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Influence of Road Management on Diurnal Habitat Use of Roosevelt Elk

Abstract

Road closures are commonly used management tools for Rocky Mountain elk, but few studies have evaluated the effects of limited vehicle access on movement and habitat associations of Roosevelt elk. We examined the influence of road management areas (RMAs) on habitat use of Roosevelt elk in the southern Oregon Coast Range by limiting vehicle access to 35% of the study area. We studied female Roosevelt elk prior to (pre-treatment phase) and during limited vehicle access (RMA phase) from 1991 to 1994. Elk use of open, foraging habitats increased significantly during the RMA phase compared to the pre-treatment phase, but elk used areas ≤150 m from roads less than expected regardless of vehicle access. In general, elk used areas near roads and areas >300 m from streams less than expected. Conversely, elk used areas near streams, areas >150 m from roads, and recent clearcuts more than expected. Roadless riparian areas should be given management priority for Roosevelt elk. Our data suggested that reduced vehicle access increased use of open, foraging habitats because of reduce human disturbance. Limiting vehicular access should be considered for other Roosevelt elk populations, particularly to lessen impacts of human-related activities during biologically important periods.

Introduction

Prior to European settlement, Roosevelt elk (*Cervus elaphus roosevelti*) were commonly associated with late-successional Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) forests in the Pacific Northwest (Starkey et al. 1982). Because of blow-downs, fire, disease, insects, and landslides, many openings were interspersed in the older forest (Franklin and Spies 1991), and Roosevelt elk were likely associated with the ecotone between older and regenerating forests (Witmer and deCalesta 1983). Since the 1940's most late-successional forests have been converted to managed plantations in western Oregon. Consequently, pressure for elk to adapt to habitat alterations and increased human disturbance associated with timber harvest, road construction, and recreation is a recent phenomena.

Many studies have suggested that human disturbance associated with roads can cause Rocky Mountain elk (*C.e. nelsoni*) to avoid habitats that otherwise might be selected. In Wyoming (Ward 1976), eastern Washington (Perry and Overly 1977), and eastern Oregon (Rowland et al. 2000), elk decreased their use of habitats in areas 0.4-0.8 km from roads and in cover that was bisected by traveled roads. Rocky Mountain elk avoided habitats near forest roads in western Montana, and road avoidance was a function of traffic volume, road quality, and density of cover near roads (Lyon 1979). There is also evidence that Roosevelt elk avoid roads. Elk selected areas less than expected ≤ 500 m from paved forest roads and ≤ 125 m from spur roads in the coastal mountains of southwest Oregon (Witmer and deCalesta 1985). Avoidance of roads by elk may be related to the amount of vehicular traffic. Increased vehicle traffic within the Mt. St. Helens National Monument, Washington, caused elk to avoid a 500-m corridor along a road (Czech 1991). Mule deer (*Odocoileus hemionus*) and Rocky Mountain elk avoided well-traveled roads in Colorado (Rost and Bailey 1979), and elk were displaced from areas near heavily traveled roads in Montana (Edge and Marcum 1985). Road closures have been used to manage for Rocky Mountain elk (Basile and Lonner 1979, Lyon et al.1985), but the benefits of limiting vehicular access for Roosevelt elk have not been thoroughly investigated. By removing vehicle access, human harassment of elk will be reduced, elk security enhanced, and suitable habitat that otherwise would have been avoided will likely be used.

The purpose of this study was to investigate the response of Roosevelt elk to Road Management Areas (RMAs) that limited vehicular access. Our

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primary objective was to determine if limiting vehicular access with gates affected elk habitat use in the southern Oregon Coast Range. We predicted that elk would increase use of foraging habitats (early-successional stages) and habitats near roads with limited vehicular access. The Wisdom model (Wisdom et al.1986) is currently used to measure habitat effectiveness for Roosevelt elk based on four parameters: 1) the size and spacing of cover and forage areas, 2) forage quality, 3) cover quality, and 4) the density of roads. In the model, roads that receive any vehicular traffic are assumed to reduce elk habitat effectiveness (elk avoidance of roads). Consequently, we hypothesized that limited vehicle access would reduce elk avoidance of roads and potentially increase habitat effectiveness.

Study Area

The 380 km^2 study area is in the Southern Oregon Coast Range in the Coos Bay District of the Bureau of Land Management, 30 km southeast of Coos Bay. Typical of the Oregon Coast Range, the terrain is dominated by steep ridges and mountain slopes, divided by extensive stream systems. Elevation ranges from 150 m along streams to 1,000 m on ridge tops. The climate is maritime, with moist winters and dry summers. Precipitation ranged from 97-218 cm per year from 1969 to 1992 (Oregon State University Climate Service 1994). Temperatures from 1969-1992 ranged from a mean minimum of 1.7°C in January to a mean maximum of 25.9°C in August (Oregon State University Climate Service 1994). Deep and persistent snowfall is possible at high elevations and may restrict road access for up to two months. However, no snowstorms prevented vehicle access to the study area for >1 wk during this study.

Until the 1970s, the area was predominately late-successional Douglas-fir and western hemlock forests. Currently, the landscape is a mosaic of recent clearcuts, Douglas-fir plantations, old-growth, and naturally regenerated mixed stands of western red cedar (*Thuja plicata*), red alder (*Alnus rubra*), bigleaf maple (*Acer macrophylum*), Douglas-fir, and western hemlock. Riparian areas typically contain red alder, bigleaf maple, and myrtle (*Umbellularia californica*). Sword fern (*Polystichum munitum*), evergreen huckleberry (*Vaccinium ovatum*), red bilberry (*V. parvifolium*), vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), Pacific rhododendron (*Rhododendron macropyllum*), and oceanspray (*Holodiscus dicolor*) are common understory species. Most of the area is alternating sections of BLM and private land. The area is also used for recreation, including camping, hunting, trapping, and berry picking.

Access for timber harvest and other forestry activities in the study area has produced an extensive network of logging roads. Road densities are high with 863 km of roads (6.04 km/km^2) in the study area and approximately 50% of the area ≤ 150 m from roads. Paved mainline roads maintained by BLM are also used by private timber companies to access and manage their forests. Rocked secondary roads branch from mainlines with rocked and non-rocked spur roads branching from secondary roads. Multiple stream systems flow across the landscape with 22% of the study area ≤ 150 m from the nearest stream.

Methods

During the pre-treatment period of our study from June 1991 to August 1992, Pope (1994) determined movements and habitat selection of elk prior to the limited road access phase. He collected movement and location data on 29 radio-collared cow elk, 20 of which lived through the entirety of this study. Subsequently, these 20 elk and 12 additional elk were monitored from July 1993 to August 1994 by Cole (1996) during the RMA phase.

In the study area, 21 gates limited motorized vehicle access on 128 km of secondary and spur roads from July 1993 to August 1994 (Cole et al. 1997). The study area was comprised of 35% RMA. Gate placement was designed to include the home ranges of as many of the original radio-marked elk as possible within RMAs (Pope 1994). Access was limited to seven discrete networks of secondary and spur roads across the study area (Cole et al. 1997). We allowed a 9–mo acclimation period after road closures in October 1992 for the elk at the end of the pre-treatment phase (Pope 1994). Road closures remained until 20 August 1994.

The gates did not provide complete road closures, but rather were intended to limit vehicle access to an average of ≤ 4 vehicle trips per week for administrative purposes. Non-motorized access was not limited (Christensen and Langenstein 1992). Although true road closures would provide a more clearly defined experimental treatment, the interspersion of private and public lands prevented the implementation of complete road closures. We installed magnetic loop traffic counters under the surface of selected roads during pre-treatment and RMA phases to estimate traffic volume (Pope 1994, Cole 1996).

Topography and cover quality (Basile and Lonner 1979, Lyon 1979) may ameliorate the effects of vehicular disturbance on elk. Ideally, the RMA boundaries would have been classified after consideration of topographic features and cover quality. However, the mixture of slope, aspect, and vegetative cover conditions in the study area made this classification logistically difficult. Instead, the RMA boundaries were defined as the midpoint between gated and the nearest non-gated road.

Elk Captures and Monitoring

Twenty-nine cow elk were immobilized in March 1991 (Pope 1994) by personnel of Oregon Department of Fish and Wildlife (ODFW) using helicopter darting with carfentanil citrate as an immobilizing compound. They attempted to capture elk from distinct bands throughout the study area. Elk were fitted with radio transmitters (Telonics MOD-600 164 MHz, Mesa AZ) with a > 3 yr operational life. Twenty of the original 29 elk lived through all phases of the study, and twelve additional elk were captured in April 1993. For statistical comparisons, efforts were made to capture an equal number of elk within and outside the RMA.

Telemetry procedures were identical to those described by Pope (1994). The loudest signal method (Springer 1979) was used to determine the direction of the radio signal, and elk were located by triangulation of 3-5 compass bearings. We conducted a field trial to determine azimuth error and reduce telemetry location error. We used an average azimuth error of 5° to generate estimates of confidence ellipses for each location. To assure independence of locations, the minimum interval between successive locations should be sufficient for the animal to move across its home range (White and Garrott 1990). Therefore, for our analysis, we set the minimum time between successive locations of an individual elk at 24 hours. All locations were diurnal.

Habitat Variables and Analysis

Vegetative cover types were determined from a Landsat Thematic Mapper (TM) image acquired on 15 July 1993. The seven distinct vegetation classes corresponded to those used by Pope (1994): grass/forb, shrub, open sapling, pole/small saw timber, large saw timber/mature, old growth, and deciduous hardwoods. A pixel-based map was plotted and and ground-truthed in the study area to verify the accuracy of the classifications for the spectral categories. Grass/forb and shrub habitats were combined to reduce apparent time related discrepancies between these early successional categories and provide better comparisons between the study periods. The final vegetative cover map was refined by consulting the cover map from the pre-treatment phase (Pope 1994), Bureau of Land Management forest resource inventory data, and interpreting 1:12,000 true color aerial photographs.

Road and stream layers were obtained from the Oregon State Service Center for Douglas and Coos Counties. Additional spur and new secondary roads identified from 7.5-minute USGS quadrangle maps were digitized and added to the road layers. During the pre-treatment phase, distance of elk locations from roads and streams was classified as: <50 m, 51-150 m, 151-300 m, 301-450 m, and >450 m based on buffer categories selected during the spectral analysis. We subsequently combined distance categories to improve statistical power, and classified distance to roads into 2 categories, ≤150 m and > 150 m from roads. The first 2 classes for distance to streams were combined into 1 buffer category that included all areas ≤ 150 m from streams.

We examined elk habitat selection for 3 habitat variables (1) vegetative cover type, (2) distance from roads, and (3) distance from streams. We used a χ^2 statistic (Neu et al. 1974, Zar 1999) to determine differences between expected and observed use for each habitat variable. If significant selection was detected for a habitat variable, we used a Bonferoni *Z*-statistic (Neu et al. 1974, Byers et al. 1984) to test whether observed use of specific habitat categories was greater or less than expected. Differences were considered significant at $P < 0.05$ for all analyses. We combined locations ($n = 3{,}508$) from all 41 elk to determine habitat selection for the pre-treatment and RMA phases. Habitat availability for the entire study area was delineated by the 100% adaptive kernel home range (Baldwin and Kie 1992).

For individual elk during both phases, a 95% adaptive kernel (ADK) (Worton 1989) home range was used to define habitat availability. To control for differences between the pre-treatment and RMA phases not related to the gates, the elk were divided into 2 groups (Cole et al. 1997): (1) RMA- associated elk with >30% of their 95% ADK home range within an RMA (n = 14), and (2) control elk with <30% of their 95% ADK home range within an RMA (n = 6). Only elk (n = 20) that survived through both the pre-treatment and RMA phases were included in these groups. We performed separate paired t-tests on each group to test for differences between the pre-treatment and RMA phases of the study. To determine if changes in foraging habitats (i.e., grass/forb/shrub) were associated with greater use of RMAs, we conducted paired t-tests on the change in the percent use of grass/forb/shrub habitats between the pre-treatment phase and the RMA phase for the control and the RMA-associated group. A Pearson correlation analysis was conducted using program SAS (SAS Institute, Inc.1990) on the percent change in use between the time periods and percentage of an elk's home range associated with an RMA. The same methods were used to determine if use of areas ≤ 150 m of roads increased with increasing RMA association, and to evaluate elk use of the remaining vegetation and stream categories between the pre-treatment and RMA phases.

Results

Traffic volume on roads was consistantly higher during the pre-treatment phase than on gated roads during the RMA phase based on time-related trends (Figure 1). The BLM objective of ≤ 4 vehicle trips per week behind each gate was satisfied, and the RMA road treatment was considered successful for the purposes of this study.

Vegetative Associations

Grass/forb and shrub vegetative cover types together represented 19.7% of the study area. Based on the pooled locations from all 41 elk, grass/forb and shrub cover types were used more than

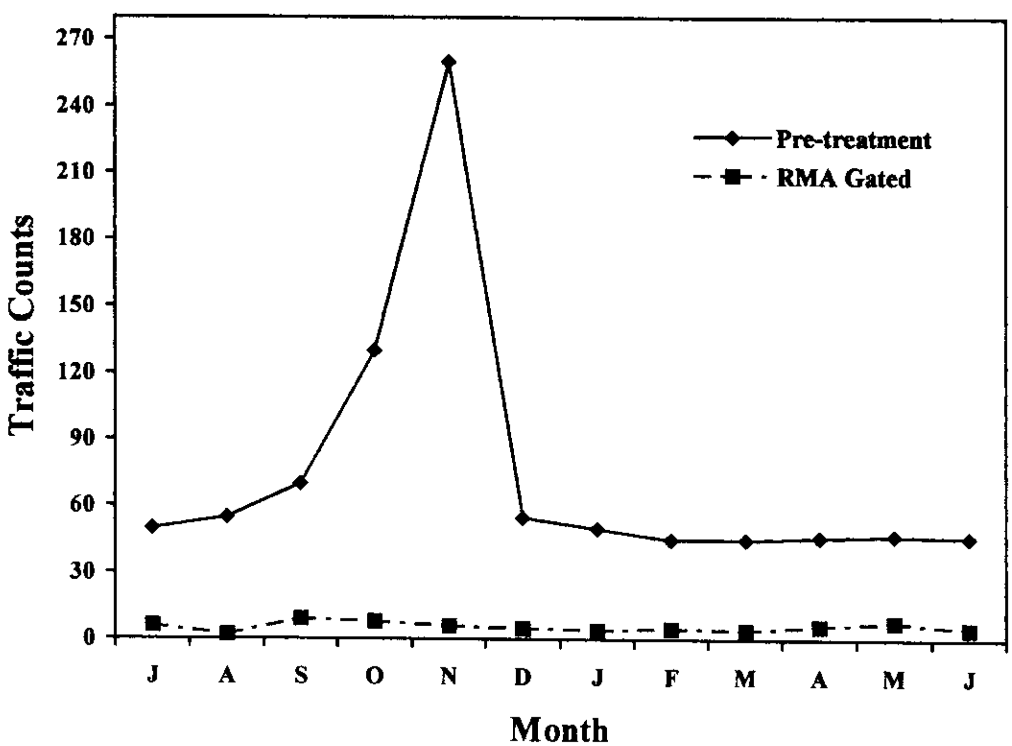

Figure 1. Mean monthly traffic counts on roads during pre-treatment phase (1991-1992) and on gated roads during RMA phase (1993-1994) in southern Oregon Coast Range.

TABLE 1. Use, availability, and selection of vegetative types by 41 elk in the southern Oregon Coast Range in 1991-94 (n = 3,508 locations). Selection is classified as more, less, or equal to expected based on availability ($P \leq 0.05$).

Cover Type	% Use	% Available	95% C.I.[1]	Selection
grass/forb	10.8	6.1	9.4-12.3	more
shrub	15.3	13.6	13.6-17.0	more
open sapling	5.5	5.8	4.4-6.5	equal
old growth	15.0	14.2	13.4-16.7	equal
hardwoods	4.1	4.7	3.2-5.0	equal
pole/small sawtimber	34.2	37.7	31.9-36.4	less
large sawtimber/mature	15.1	17.9	3.4-16.8	less

[1] C.I. = Confidence interval

TABLE 2. Mean change in percent use of vegetative cover types for 11 elk (n = 1964 locations) associated with Road Management Areas (n = 14) and 6 control elk (n = 362 locations) from the pretreatment phase (1991-92) to the RMA phase (1993-94) in the southern Oregon Coast Range.

	RMA Elk			Control Elk		
Cover Type	Mean Change	SE	P-Value	Mean Change	SE	P-Value
grass/forb/shrub	+7.7	2.6	0.01	+3.6	2.6	0.2
open sapling	+2.8	1.6	0.1	+1.1	1.4	0.5
old growth	-2.4	2.1	0.03	+3.1	3.6	0.4
hardwoods	-4.2	1.8	0.8	-1.9	3.1	0.6
pole/small saw	-0.5	1.8	0.8	+2.3	4.7	0.6
large saw/mature	-5.4	1.8	0.01	-4.8	0.8	0.002

expected by elk (Table 1). Elk used closed pole and large saw timber/mature types less than expected. Open sapling, old growth, and hardwoods were used equal to expected (Table 1).

There was a significant increase in percent use of grass/forb/shrub habitats between the pre-treatment and RMA phases for the 11 elk associated with RMAs, but not for the 6 control elk (Table 2). There was no significant correlation between the increase in percent use between the pre-treatment and RMA phases and the percent association with RMAs ($r = 0.13$, $P = 0.59$). For the 11 elk associated with RMAs, large saw timber/mature habitats were used significantly less during the RMA phase, with a mean decline of -5.4 percent (Table 2). Similarly, there was a significant decline (-4.8%) in use of large saw timber/mature habitats for the 6 control elk (Table 2).

Influence of Roads and Streams on Habitat Associations

The study area was almost equally divided between areas ≤ 150 m from roads and areas > 150 m from roads (Table 3). Based on the combined locations from all 41 elk during both phases of the study, areas ≤ 150 m from roads were used less than expected and areas > 150 m from roads more than expected. Areas < 150 m from streams were used more than expected (Table 3). Areas 151-300 m from streams were 21.49% of the study area, and were used in proportion to availability. The remaining portion of the study area was > 300 m from streams, and elk used these areas less than expected (Table 3).

TABLE 3. Use, availability, and selection of distances from roads and streams by 41 elk (n = 3,508 locations) in the southern Oregon Coast Range, 1991-94. Selection is classified as more, less, or equal to expected based on availability ($P \leq 0.05$).

Road Class (m)	% Use	% Available	95% C.I.[1]	Selection
0-150	40.8	49.4	38.9-42.7	less
>150	59.3	50.6	57.3-61.1	more
Stream Class (m)				
0-150	33.6	22	31.5-35.6	more
151-300	21.9	21.5	20.1-23.7	equal
301-450	17.1	19.5	15.4 –18.7	less
451-600	13.1	16.3	11.6-14.6	less
>600	14.3	20.7	12.8-15.9	less

[1] C.I. = Confidence interval

There was a significant increase in percent use of areas ≤ 150 m of roads between the pre-treatment and RMA phases. For the 11 RMA associated elk, the mean increase was 8.1 ± 2.7 ($P = 0.01$) percent. There was a similar increase ($\bar{x} = 7.3$, SE = 2.6) in use of areas ≤ 150 m of roads for the 6 control elk, but this increase was not statistically significant. Further, the increase in use during the RMA phase was not significantly correlated with the percent association of an individual elk's home range and the RMAs ($r = 0.27$, $P = 0.25$).

There were no differences in percent use of the stream categories between the pre-treatment and RMA phases for the 11 RMA-associated elk (Table 4). For the 6 control elk, there was a significant decrease in use of areas ≤ 150 m of streams (Table 4).

Discussion

We predicted that elk selection of open, foraging habitats (grass/forb and shrub) would increase during the RMA phase compared to the pre-treatment phase, and that use of these habitats would be positively correlated with the degree of association with RMAs. Our results supported our first prediction as there was a significant increase in use of grass/forb/shrub habitats during the RMA phase. However, there was no support for the second prediction from our data. The reduction in vehicular traffic and human disturbance during the RMA period was associated with increased elk use of open, foraging habitat, but we believe this relationship was more complex than a simple correlation with the degree of overlap of elk home ranges with RMAs. Previous studies found that Rocky Mountain elk avoided open areas and selected forest cover during periods of increased human disturbance (McLean 1972, Bohne 1974, Lonner 1976). Our study is the first evidence of increased use of foraging habitat by Roosevelt elk due to a decrease in human disturbance. These habitats often provide less hiding cover, and elk may avoid them despite the potential foraging benefits because of disturbance factors. During our study, elk from both the pre-treatment and RMA phases used closed sapling/pole stands significantly less than expected. Similar behavior was noted in the 1980s when radio-marked elk in the same area avoided pole/sapling stands (Witmer and deCalesta 1983). Avoidance of these habitats was attributed to the lack of forage typically found in closed canopy forests (Witmer and deCalesta 1983). In contrast, elk on the Olympic Peninsula, Washington, avoided even-aged regenerating stands (Schroer et al. 1993). In our study, elk did not use old-growth more than expected, in contrast to Witmer and deCalesta's (1983) findings that adult cows used old-growth and hardwood forests greater than their availability. Their limited sample size of elk may have accounted for these differences.

Avoidance of roads by Rocky Mountain elk is well documented (Hershey and Leege 1976, Ward 1976, Perry and Overly 1977, Lyon 1979, Rowland et al. 2000, McCorquodale 2003, McCorquodale et al. 2003), but there are few studies that reported avoidance of roads by Roosevelt elk. In the Oregon Coast Range, Roosevelt elk used areas ≤ 500 m from paved forest roads less than expected, and there were fewer than expected observations ≤ 125 m from spur roads (Witmer and deCalesta 1985). Similarly, our results indicated that Roosevelt elk used areas ≤ 150 m from roads less and areas >150 m from roads more than expected. We predicted that use of areas near roads would increase during the RMA phase compared to the pre-treatment phase. During the RMA phase, elk increased use of areas ≤150 from roads, but we also observed a similar increase in use by the control group. The lack of statistical significance for the control group was likely related to the smaller sample size of control elk, and comparisons with larger

TABLE 4. Mean change in percent use of distances from streams for 11 elk associated with Road Management Areas ($n = 1964$ locations) and for 6 control elk ($n = 362$ locations) from the pretreatment phase (1991-92) to the RMA phase (1993-94) in the southern Oregon Coast Range.

	RMA Elk			Control Elk		
Distance (m)	Mean Change	SE	*P*-Value	Mean Change	SE	*P*-Value
<150	-2.4	2.6	0.4	-11.2	4.6	0.06
151-300	-1.3	2.3	0.6	+2.9	3.1	0.4
301-450	+4.9	2.8	0.1	+3.8	2.6	0.2
>450	-1.8	2.5	0.5	+4.5	2.7	0.2

samples should provide a better understanding of these relationships.

Rocky Mountain elk have been shown to select riparian areas seasonally (Lyon 1973, Marcum 1976, Pedersen and Adams 1976). Similarly, Roosevelt elk in northern California were typically found < 500 m from permanent water (Grenier 1991), and Roosevelt elk in Oregon selected areas near permanent water during calving season (Witmer and deCalesta 1983). During our study, elk selected areas ≤ 150 m from streams and avoided areas more distant from streams regardless of their association with RMAs. Riparian areas function as natural travel corridors, provide greater potential forage, and more beneficial microclimates that ameliorate temperature extremes (Thomas et al.1979, Oakely et al.1985). In the southern Oregon Coast Range, riparian areas typically have dense vegetation which provides excellent hiding cover for elk.

In this study, limited vehicle access produced modest but important changes in habitat use by elk. Reducing traffic on logging roads may lessen impacts of human disturbance on elk during biologically significant periods such as calving and rutting seasons. There is some evidence that human-related recreational activities near elk calving grounds resulted in reduced cow/calf ratios in central Colorado (Phillips and Alldredge 2000). We also found (Cole et al.1997) that restricting vehicle access increased elk survival and reduced their movements. The influence of road closures on hunting season survival has been documented (Leptich and Zager 1991, Gratson and Whitman 2000, Hayes et al. 2002, McCorquodale et al. 2003), so road access management may provide protection for elk populations that are subjected to high hunter numbers. Rowland et al. (2000) recommended the retention of a road component in habitat effectiveness models for elk. They suggested that a spatially explicit road variable based on buffered road categories rather than road densities may provide a more appropriate evaluation for habitat effectiveness. We agree that road density should remain a critical component in habitat effectiveness models for Roosevelt elk, and should be considered, particularly if complete road closures are not feasible.

The Wisdom model (Widsom et al. 1986) considered old-growth forests as optimal habitat (habitat effectiveness=1) for Roosevelt elk. We found no strong selection for old-growth habitats in either the pre-treatment or RMA phase and believe this factor is over-emphasized in the Wisdom model. The importance of riparian areas is not included in the Wisdom model, but we believe these areas should receive stronger consideration. Elk consistently selected areas near riparian zones during the pre-treatment and RMA phases during our study. We suggest wildlife managers should consider areas ≤150 m from streams and >150 m from roads as important for Roosevelt elk in future management decisions and models of habitat suitability.

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Literature Cited

Baldwin, J., and J. Kie. 1992. Program CALHOME. Unpublished report, USDA Forest Service, Forest Science Laboratory, Fresno, California.

Basile, J. V., and T. N. Lonner. 1979. Vehicle restrictions influence elk and hunter distribution in Montana. Journal of Forestry 77:155-159.

Bohne, J. R. 1974. Food habits, seasonal distribution, and habitat utilization of elk in the South Fork of Fish Creek, Lolo National Forest, Montana. M.S. Thesis. University of Montana, Missoula, Montana.

Byers, C. R., R. K. Steinhorst, and P. R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. Journal of Wildlife Management 48:1050-1053.

Christensen, B. and S. Langenstein. 1992. A proposal to temporarily limit vehicle access on selected federal and private administered roads in the Tioga and Myrtlewood resource areas of the Coos Bay District.

EA No. OR129-92-13. Unpublished report. Bureau Land Management, North Bend, Oregon.

Cole, E. K. 1996. Influence of limited access roads on Roosevelt elk in the Oregon Coast Range. M.S. Thesis. Oregon State University, Corvallis, Oregon.

Cole, E. K., M. D. Pope, and R. G. Anthony. 1997. The effects of road management on movements and survival of Roosevelt elk. Journal of Wildlife Management 61:1115-1126.

Czech, B. 1991. Elk behavior in response to human disturbance at Mt. St. Helens National Volcanic Monument. Applied Animal Behaviour Science 29:269-277.

Edge, W. D., and C. L. Marcum. 1985. Movements of elk in relation to logging disturbances. Journal of Wildlife Management 49:926-930.

Franklin, J. F., and T. A. Spies. 1991. Composition, function, and structure of old-growth Douglas fir forests. Pages 71-83 *in* K.B. Aubry and M.H. Brookes (editors), Wildlife and vegetation of unmanaged Douglas-fir forests. USDA, Forest Service General Technical Report PNW-GTR-285, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Gratson, M.W., and C. L. Whitman. 2000. Road closures and density and success of elk hunters in Idaho. Wildlife Society Bulletin 28(2):302-310.

Grenier, J. J. 1991. Habitat use by Roosevelt elk in the Bald Hills of Redwood National Park. M.S. Thesis, Humboldt State University, Arcata, California.

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.

Hershey, T. J., and T. A. Leege. 1976. Influences of logging on elk on summer range in north-central Idaho. Pages 73-80 *in* S. R. Hieb (editor), Proceedings of elk/logging roads symposium. University of Idaho, Moscow, Idaho.

Leptich, D. J. and P. Zager 1991. Road access management effects on elk mortality and population dynamics. Pages 126-131 *in* A. G. Christensen, L.J. Lyon, and T.N. Lonner, (editors), Proceedings of elk vulnerability-a symposium. Montana State University, Bozeman, Montana.

Lonner, T. M. 1976. Elk use-habitat type relationships on summer and fall range in Long Tom Creek, southwestern Montana. Pages 101-109 *in* S.R. Hieb (editor), Proceedings of elk/logging roads symposium. University of Idaho, Moscow, Idaho.

Lyon, L. J. 1973. Elk use of Burdette Creek. Pages 101-106. Proceedings of western states elk workshop, Bozeman, Montana.

Lyon, L. J, 1979. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry 77:658-660.

Lyon, L. J, T. N. Lonner, J. P. Weigland, C. L. Marcum, W. D Edge, J. D. Jones, D. W. McCleery, and L. L. Hicks. 1985. Coordinating elk and timber management. Final report of the Montana cooperative elk-logging study 1970-1985. Unpublished report. Montana Department of Fish, Wildlife and Parks, Bozeman, Montana

Marcum, C. L. 1976. Habitat selection and use during summer and fall months by a western Montana elk herd. Pages 91-96 *in* S.R. Hieb (editor), Proceedings of elk/logging roads symposium. University of Idaho, Moscow, Idaho

McLean, L. S. 1972. Movements and migrations of the Lochsa elk herd. M.S. Thesis. University of Idaho, Moscow, Idaho.

McCorquodale, S. M. 2003. Sex-specific movements and habitat use by elk in the Cascade Range of Washington. Journal of Wildlife Management 67(3):739-741.

McCorquodale, S. M., R. Wiseman, C. L. Marcum. 2003. Harvest vulnerablility in elk. Journal of Wildlife Management 67(2): 248-257.

Neu, C. W., C. R. Byers, and J. M. Peek. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 38:541-545.

Oakley, A. L., J. A. Collins, L. B. Everson, D. A. Hellar, J. C. Howerton, and R. E. Vincent. 1985. Riparian zones. Pages 57-80 *in* E. R. Brown (editor), Management of wildlife and fish habitats in forest of western Oregon and Washington. USDA, Forest Service, Pacific Northwest Region No. R6-F&WL-192, Portland, Oregon.

Oregon State University Climate Service. 1994. Climate data. Unpublished report on file at Oregon State University, Corvallis, Oregon.

Pedersen, R. J., and A. W. Adams. 1976. Rocky Mountain elk research project progress report. Unpublished Progress Report. Project No. W-70-R-6. Oregon Department of Fish and Wildlife, Portland, Oregon.

Perry, C., and R. Overly. 1977. Impacts of roads on big game distribution in portions of the Blue Mountains of Washington, 1972-1973. Applied Research Section Bulletin Number 11. Washington Game Department, Olympia, Washington.

Phillips, P. E., and A. W. Alldredge. 2000. Reproductive success of elk following disturbance by humans during calving season. Journal of Wildlife 64(2):521-530.

Pope, M. D. 1994. Roosevelt elk habitat use in the Oregon Coast Range. M.S. Thesis. Oregon State University, Corvallis, Oregon.

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., M. J. Wisdom, B. K. Johnson, and J. G Kie. 2000. Elk distribution and modeling in relation to roads. Journal of Wildlife Management 64(3):672-684.

SAS Institute Inc. 1990. SAS/STAT user's guide. Release 6.0. SAS Institute, Inc. Cary, North Carolina.

Schroer, G. L., K. J. Jenkins, and B. B. Moorhead. 1993. Roosevelt elk selection of temperate rain forest seral stages in western Washington. Northwest Science 67:23-29.

Springer, J. T. 1979. Some sources of bias and sampling error in radio triangulation. Journal of Wildlife Management 43:926-935.

Starkey, E. E., D. S. deCalesta, and G. W. Witmer. 1982. Management of Roosevelt elk habitat and harvest. Transactions of North American Wildlife Natural Resource Conference 47:353-362.

Thomas, J. W., C. Maser, and J. E. Rodiek. 1979. Riparian zones. Pages 40-47 *in* J. W. Thomas (editor), Wildlife habitat in managed forests-the Blue Mountains of

Oregon and Washington. USDA, Forest Service, Agriculture Handbook No. 553. Portland, Oregon.

Ward, A. L. 1976. Elk behavior in relation to timber harvest operations and traffic on the Medicine Bow Range in south-central Wyoming. Pages 32-43 *in* S.R. Hieb (editor), Proceedings of elk/logging roads symposium. University of Idaho, Moscow, Idaho.

White, G. C., and R. A. Garrott. 1990. Analysis of Wildlife Radio-tracking Data. Academic Press Inc, San Diego, California.

Wisdom, M. J., L. R. Bright, C. 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. USDA, Forest Service Publication. No. R6-F&WL-216-1986.

Witmer, G. W., and D. S. deCalesta. 1983. Habitat use by female Roosevelt elk in the Oregon Coast Range. Journal of Wildlife Management 47:933-939.

Witmer, G. W., and D. S. deCalesta. 1985. Effect of roads on habitat use by Roosevelt elk. Northwest Science 59:122-125.

Worton, B. J. 1989. Kernal methods for estimating the utilization distribution in home range studies. Ecology 70:164-168.

Zar, J. H. 1999. Biostatistical Analysis. Prentice-Hall Inc. Upper Saddle River, New Jersey.

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