Abstract: We studied landscape elements that influence elk (Cervus elaphus) vulnerability to hunting in western Montana from 1993-1995. We used six Geographic Information System (GIS) coverages to describe 84 elk kill locations, 267 live elk locations, and 166 random locations at 3 scales (point, 17.6 ha, and 125 ha). Discriminant function analysis (DFA) was used to differentiate among these locations using 4 road variables, 3 topographic variables, 24 vegetation classes, 4 vegetation-change classes, hydrography, and a fragmentation index. Road proximity or density discriminated among elk kill, live elk, and random locations at each scale. In addition, a vegetation-change variable and 2 vegetation classes (lodgepole pine [Pinus contorta] and open Douglas-fir [Psuedotsuga menzeseii])

1 Current location: Idaho State University, Campus Box 8130, Pocatello ID 83209-8130
classes) improved differentiation of the locations (x = 50% correct classification). Elk selected locations away from open roads, in areas with low road density and large forested patches with substantial hiding cover.

Key words: Cervus elaphus, elk, GIS, habitat, hunting, landscape, mortality, security, vulnerability, wapiti.

A current wildlife management concern involves several aspects of elk vulnerability to hunting. Management of elk hunting in Montana has focused on maintaining a 5-week season for bulls, without controlling the number of licensed residents. One result has been a decline in the number of mature bulls in some populations. In parts of Oregon, some elk herds have distorted population structures (Leckenby et al. 1991) that deviate substantially from public expectations and may be biologically unsound (Squibb et al. 1991, Prothero et al. 1979, Noyes et al. 1996). Reduced bull:cow ratios may lead to an increased reliance on immature bulls for breeding and a prolonged calving season. This, in turn may result in higher predation losses and/or lower winter-survival of elk calves.

While the sources of these problems have been studied and discussed by numerous researchers, no individual factor has been isolated. However, three sources have been routinely identified: 1) insufficient hiding cover, 2) increased or unimpeded access of hunters via roads, and 3) hunting seasons that are too long or regulations that are too liberal.

Our research objective was to examine sites where elk were killed by hunters, and assess the vulnerability and security (Lyon and Christensen 1992) of elk in relation to various landscape elements such as vegetation and topography. Although other factors likely were involved, we
presumed that animals killed were associated with inadequate security. Locations of elk kills were compared with random locations and with locations used by live radio-collared elk during the same time period using numerous spatial variables at 3 landscape scales (point, near (200m radius), and far (700m radius)). Both bull and cow elk were radio-collared, and both bull and cow elk were hunted during this study. As a result of these efforts, this study will provide land managers with suggestions that could reduce elk vulnerability.

This project was a cooperative research effort involving the USDI Bureau of Land Management, USDA Forest Service Rocky Mountain Research Station, The University of Montana School of Forestry, Rocky Mountain Elk Foundation, Plum Creek Timberlands Limited Partnership (LP), the Boone and Crockett Club, and Montana Department of Fish, Wildlife and Parks.

**STUDY AREA**

The 259km² Chamberlain Creek study area lies approximately 56km east of Missoula, Montana in the Garnet Mountains. The primary recreational use of the study area is sport hunting. As part of the Blackfoot Block Management Area, interior roads were closed to motorized traffic from 1 September through 1 December. Bicycles and horses were allowed, but commercial outfitting was prohibited. Hunters wishing to use the walk-in area entered at any of 12 parking and access sites (i.e., trailheads). Two elk herds were identified in the study area, each containing approximately 200-250 elk. During this study (1993-95) elk hunting season began on the first Saturday in September and ended on the last Sunday in November. The 5-week rifle season followed a 7-week archery-only season and 1 week of no big game hunting. During the general rifle season hunters possessing a valid license could harvest any antlered bull. The number of antlerless elk permits (n =
METHODS

Aerial telemetry was performed twice per week throughout the rifle season to locate approximately 30 radio-collared elk (mature bulls = 7, juvenile bulls = 3, cows = 20). The majority of radio-collared elk were located during each flight. Location accuracy was ±100m.

Hunters who killed an elk in the study area were interviewed at a game check station and asked to indicate on a map the exact site where the elk was initially shot and where the viscera were located. Hunters were also asked whether the elk had run after being shot. Using this information, a search was conducted to locate the remaining viscera of the elk and record the location of the kill using a global positioning system (GPS) receiver. All recorded kill sites represent the point where the animal was initially shot and not necessarily where the viscera were found. Normally, however these locations were one-and-the-same as 95% of hunters stated the elk did not run after being shot and little evidence was found to suggest otherwise when the site was investigated. Not all elk kill locations reported were found during our investigation. To assess this potential bias we tested located versus non-located (using the point supplied by the hunter) elk kill sites for distance to a road and distance to an open road.

We used 84 elk kill locations, 267 live elk locations, and 166 random locations in our analysis. All locations on properties closed to public hunting were removed from the sample to eliminate the potential bias caused by varying accessibility to hunters. We used 6 Geographic Information System (GIS) coverages to describe these locations: (1) trailheads, (2) roads (created by digitizing USGS 7.5’ topographic series maps [1:24,000 scale] and aerial orthophotography [1:24,000 scale]), (3)
hydrography (obtained from the Montana Department of Fish, Wildlife and Parks [1:24,000 scale]), (4) hunter density (Weber 1996) (created using hunter-GPS routes [Lyon and Burcham 1998], a trailhead coverage, and trailhead-use data [684 trailhead-use samples from 11 trailheads during the 1993, 1994, and 1995 hunting seasons]), (5) vegetation (containing 24 vegetation classes created by ground-truthing a 1992 Landsat Thematic Mapper digital coverage using methods similar to those described by Hart [1994]), and (6) vegetation-change between 1984 and 1992. The vegetation-change coverage used four change classes: (1) no vegetation-change, (2) intermediate vegetation loss (e.g., shelterwood and selection timber harvest treatments), (3) high vegetation loss (e.g., clear-cut and seed tree timber harvest treatments), and (4) gained vegetation. This coverage was created using methods described by Winne (1996). Polygon coverages describing vegetation were derived from 30 m-resolution satellite imagery.

To assess the impact of various landscape elements and to better understand the scale at which elk respond to their environment, we chose three landscape scales to analyze each kill, live elk, and random location. We assembled a point analysis database that contained 10 variables describing each location: distance to any road, distance to an open road, distance to a mapped source of water, distance to the nearest trailhead, vegetation class, vegetation-change class, hunter density, elevation, slope, and aspect. The latter three variables were determined using mean elevation, mean slope, and majority aspect for the vegetation polygon where the point was located. A near analysis database contained a description of the landscape within a 200m radius of each location. This scale was selected because it closely emulates the distance at which an elk and a hunter might first encounter one another. Further, it represents a reasonably long-range shot for the hunter. Variables in this database were the area of each vegetation class and vegetation-change class, the number of pixels of
open and closed roads, the number of non-road pixels, and the number of different vegetation classes within the sampling perimeter (a fragmentation index). A far analysis database contained a description of the landscape within a 700m radius of each location using the same variables as the near analysis database. This scale was chosen to approximate short-term habitat availability for the elk.

To perform these analyses, vector coverages of vegetation, vegetation-change, and roads were rasterized using 30x30 m pixels. As a result of the rasterization process, the actual area sampled was different than predicted when computing the area of a circle (e.g., area = \( \pi r^2 \), \( 3.14 * 200^2 = 12.6 \) ha compared with 17.6 ha actually sampled, and \( 3.14 * 700^2 = 154 \) ha compared with 124 ha actually sampled). MAYA software (Glassy and Lyon 1989) determined the number of pixels of each vegetation class, vegetation-change class, and road type for both near and far analyses.

We used discriminant function analysis (DFA) to differentiate among kill, live elk, and random locations at each scale. A step-wise procedure that maximized Wilks-lambda was used (i.e., the variable that provided the best discriminating ability was used by the DFA first). The three groups (kill, live elk, and random) were tested simultaneously and in pairs. To compensate for the bias induced by disproportionate sample sizes (Norusis 1990) classification rates were corrected using the Kappa statistic (Titus et al. 1984). This technique provides a statistic that indicates how much better (or worse) the classification performed relative to what would have occurred by chance alone.

To examine the importance of the vegetation classes detected by DFA, a use-availability comparison was made using Chi-square analysis (Neu et al. 1974, Byers et al. 1984). Use was calculated as the percent of each vegetation class identified by a live elk location (site specific), and availability was calculated as the percent of each vegetation class contained within the 95% isopleth
of the home range of each elk herd. Herd home ranges were determined with the adaptive kernel method (Worton 1989) using independent cow elk locations \( n = 112 \).

**RESULTS**

During 3 hunting seasons (1993-95) 257 elk kills were reported, but only 125 of these were located. Of those located, 41 were found on land closed to the general public. Eighty-four elk kill sites were used in the DFA. The 132 kill sites never located in the field were termed *lost* due to weather conditions, and/or errors in map interpretation.

One concern was the kill sites most likely to be found were not randomly distributed, but those which were easiest to locate (i.e., close to open roads, trailheads, or open areas). Concerted efforts were made to locate each kill site, including those in areas difficult to access, but the probability of finding these points, using only verbal instructions from excited hunters, seem to diminish as the complexity of the instructions increased. We also note that few kills were reported in areas far from open roads and trailheads, or in dense forests. Still, to understand the potential affect of this bias we determined the distance of each *lost* kill site to an open road \( x = 1.28 \text{km} \) and to any road \( x = 0.25 \text{km} \). These estimates were determined using the map location designated by the hunter. Compared to kill sites that were found and included in the DFA, the mean distance to an open road \( x = 1.54 \text{km} \) or to any road \( x = 0.19 \text{km} \) varied little between found and *lost* kill sites. Further, the maximum distance from an open road is nearly identical for all elk locations (found kill sites = 5.65 km, lost kill sites = 5.50 km, and live elk = 5.77 km). This suggests that due to the heavily-roaded condition of the study area, elk cannot find areas >6 km from an open road. Based on this potential, the actual error caused by this bias was considered minimal.
Live elk were found, on average, 1km farther from open roads than kill or random locations. The Douglas-fir vegetation class had the highest frequency of kill and random locations (20%), and was also one of the most common vegetation classes (20%) (Table 1). Live elk were most often associated with the lodgepole pine vegetation class (52%). Elk use of lodgepole pine exceeded availability, while elk use of the open Douglas-fir vegetation class, characterized by having ≤30% canopy closure) was not different than availability (Table 1).

Distance to open road and vegetation-change variables provided an overall correct classification of 53% using the point analysis database. Kill, live elk, and random locations were ordinarily associated with areas of no vegetation-change. However, 35% of kill locations were found in areas of intermediate vegetation loss (e.g., shelterwood and selection timber harvest). Lodgepole pine area and the number of non-road pixels found within the sampling perimeter of each location, achieved the best overall classification (50%) in near analyses. Similarly, the area of open Douglas-fir and the number of pixels of open road were used to achieve the best overall classification (49%) for far analyses.

The highest correct classifications were achieved using the point analysis database. At this scale, 80% of live elk locations were correctly classified (Table 2).

**DISCUSSION**

While elk distribution was relatively uniform (Fig. 1), nearly 50% of all elk kills occurred ≤1km of an open road, suggesting elk vulnerability increased close to open roads. Road variables were also included in both the near and far analyses. The effect or roads at each landscape scale illustrates not only the impact of open roads on elk security, but a discernible benefit of walk-in
areas. This result concurs with findings reported by Basile and Lonner (1979), Lyon and Canfield (1991), Unsworth and Kuck (1991), and Unsworth et al. (1993).

Although elk kills were associated most with areas of no vegetation-change, 35% of kills were found in areas of intermediate vegetation loss (e.g., shelterwood and selection timber harvest), compared to only 4% of live elk locations. This suggests elk vulnerability increased greatly where a timber harvest treatment had occurred. However, vegetation change may not be the sole contributing factor to this increase in vulnerability. The roads that lead to these places provide hunters easier access and reduced visual obstruction.

Elk vulnerability increased in the open Douglas-fir vegetation class (characterized by minimal canopy cover [\(\leq 30\%\)] and a lack of hiding cover). Only 5% of live elk locations were found in open Douglas-fir, compared to nearly 17% of kill locations. This agrees with the results of other researchers (Irwin and Peek 1983, Wright 1983, Canfield 1988, Hurley and Sargeant 1991, Vales 1996), who found elk use of open areas decreased during the hunting season. Elk that ventured into areas with poor security appeared to have a higher probability of being killed.

Based on field data describing the 242 ground-truth samples used to create the vegetation coverage, the lodgepole pine vegetation class had the highest hiding cover estimate and densest canopy cover, which probably explains why elk selected this vegetation class. Numerous other hunting season studies have arrived at similar conclusions. Marcum (1975) and Edge et al. (1987) reported elk selected sites with high canopy closure and/or dense cover. Irwin and Peek (1983) found elk preferred pole-timber sites with >75% canopy closure with little use of clear-cuts, grass-shrub, or brushfield sites. Hurley and Sargeant (1991), and Hurley (1994) reported elk in roaded or partially roaded areas increased their use of dense coniferous cover and subsequently decreased their
use of more open sites during the hunting season. Of the 415 individual polygons assigned the lodgepole pine vegetation class, elk in the study area routinely selected 10 large polygons, with 85% of those locations occurring in the same polygon. This polygon was the largest available polygon on the landscape (Lyon and Canfield 1991, Hillis et al. 1991). These results, when coupled with data we have presented regarding use-availability and the results of DFA, indicate selection for large patches. It seems apparent that elk are not selecting these sites for lodgepole pine but rather for the security provided by these forests. In other regions, security may be provided by sub-alpine fir (Abies lasiocarpa) or Douglas-fir. Thus, the vegetation classification becomes less important than the characteristics used to describe them.

MANAGEMENT IMPLICATIONS

Implementing the following suggestions in timber harvest planning, road construction, and property development has the potential to dramatically decrease the vulnerability of elk to hunting: (1) design road closures (i.e., walk-in areas) that provide security cover >1km from an open road, (2) reduce road densities inside the walk-in area by limiting road development and instituting road obliteration projects, and (3) retain large patches of forest with high canopy cover values, and hiding cover that will provide elk with complete or nearly complete concealment at a distance ≥61 m. These considerations must be applied collectively to be effective because forest patches with dense canopy cover only marginally diminish elk vulnerability when an unrestricted use of roads is maintained (Lyon 1979). It does not seem feasible to assign threshold values to act as maximum road density or minimum patch size guidelines. However, our data suggests the minimum patch size required by elk may be >100ha previously recommended by Hillis et al. (1991). Because of numerous interacting
variables, land managers must assess each landscape individually, considering hunter density and
hunter use patterns in conjunction with road and forest variables.

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Table 1. Use of various vegetation classes by live elk during the hunting season, and vegetation class availability.

<table>
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<th>Vegetation class</th>
<th>Significance</th>
<th>% live elk use</th>
<th>% Availability</th>
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<tr>
<td>Cropland/pasture</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Foothills/parklands</td>
<td>1.6</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Disturbed grasslands</td>
<td>0.5</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Other herbaceous</td>
<td>0.5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Sagebrush</td>
<td>1.1</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>Mixed grass/shrub</td>
<td>0.5</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>+</td>
<td>51.9</td>
<td>17.9</td>
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<tr>
<td>Ponderosa pine</td>
<td>7.0</td>
<td>5.3</td>
<td></td>
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<tr>
<td>Douglas-fir</td>
<td>20.0</td>
<td>20.0</td>
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<tr>
<td>Mixed coniferous</td>
<td>-</td>
<td>9.7</td>
<td>20.2</td>
</tr>
<tr>
<td>Open Douglas-fir</td>
<td>4.3</td>
<td>9.9</td>
<td></td>
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<tr>
<td>Regenerating clearcut</td>
<td>1.6</td>
<td>2.1</td>
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Chi-square 83.8
Critical Chi-value (0.05) 19.7
d.f. 11
Table 2. Results of discriminant function analysis (DFA) and chance-correction classification (Kappa statistic)

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<thead>
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<th>Database type</th>
<th>% Correctly classified</th>
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<th>Kappa</th>
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<tbody>
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<td></td>
<td>Elk kill locations</td>
<td>Live elk locations</td>
<td>Random locations</td>
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<td>Far analysis</td>
<td>38</td>
<td>63</td>
<td>46</td>
<td>0.26</td>
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Figure 1. Distance of elk kill, live elk, and random locations to the nearest open road.