A Brief Review of the Scientific Literature on Elk, Roads, & Traffic

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Introduction

Outside of wilderness areas, road networks are a ubiquitous feature of most landscapes inhabited by elk (*Cervus elaphus*). Roads have obvious utility: they facilitate basic transportation, commerce, recreation, land and facility management, firefighting, etc. However, roads also potentially have effects on ecosystems and the organisms that inhabit them (Forman et al. 1997, Coffin 2007). These effects commonly vary with season; road type, location, and construction; time-of-day; type and/or level of use; and species of organisms potentially affected. Fahrig and Rytwinski (2009) recently summarized nearly 80 studies that quantified the effects of roads and traffic on the abundance of 130 species of wildlife. In the studies they reviewed, the ratio of negative to positive effects of roads on the abundance of wildlife was 5:1. Across species groups, road effects on large mammals were predominantly negative. Others have also broadly reviewed the influences of roads on ecosystems and species based on published research (Forman and Alexander 1998, Spellerberg 1998); these authors also concluded that roads and traffic often mediate complex effects and impacts, despite their utility.

Dating back to the 1970s, a substantial number of published scientific papers have specifically explored and quantified the influences of roads and traffic on elk, in part because of the importance of elk-centered recreation in the Pacific Northwest and Intermountain West (Bolon 1994). In this paper, I review many of these published reports. Research on the effects of roads and traffic on elk and elk management have focused on 3 broad, yet inter-related ways roads may potentially affect elk: 1) physiologic and energetic effects, 2) effects on distribution and habitat use, and 3) effects on vulnerability to mortality and, potentially, population dynamics. See also Gaines et al. (2003), Rowland et al. (2004), and Gagnon and Dodd (2007) for other reviews of the influence of roads on elk behavior.

Physiological and Energetic Effects

If elk respond negatively to the presence of vehicles on roads, then it follows that there should be evidence that their physiological mechanisms triggered by stress are activated following exposure to traffic. To explore this, Ward and Cupal (1979) instrumented several wild elk with special radio-transmitters that provided heart rate data via telemetry. Elk heart rates were elevated in all or most trials when the elk were exposed to gunshot noise, humans disembarking from stopped vehicles, vehicles on secondary roads, and motorcycles. Elk heart rate responses to perceptible highway traffic were minimal in most cases, as were responses to airplane noise.

Millspaugh et al. (2001) quantified glucocorticoids, stress hormones produced by the adrenal gland, in elk fecal samples at Custer State Park, South Dakota. They found that the density and use of primary roads were 2 of the 3 best predictors of fecal glucocorticoid levels, indicating elk perceived regular vehicle activity as a psychological stressor. Interestingly, the fecal glucocorticoid levels they detected suggested elk experienced more stress during periods of high non-hunting, recreational activity than during limited hunting seasons with fewer numbers of people driving the road system. Creel et al. (2002) also used fecal glucocorticoids to quantify elk stress responses to snowmobile activity in resident elk in Yellowstone National Park. In their analysis, they statistically controlled for potentially confounding effects of elk age and weather. Elk demonstrated pronounced elevation of fecal glucocorticoid production at higher levels of snowmobile activity, despite that the snowmobiles were limited to established roads, that these national park elk were presumably somewhat habituated to human activity, and that the elk were not subject to hunting.

The effects of roads and traffic on elk energy (*i.e.*, caloric) budgets are difficult to quantify directly, but can be easily inferred by quantifying behavioral states and changes in time devoted to specific activities. If traffic on roads causes elk to reduce foraging time and/or increase energy expenditure by moving away from disturbances, or simply by moving more, then they experience a net energy deficit attributable to disturbance avoidance. Stankowich (2008) reviewed the extensive literature on flight responses of ungulates (including elk) following disturbance and found broad evidence that human activity consistently evokes avoidance behavior in this group. He also noted that responses to disturbance tended to be higher in open habitats, for mixed adult female / juvenile groups, and for populations that were hunted.

In an Oregon study that contrasted elk behavior prior to and following a reduction in open road densities, researchers found that elk core area and home ranges decreased in size after open road densities were reduced (Cole et al. 1997); daily movement rates also declined following the reductions in vehicle disturbance. Movement rates were also found to be lowest for elk whose home ranges overlapped the most with the road management area (Cole et al. 1997). Rumble et al. (2005) demonstrated that elk in South Dakota moved away from roads during modern firearm deer and elk seasons, relative to other times; elk also moved more (distance/hr) during periods centered on hunting seasons than just prior to or just after these seasons associated with increased traffic levels.

In another Oregon study that examined elk responses to motorized off-highway vehicles (OHVs), mountain bikers, hikers, and horseback riders, elk were most disturbed by OHVs, followed by mountain bikers (Naylor et al. 2009). Elk responded by reducing foraging time and increasing movements immediately following exposure to disturbance treatments, relative to control elk that were not subject to disturbance. Preisler et al. (2006) also studied elk responses to experimental treatments involving OHV traffic exposure. They controlled for potentially confounding factors and demonstrated that elk reacted negatively to OHV traffic at distances up to 1,000 meters. They also found a high probability that elk would flee in response to OHV disturbance when the elk were near an OHV trail, even when the OHV was at a considerable distance. Borkowski et al. (2006) similarly quantified elk behavioral responses to snowmobile and snow coach traffic. They found that elk had a high probability of an active response to traffic if the elk were near a road; they also found the probability of an active response increased if people disembarked and began to approach the elk group on foot.

Ciuti et al. (2012), working in Alberta, Canada, found that elk reduced the time they devoted to feeding when they were closer to roads; traffic volumes of ≥ 1 vehicle every 2 hours also caused elk to switch to a more vigilant mode of behavior. They noted that the highest level of vigilance behavior was associated with public lands where hunting and non-hunting recreational traffic produced a cumulative effect that strongly affected elk behavior. Interestingly, these authors found that human disturbance more strongly influenced elk behavior than did habitat or natural predators. St. Clair and Forrest (2009) studied rutting elk behavior in a Canadian National Park, specifically quantifying the effects of alternating a key road's status (open vs. closed) at 3-4 day intervals. These un-hunted national park elk were habituated to the presence of vehicles and people. The authors found minimal effects on elk distribution on "road open" vs. "road closed" days, but determined that elk engaged in more vigilance behavior and less breeding behavior on days the road was open, and some behaviors (e.g., sparring among bulls) occurred further from the road on "open road" days. They did not quantify the energetic effects of the observed differences in behavior.

Effects on Distribution and Habitat Use

More research has focused on road and traffic effects on elk distribution and habitat use than on any other effect to elk ecology. The earliest research on this topic focused on quantifying relative densities of elk fecal pellet groups as a function of distances-to-roads. The distribution of pellet groups was thus used as an index of elk use. Using this approach Perry and Overly (1977) estimated that roads reduced elk use up to ½ mile from the actual road in the Blue Mountains of Washington; elk avoided habitat in proximity to main forest roads the most and habitat near primitive roads the least. In some cases, elk use near roads was reduced by 95% relative to adjacent, similar habitats. Lyon (1979) reported on a pellet group analysis based on 8 years of data collected in western Montana. He found that elk use, as indexed by pellet groups, was consistently lower near open roads than in similar habitats further from roads. The effect size he noted was dramatic and was higher in areas of low tree canopy cover; in areas with less than 25% tree cover, predicted elk use declined by approximately 50% at open road densities as low as 1 mile of road per square mile. Lyon (1983) revisited his previous analysis, adding additional datasets from Washington and Idaho, using more sophisticated analyses, and including consideration of the age of the road. His results confirmed that elk use consistently declined in areas near open roads across 3 large, non-contiguous western landscapes. As road densities increased above 2 miles of open road per square mile, habitat effectiveness (*i.e*., percent of expected use) declined rapidly (loss of 55-80% habitat effectiveness). Lyon and Jensen (1980) also documented that elk use of clearcuts, a preferred foraging habitat, was strongly influenced by perceived security; use was clearly depressed in proximity to open roads, relative to nearby clearcuts further from such roads.

Rost and Bailey (1979) used pellet group data to quantify the effects of roads on elk and mule deer (*Odocoileus hemionus*) on several winter ranges in Colorado. They demonstrated strong road avoidance behavior in both species during winter. Use was particularly depressed within 200 meters of open roads. Road avoidance behavior was stronger near well-traveled roads and on winter ranges that had less security cover. Hayden-Wing (1979) examined pellet group distributions for wintering elk in southeastern Idaho and concluded that "*elk distribution appeared to be influenced primarily by man's activities and secondarily by snow depths and vigor of browse*". Elk concentrated on areas furthest from human activities (*e.g*., roads). After many of these pellet groups studies were published and researchers began to formulate models to predict elk habitat effectiveness based on road densities and cover:forage ratios, Lyon (1984) used pellet group data from 11 sites in Montana and Idaho to attempt to validate these models. Cover:forage ratios were imprecise predictors of elk use, but open road densities validated well as a predictor of elk use levels. The author noted that road density models consistently explained over 50% of the variation in elk use across sites in this broad geographic area.

Following on years of pellet group studies, researchers began to extensively explore road effects on elk via the use of radiotelemetry data (collared elk) in the late 1970s and 1980s. This approach facilitated measuring elk use directly, rather than indirectly, as had been done using pellet group indices. The earliest studies were largely based on contrasting elk use relative to proximity to roads with the overall availability of habitat relative to proximity to roads; these studies affirmed the inference from pellet group studies and showed elk use near open roads was consistently less than expected based on features elk selected in the same habitats away from roads (Marcum 1975, Hershey and Leege 1976, 1982, Edge 1982, Irwin and Peek 1983, Edge and Marcum 1985, Edge et al. 1987). As an example, Witmer and deCalesta (1985) found that radiocollared elk in Oregon used habitat within 500 meters of open roads about 50% less than expected based on habitat availability. Lyon (1998) explored a long-term telemetry dataset from western Montana that included a pre-logging, logging, and post-logging phase, and he found that open road avoidance typified elk behavior during all 3 phases. In a winter study, Jones and Hudson (2002) showed that elk home ranges had a lower road density than typical of the landscape, indicating elk selected for relatively non-road-affected areas. Using a grid cell approach, Burcham et al. (1998) found that open road density was negatively correlated with the proportion of elk telemetry points in the grid cells across all scales of analysis they performed using 11 years of elk location data. Czech (1991) found elk avoided a 0.5 km buffer centered on a previously closed road after it was re-opened. In an observational study, Morgantini and Hudson (1979) found elk used marginal habitats during winter through spring, principally to avoid human disturbance, particularly from vehicle activity. Disturbance was sufficient to depress elk use of the best available habitats.

Marcum and Edge (1991) reported that radiocollared bull elk during summer-fall were even more averse to using areas near open roads than were radiocollared cow elk. McCorquodale (2000, 2003) also documented higher road aversion behavior during summer-fall in adult bull elk relative to cow elk in southcentral Washington, but found the reverse during winter (cow elk used areas further from roads than bulls did). Hurley and Sargeant (1991) explored bull elk habitat use in Idaho, specifically relating bull elk use of cover to the distribution of roads during hunting seasons. They found that bull elk in well-roaded areas used dense cover more than bulls in areas further from open roads. Hunting pressure often displaced bulls from more roaded areas. Leptich et al. (1995a) also documented that radiocollared bull elk in northcentral Idaho selected for lower road densities than did cows, and during hunting seasons bulls selected habitat patches with low open road densities.

Rowland et al. (2000), using elk telemetry data, eventually revisited the issue of validating the early road-density models that predicted loss of elk habitat effectiveness as a function of road densities. Conceptually, their research question was essentially the same as in Lyon's (1984) earlier validation work using pellet group data, but Rowland et al.'s analytic approach was more sophisticated. Their analysis confirmed that roads strongly influenced elk habitat use—elk clearly preferred habitat away from open roads—but, they found that a distance-to-road approach predicted observed use better than a simple road-density metric approach.

With the advent of powerful computers capable of more sophisticated approaches to modeling elk habitat use from radiotelemetry data, researchers began to develop more complex statistical models that actually predicted the probability that elk would use specific cells on a landscape map as a function of landscape features (as opposed to simply testing hypotheses that features were important vs. unimportant to elk). Johnson et al. (2000) used such an approach to predict elk use of a northeast Oregon landscape based on a number of potential predictor variables. Among the variables that best predicted observed elk use was the distance to high and medium use roads (> 4 vehicles per 12 hours and 2-4 vehicles per 12 hours, respectively). Elk use was predicted to increase as the distance to such roads increased. Anderson et al. (2005) developed predictive elk habitat selection models from radiocollared elk data that indicated elk selected home range areas to avoid open roads, and Edge and Marcum (1991) found that the probability of cow elk use on a western Montana study area was related to traffic volume; elk use declined as traffic volume increased.

In a study in relatively open country in Wyoming, Sawyer and Nielson (2005) and Sawyer et al. (2007) found that the distance to the nearest road was one of the most powerful predictors of radiocollared elk use; areas predicted to have the highest elk use in summer were 2.8 km from major roads, and in winter, were 1.2 km from major roads. The authors attributed the difference in the winter model predictions to lower observed traffic in winter. The authors noted, "…*if human activity were to increase during the winter due to landscape–use changes, such as off-road vehicle use, energy development, or mineral extraction, we would expect elk to distance themselves from roads in a manner similar to summer, altering the amount of winter habitat available to them*". Stubblefield et al. (2006) studied elk core use areas ("activity centers" in their terminology) and explored landscape attributes associated with high and low elk use.

They subdivided their elk data into geographic zones, and found variability in the exact effects of roads on elk use across zones. However, they generally found strong effects wherein elk were most likely to use habitat patches that were not highly dissected by roads and that were distant from roads with higher traffic levels. In a very recent study, Montgomery et al. (2013) used sophisticated statistical methods to explore road effects on bull and cow elk at different spatial scales and in different seasons. They found bull elk located their home ranges during winter, spring, and fall away from roaded areas; in summer, bull elk also reduced their use of habitat that was visible from and/or close to primary roads. Cow elk demonstrated road-averse behavior primarily in spring and fall. During summer, cow elk selected habitats near closed roads.

Coe (2007) and Coe et al. (2011) attempted to validate the predictive elk habitat models developed by Johnson et al. (2000) and Ager et al. (2003) by collecting data for elk on a different landscape and quantifying how well radiocollared elk use on the new landscape was predicted by the earlier models. Their analysis explored seasonal agreement between model predictions and observed elk use on the independent landscape. They used several seasonal delineations and different year datasets to explore 36 total predicted vs. observed contrasts. In 22 cases (61%) the earlier model predicted the new observed data well or acceptably well. The models did very well at predicting elk use on the new landscape during periods of restricted forage availability (*i.e.*, spring, late summer, early fall). Across variables in the models, the road variables were consistently effective predictors of elk use in the newer dataset.

Gagnon et al. (2007) examined a unique and rarely studied elk-roads context: elk responses to major highway traffic. This Arizona study focused on an area where very high quality elk habitat occurred alongside a state highway (SR260), and elk often used adjacent habitat. Even here, the authors found that the probability that radiocollared elk used meadows near the highway declined as traffic levels increased. Blan and West (1997) also explored an elk-roads context that was geographically unique; they studied landscape effects, including road effects, on the probability that elk would use specific areas for calving in Kansas. They found that the distance to paved and gravel roads were useful predictors of the likelihood that cow elk would birth and rear calves at specific locations across the landscape; elk avoided areas near these roads.

Effects on Elk Vulnerability

Data from pellet group studies and from telemetry studies consistently have shown that elk apparently perceive vehicle traffic as a threat and select for areas with lower exposure to open roads, if they can. Additional research has explored how roads affect, not elk distribution, but elk vulnerability to mortality. This is not a trivial question, as state agencies that manage hunting regularly face a greater demand for elk hunting opportunity (tag demand) than there are elk. Managing vulnerability is essential to avoiding overly restricting hunting opportunity or depleting the elk resource (Leckenby et al. 1991, Vales et al. 1991).

In northeast Oregon, Johnson et al. (2004) found elk moved away from roads as hunter density and traffic levels increased. They also found that elk were increasingly mobile as a response to hunting season pressure and that this additional mobility would conservatively raise elk daily energy expenditures by 10%. Elk appear to predictably respond to hunting seasons by selecting habitat providing additional security, moving away from roads or selecting for dense cover in the presence of roads (Lyon and Canfield 1991, Hurley and Sargeant 1991). In their study, Hurley and Sargeant also found consequences of roads to elk survival; a disproportionate amount of the harvest occurred in areas with open roads (*i.e.*, 43% of the harvest came from 25% of the area). This area also contained only 14% of the elk telemetry locations. Similarly, Unsworth and Kuck (1991) found that radiocollared bull elk in roaded habitats of the Clearwater drainage of Idaho were more than twice as likely to be killed in fall hunting seasons as bulls residing in relatively unroaded habitats. The annual survival rate of adult bulls in the roaded portion of the study area was 41%, compared to 78% for adult bulls in the unroaded portion. The comparative rates for yearling bulls were 44% and 79%.

In a separate analysis that included cow elk, Unsworth and Kuck (1993) found that the probability of mortality during fall hunting seasons increased with road and hunter densities. In another Idaho study, Leptich and Zager (1991) found bull elk survival was

38% in a highly roaded portion of their study area; survival was 69% in a nearby area with few roads. Survival was intermediate (55%) in an adjacent road management area where some of the roads were closed. Using those rates to project effects on bull:cow ratios, the authors predicted ratios of <10:100, 20:100, and 35:100 for the highly roaded, managed access, and relatively roadless subareas, respectively. In a separate analysis, Leptich et al. (1995b) used radiocollared elk data to develop a statistical model to predict hunting season mortality and found that predicted mortality increased with increasing road densities.

Youmans (1991) analyzed long-term trends in elk harvest on 2 Montana Hunting Districts (HD; equivalent to Game Management Units) the Bitterroot National Forest in western Montana. He found that the total bull elk kill increased as the number of road miles in the 2 HDs increased over a 25-year span. During the same time, the number of mature bulls killed declined dramatically as road miles increased. Cooper et al. (2002) used a variety of variables to attempt to predict hunter success rates in Idaho, and they found that road density was among the useful predictors of hunter success.

Weber (1998) quantified landscape variables at elk kill sites, at live elk locations, and at random sites in western Montana. Landscape characteristics at live elk sites were easily distinguishable from those at random sites based on security variables: live elk sites were further from open roads, were in areas of lower road density, and had more security cover. Elk kill sites were more likely to be close to roads than live elk locations were. McCorquodale (2000, 2003) also found that elk kill sites were typified by higher local road densities than were fall live elk location sites in southcentral Washington. McCorquodale et al. (2010) similarly found that distance-to-road and road density variables were useful predictors of harvest mortality risks for yearling bull elk in the Washington Blue Mountains. Mortality risk was elevated where road densities were higher and when yearling bulls were near roads. Hayes et al. (2002) studied proximate factors affecting bull elk mortality in Idaho and found that risk of mortality increased statistically as road density increased; hunts during the rut also were associated with elevated mortality risk.

In another Idaho study, Gratson et al. (1997) studied bull elk survival in 3 nearby areas under different access management (highly roaded [1.5 km of road per km^2], managed access [0.6 km of road per km^2], and unroaded). Bull survival was similar in the unroaded and managed access areas; in both areas survival was about 20% higher than in the highly roaded area. Interestingly, Gratson and Whitman (2000a) found hunter success was about 15% in the highly roaded area, but was nearly 25% in both the managed access and roadless areas. This suggested that although elk vulnerability (mortality risk) is higher in areas with high road density, this does not translate to higher hunter success, presumably because elk select for less roaded areas and survive better there (collectively leading to more long-term opportunity to kill an elk in less roaded habitats). Consistent with this, Millspaugh et al. (2000) found that the probability of shared space use by hunters and elk was negatively correlated with secondary road use (traffic) and tertiary road density (*i.e.*, elk and hunters were more likely to be in the same places where road effects were lower).

Phillips and Alldredge (2000) and Shively et al. (2005) explored completely different effects of elk disturbance by people in a pair of related and well-designed field experiments. Their studies explored potential increased mortality risk to young elk from disturbances during the calving season. In the first study, a treatment group of radiocollared elk and a control group were randomly selected, and cow elk in the treatment group were subjected to repeated disturbance (average of 10 events per year) by people for 3-4 weeks during the peak of the calving season; control group elk were subject only to background levels of disturbance. The researchers subsequently quantified the proportion of radiocollared elk that still had a calf on summer range 1-2 months post-treatment. A 1-year pre-treatment period showed no difference in proportion of the radiocollared elk with a calf on summer range for the 2 groups of elk. During the treatment phase, the researchers determined that that treatment elk were, on average, about 22% less likely than control elk to still have a calf on summer range; the number of disturbance exposures each treatment elk had received also effectively predicted the likelihood of losing a calf. In the follow-up study by Shively et al. (2005), no treatment was applied to the treatment group elk for 2 years (essentially both groups were allowed to return to the pre-experiment state for 2 years). Productivity in treatment elk rebounded in the absence of disturbance, and the proportion of cows still with calves on summer range was the same for treatment and control elk after removal of the treatment.

In an earlier study, also employing disturbance treatments in a controlled experiment design, Kuck et al. (1985) found that elk cow/calf pairs readily abandoned traditional calf-rearing areas when faced with repeated disturbance from people. Treatment calves also moved more, used larger areas, and reduced selection for normally preferred habitats.

Summary and Practical Inference

Collectively, the published scientific reports on the influence of roads and traffic on elk is not a small body of literature. To the contrary, extensive research over decades has demonstrated that high road densities and traffic negatively affect elk use, and—in hunted populations—elk vulnerability to excessive mortality. These results have been consistently demonstrated across a broad geographic range, to include Washington, Oregon, Idaho, Montana, Wyoming, Colorado, Arizona, South Dakota, Wisconsin, Kansas, and western Canada. The results have also been consistent for both Roosevelt (*C. e. roosevelti*) and Rocky Mountain elk (*C. e. nelsoni*) subspecies, further suggesting the results generalize well.

The scientific evidence is compelling that disturbance associated with traffic on open roads can strongly affect elk distribution and limit use of even highly preferred habitat near roads. What practical inference should be derived from these collective research findings? No elk manager or researcher really believes roads can or should be eliminated from elk inhabited landscapes. Roads are useful and necessary to support a host of important and desirable human uses of public lands where elk live. A reasonable implication of this body of literature is not that roads need to be eliminated to achieve success in elk and elk habitat management; pragmatically, the research simply suggests that managing roads strategically to achieve specific management goals relative to densities, location of roads, and seasonal traffic are likely to be powerful tools to support elk management objectives. Prudent road management decisions can also be very important to reducing negative ecological consequences of poorly designed, located, or constructed historical roads (Gaines et al. 2003, Switalski et al. 2004, Grace and Clinton 2007).

Obviously, included in potential road (or access) management decisions are selective road closures, including both permanent and seasonal closures. Proposing to close roads or otherwise manage access is often controversial. However, human dimensions research suggests that public support for resource-oriented road management is considerable, if public education is included. Thompson et al. (1991) reported on 3 case studies from Montana. The authors systematically collected hunter-opinion data relative to 3 road management initiatives intended to address elk habitat security issues. Support for the "Three-mile" initiative was 56%, 69%, 65%, and 76% of respondents during years 1-4 (non-support was 22%, 14%, 16%, and 14%, across years). Support for the 2 other initiatives was measured at 59% (34% opposed) and 69% (20% opposed) during the single year surveys were conducted in each case. The authors reported that support was broadly spread across older and local hunters, as well as younger and non-local hunters. Firebaugh et al. (1980) found that 47% of Missoula, Montana-area hunters favored reducing public land road access, 37% would maintain current levels of access, and 12% favored increased road access.

Gratson and Whitman (2000b) surveyed elk hunters using a well-roaded area, a managed access area, and an unroaded area in Idaho to assess opinions about road restrictions to achieve elk management objectives. Over 60% of hunters indicated road closures were *acceptable* or *tolerable* as an elk management tool. Non-support was lowest among hunters primarily hunting the well-roaded area, among hunters ranking themselves as "experienced", and among hunters who hunted the closest to home.

Applying the Science

As results from a plethora of studies addressing the effects of roads on elk behavior accumulated during the 1970s and 1980s, land and elk management agencies began to incorporate the findings into management objectives and strategies.

Numerous "Guidelines" documents were developed that attempted to integrate the results of elk and roads research with other resource management objectives into formal planning for state and federal lands (Leege 1984, Brown 1985, Lyon et al. 1985, Christensen et al. 1993). Several authors also attempted to synthesize research results into an emerging management paradigm, particularly to deal with elk habitat security issues (Hillis et al. 1991, Moroz 1991).

Recently, a collaborative effort of federal and state scientists revisited the issue of integrating elk habitat management objectives into land management planning. The group, led by scientists at the U. S. Forest Service's Starkey Experimental Forest in northeastern Oregon, developed and tested 2 "next generation" elk habitat models, one for western Washington and Oregon, and one for the Blue Mountains of Oregon and Washington. Both models were developed from large, recent datasets contributed by the region's state, federal, tribal, and academic elk research community. Both models are designed to be an assessment tool for elk habitat values on existing landscapes and as a tool for predicting gains and losses in elk habitat values under specific land management alternatives. Both models include key variables reflecting road effects—not because of the collective body of literature on the topic—but because the meta-analysis of the most recent data again demonstrated empirically that elk distribution and habitat use are strongly influenced by road effects; high road densities and traffic levels predictably reduce elk use.

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