity) was not derived empirically for this analysis; rather, a default value of 0.5 was input for this variable.

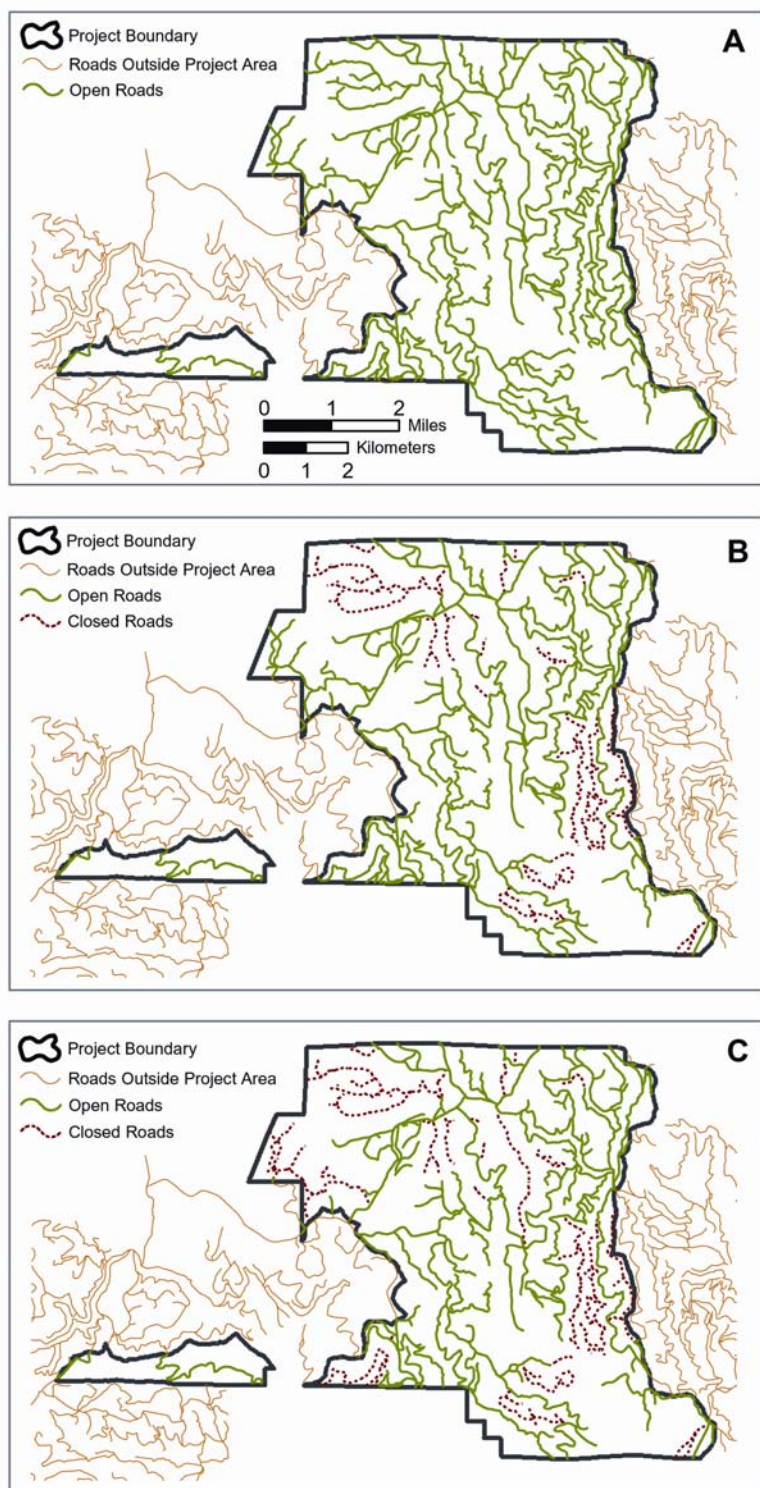


Figure 1. Open roads under three alternatives of the Dark Meadow Restoration Project, Wallowa-Whitman National Forest, northeastern Oregon: the “no action” alternative (A); Alternative 1 (B); and Alternative 2 (C). Open roads were defined as any road available to motorized traffic, including roads officially designated as open and closed roads that have no promulgation.