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Refinement of the Arc-Habcap Model to Predict Habitat Effectiveness for Elk

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Abstract

Wildlife habitat modeling is increasingly important for managers who need to assess the effects of land management activities. We evaluated the performance of a spatially explicit deterministic habitat model (Arc-Habcap) that predicts habitat effectiveness for elk. We used five years of radio-telemetry locations of elk from Custer State Park (CSP), South Dakota, to test predicted habitat effectiveness by the model. Arc-Habcap forage and cover-forage proximity components predicted elk distribution in CSP. However, the cover component failed to predict elk distribution in CSP. Habitat effectiveness calculated as the geometric mean of the model components failed to predict elk distribution and resulted in under-utilization of habitats predicted to be good and over-utilization of habitats predicted to be poor. We developed a new formula to calculate habitat effectiveness as an arithmetic average of the model components that weighted forage more than cover or cover-forage proximity. The new formula predicted actual elk distribution across categories of habitat effectiveness. Elk selected cover and forage areas ≤100 m from cover-forage edges. Arc-Habcap predicted that areas adjacent to roads were not usable by elk. Elk used areas adjacent to primary roads, but use was less than the proportional area comprised for primary roads, and about equal to proportional area adjacent to secondary roads and primitive roads. All sapling/pole and mature structural stages of ponderosa pine (Pinus ponderosa) were considered as both forage and cover by Arc-Habcap and consequently considered optimal in the cover-forage model component. We suggested revisions for both the cover-forage proximity component and areas adjacent to roads.

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Introduction

Assessing the effects of land management activities, such as timber harvest on federal lands, is required by the National Environmental Policy Act (1969). It requires an assessment of changes in habitat conditions for certain species, which can be complex and expensive. Consequently, wildlife habitat models are often preferred. Several wildlife-habitat relationships models have been developed for forest managers to predict future distribution and abundance of a species given information on existing or future habitat conditions (Black and Scherzinger 1976; Schamberger et al. 1986; Lyon 1983; Wisdom et al. 1986; Morrison et al. 1992; Roloff 1998; Rowland et al. 2000; Roloff et al. 2001). Some of these models are currently used in a wide range of applications. A comprehensive review of these habitat models and their concepts is provided in Holthausen et al. (1994).

A species of high interest in the Black Hills is Rocky Mountain elk (*Cervus elaphus nelsoni*). Because of the size, adaptability, and mobility of elk, there is substantial potential for conflicts between elk and other multiple-uses of public lands. Public interest in elk is high for recreational hunting, which can result in important contributions to local economies. To fulfill the requirements for assessing the impacts of silvicultural managements on elk and other wildlife species, the Black Hills National Forest (BHNF) developed a spreadsheet-based habitat capability (Habcap) model. This model was structured following concepts outlined by Hoover and Wills (1984) for managing forested lands for wildlife and by Wisdom et al. (1986) for predicting habitat effectiveness for elk. Habcap was then converted to a spatially explicit GIS-based model (Arc-Habcap) by Utah State University (unpublished). Since wildlife habitat models are simplifications of complex reality (Starfield 1997), their predictions should be validated using research studies designed to test and improve their reliability before making long-term commitments of resources (Laymon and Barret 1984; Shamberger and O'Neil 1986; O'Neil et al. 1988). Our objectives were to: (1) test the ability of Arc-Habcap to predict and display habitat effectiveness for elk, (2) identify bias or shortcomings in model outputs, and (3) make recommendations to improve predictions of habitat effectiveness for elk. Habitat effectiveness in this study does not equate to population densities that may be manipulated by hunting regulations; it is elk use of vegetation communities relative to the optimum local conditions (Wisdom et al. 1986) that provide food and cover for elk.

Arc-Habcap Model

Arc-Habcap is a deterministic GIS-based wildlife habitat model developed for USDA Forest Service, Rocky Mountain Region. The foundation for Arc-Habcap came from habitat capability models adapted to the Rocky Mountains (Hoover and Wills 1984) and the elk habitat effectiveness model developed by Wisdom et al. (1986) for western Oregon. Arc-Habcap assigns habitat condition quality indices (Wisdom et al. 1986) from 0 to 1.0 (0 = low condition and 1 = optimum condition) to land management units (stands) for forage and cover. Vegetation and roads GIS coverages are the input for Arc-Habcap. The model then predicts effectiveness of forage (FV), cover (CV), and cover-forage proximity (HDV), as well as effects of roads, on elk distributions. Calculations for predicting the effectiveness of forage-cover proximity are as follows. Each stand is classified as cover if CV ≥ 0.5; forage if FV ≥ 0.2; and both cover and forage if CV ≥ 0.5 and FV ≥ 0.2. The model then creates buffer regions based on proximity to cover-forage edges. Areas of forage or cover occurring within 90 m from a cover-forage edge are assigned 1.0 for HDV. Forage areas 90 - 274 m from cover-forage edges are assigned HDV = 0.54. Cover areas 90 - 274 m from cover-forage edges are assigned HDV = 0.14. Forage or cover beyond 274 m from cover-forage edges are considered unusable by elk and are assigned HDV = 0. Stands classified as both forage and cover are assigned HDV = 1.0.

Arc-Habcap model outputs include GIS coverage of the effectiveness of vegetative conditions for each component, FV, CV, and HDV. The effects of roads on the effectiveness of these vegetative conditions are also displayed in the GIS outputs (see below). The model outputs also include relational attribute tables displaying effectiveness values for FV, CV, and HDV. Habitat effectiveness (HE) for elk is calculated as a geometric mean of the three model components $(FV \times CV \times HDV)^{1/3}$ (U.S. Fish and Wildlife Service 1981; Wisdom et al. 1986) and is also displayed in the GIS output coverage. Areas adjacent to roads are modeled as unsuitable for elk and are removed from the land base. The size of area considered ineffective habitat due to roads depends on road classes. Road classes are determined from estimates of vehicle traffic (primary roads have 30-35 vehicles/week; secondary roads have 10-35 vehicles/week; and primitive roads have < 7 vehicles/week). Effects of roads in Arc-Habcap extend 180 m from primary roads, 60 m from secondary roads, and 30 m from primitive roads.

This habitat model assumes that: (1) habitat effectiveness for elk can be evaluated based on the amount, quality, and distribution of forage and cover; (2) cover and forage are optimally distributed when they are close to a cover-forage edge; and (3) roads have a negative effect on elk rendering a portion of the habitat unsuitable. The effects of land management on elk are evaluated by altering vegetation conditions of stands to reflect future conditions after management and comparing to model outputs.

Study Area

The area included in this evaluation of Arc-Habcap was Custer State Park (CSP), South Dakota. CSP is in the southeastern portion of the Black Hills. It includes 29,150 ha under the management jurisdiction of the Division of Custer State Park of South Dakota Department of Game, Fish, and Parks. CSP is bordered by private lands on the east, Black Hills National Forest on the west, Wind Cave National Park on the south, and Peter Norbeck Wildlife Preserve on the north. Elevations range from 1,137 to 2,083 m. Average annual precipitation is approximately 47 cm. Average monthly temperatures, during the coldest and warmest months (February and August), are - 4° C and 24° C respectively (NOAA 1994).

Coniferous forests in CSP are mostly ponderosa pine (*Pinus ponderosa* Laws.). White spruce (*Picea glauca* Moench) occurs on some north-facing slopes. Deciduous woodlands in the park usually occur in drainages and include quaking aspen (*Populus tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), bur oak (*Quercus macrocarpa* Michx.), and green ash (*Fraxinus pennsylvanica* Marsh.). Common shrubs include common juniper (*Juniperus communis* L.), mountain mahogany (*Cercocarpus montanus* Raf.), and western snowberry (*Symphoricarpos occidentalis*). Grasslands are dominated by western wheatgrass (*Agropyron smithii* Rydb.), blue grama (*Bouteloua gracilis* H.B.K.), buffalo grass (*Buchloë dactyloides* Nutt.), sideoats grama (*Bouteloua curtipendula* Michx.), little bluestem (*Schizachyrium scoparius* Michx.), big bluestem (*Andropogon gerardi* Vitman), and Kentucky bluegrass (*Poa pratensis*). A large wildfire burned approximately 6,500 ha of CSP during the summer of 1988. Elk population in the park ranged from 750 to 1,000 and the population is regulated through permitted elk hunting (Millspaugh 1999). The park receives 1.7 million visitors/year, mostly during the summer. There are about 78 km of primary roads, 93 km of secondary roads, and 140 km of primitive roads in CSP.

Methods

To test the model, we used 12,067 locations of 21 female and 15 male elk obtained by Millspaugh (1999) using standard VHF radio-telemetry techniques from 1993 to 1997. Information on animal trapping and radio transmitters is in Millspaugh et al. (1994). We created geographic coverages for the vegetation, roads, and radio-telemetry elk locations using ArcInfo 7.2.1 (ESRI Inc. 1998). We reclassified a vegetation GIS coverage of CSP according to Buttery and Gillam (1984). The vegetation classification was based on vegetation types, structural stages (based on diameter-at-breast hight, DBH), and overstory canopy cover categories. Vegetation types were represented based on the dominant plant species of a stand. Structural stages for forest vegetation include grass-forb, shrub-seedling, sapling-pole (2.5 – 22.9 cm DBH), and mature (>22.9 cm DBH). There is an old growth structural stage, but it was not included in our study. Sapling-pole and mature stages include categories of overstory canopy cover: 0-40%, 41-70%, and >70%. Table 1 shows the area in CSP for vegetation types and structural stages. Since Arc-Habcap does not include a category for fire-killed forest, we included these areas with the grass-forb structural stage of ponderosa pine. Tables 2 – 5 include summer and winter coefficients for vegetation structural stages that occurred in CSP. Vegetation and road coverages were used as input for

Table 1—Area (ha) of vegetation types and structural stages used in the validation of Arc-Habcap predictions of elk use of habitats in Custer State Park, South Dakota.

			Structural stages					
			Sapling pole (2.54 - 22.9 cm dbh)			Mature (>22.9 cm dbh)		
Vegetation types	**Grass/ forb**	**Seedling/ shrub**	**0-40%**	**41-70%**	**>70%**	**0-40%**	**41-70%**	**>70%**
Aspen				26				
Bur oak				53				
Grasslands	5,035							
Other hardwoods				143				
Rocky Mtn. juniper		19						
Ponderosa pine	3,988	189	765	1,275	386	2,321	2,605	2,719
White spruce							101	
Mountain mahogany		29						
Other shrublands		161						
Total	9,023	398	765	1,497	386	2,321	2,706	2,719

Arc-Habcap to obtain and display habitat effectiveness FV and CV, to calculate HDV for each stand, and to calculate HE. Then, we reclassified habitat effectiveness of stands as "good" if values were > 0.7; "fair" if the values were between 0.3 and 0.7; and "poor" if the values were < 0.3. Categories of HE were defined from frequency plots of HE values output by Arc-Habcap. There were three distinct groups (categories) of values (<0.3, 0.3-0.7, and >0.7) in these plots.

GIS coverages of winter and summer elk locations were overlaid separately on the coverage of predicted effectiveness resulting from Arc-Habcap for FV, CV, HDV, and HE. Although Arc-Habcap removed the spatial components of areas adjacent to roads from the GIS coverages, we created a GIS-coverage for those areas and for corresponding elk locations. We also created 100-m band intervals from cover-forage edges using ArcView 3.2 (ESRI Inc. 1999). Predicted use for each habitat category was calculated using the proportion of area in each habitat category multiplied times elk locations during summer or winter (Aebischer and Robertson 1993).

Table 2—Coefficients used as input in Arc-Habcap during summer for forage areas.

			Structural stages					
			Sapling pole (2.54 - 22.9 cm dbh)			Mature (>22.9 cm dbh)		
Vegetation types	Grass/ forb	Seedling/ shrub	0-40%	41-70%	>70%	0-40%	41-70%	>70%
Aspen	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5
Bur oak	1.0	1.0	1.0	0.5	0.2	1.0	0.5	0.2
Other hardwoods	1.0	1.0	1.0	0.5	0.2	1.0	0.5	0.2
Grasslands	1.0	NA	NA	NA	NA	NA	NA	NA
Rocky Mtn. juniper	0.5	0.5	0.5	0.2	0.2	0.5	0.2	0.2
Ponderosa pine	1.0	1.0	1.0	0.5	0.2	0.5	0.5	0.2
White spruce	1.0	1.0	1.0	0.5	0.2	0.5	0.2	0.2
Mountain mahogany	0.5	0.0	NA	NA	NA	NA	NA	NA
Other shrubs	0.5	0.0	NA	NA	NA	NA	NA	NA

Table 3—Coefficients used as input in Arc-Habcap during summer for cover areas.

			Structural stages					
			Sapling pole (2.54 - 22.9 cm dbh)			Mature (>22.9 cm dbh)		
Vegetation types	Grass/ forb	Seedling/ shrub	0-40%	41-70%	>70%	0-40%	41-70%	>70%
Aspen	0.0	0.5	0.5	1.0	1.0	1.0	1.0	1.0
Bur oak	0.0	0.5	0.5	0.5	1.0	0.5	0.5	1.0
Other hardwoods	0.0	0.5	0.5	0.5	1.0	0.5	0.5	1.0
Grasslands	0.0	NA	NA	NA	NA	NA	NA	NA
Rocky Mtn. juniper	0.0	0.5	0.5	0.5	1.0	0.5	0.5	1.0
Ponderosa pine	0.0	0.0	0.5	0.5	1.0	0.5	0.5	1.0
White spruce	0.0	0.0	0.5	1.0	1.0	0.5	1.0	1.0
Mountain mahogany	0.0	0.0	NA	NA	NA	NA	NA	NA
Other shrubs	0.0	0.0	NA	NA	NA	NA	NA	NA

Table 4—Coefficients used as input in Arc-Habcap during winter for forage areas.

			Structural stages					
			Sapling pole (2.54 - 22.9 cm dbh)			Mature (>22.9 cm dbh)		
Vegetation types	Grass/ forb	Seedling/ shrub	0-40%	41-70%	>70%	0-40%	41-70%	>70%
Aspen	1.0	1.0	0.5	0.2	1.0	0.5	0.5	0.2
Bur oak	1.0	1.0	1.0	0.5	0.2	1.0	0.5	0.2
Other hardwoods	1.0	1.0	1.0	0.5	0.2	1.0	0.5	0.2
Grasslands	1.0	NA	NA	NA	NA	NA	NA	NA
Rocky Mtn. juniper	0.0	0.0	0.5	0.5	1.0	0.5	0.5	1.0
Ponderosa pine	1.0	1.0	1.0	0.5	0.2	1.0	0.5	0.2
White spruce	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mountain mahogany	0.5	0.0	NA	NA	NA	NA	NA	NA
Other shrubs	0.5	0.0	NA	NA	NA	NA	NA	NA

Table 5—Coefficients used as input in Arc-Habcap during winter for cover areas.

Vegetation types	Grass/ forb	Seedling/ shrub	Structural stages: Sapling pole (2.54 - 22.9 cm dbh) 0-40%	41-70%	>70%	Mature (>22.9 cm dbh) 0-40%	41-70%	>70%
Aspen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bur oak	0.0	0.2	0.2	0.5	0.5	0.2	0.5	0.5
Other hardwoods	0.0	0.2	0.2	0.5	0.5	0.2	0.5	0.5
Grasslands	0.0	NA	NA	NA	NA	NA	NA	NA
Rocky Mtn. juniper	0.0	0.5	0.5	0.5	1.0	0.5	0.5	1.0
Ponderosa pine	0.0	0.0	0.2	0.5	1.0	0.2	0.5	1.0
White spruce	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mountain mahogany	0.0	0.0	NA	NA	NA	NA	NA	NA
Other shrubs	0.0	0.0	NA	NA	NA	NA	NA	NA

We used the Design 1 resource analysis selection (Manly et al. 1993) to test hypotheses that Arc-Habcap predicted observed elk distribution relative to habitat effectiveness categories for FV, CV, HDV, HE, and distance intervals from cover-forage edges. We tested for differences between predicted and observed use by elk of individual habitat effectiveness categories using Bonferroni's correction to the probability of a 1 df χ^2 test that the estimated selection ratio w = 1.0 (H_0: w = 1.0, Manly et al. 1993).

Results

Ponderosa pine was the most common vegetation type in CSP. Grassland and the grass-forb structural stage of ponderosa pine resulted in classifying most of CSP as a herbaceous vegetation structural stage. There were 5,775 elk locations in CSP during summer (June-November) and 5,413 elk locations in CSP during the winter (December-May). Elk that occurred in areas adjacent to roads considered as ineffective elk habitat were not included in the analyses for FV, CV, HDV, and HE. The resulting sample sizes of elk locations for testing Arc-Habcap during summer and winter were 4,545 and 4,107, respectively.

Forage effectiveness

During summer, Arc-Habcap predicted that about 50% of CSP had good effectiveness for forage; 38% was classified as fair and 18% was classified as poor. Summer elk dispersion patterns differed from patterns predicted by the forage component in Arc-Habcap (χ^2 = 20.65, P < 0.01) (figure 1,

Table 6—Elk use (no. of locations) compared with expected use in areas classified by Arc-Habcap as good, fair, and poor habitats for elk in Custer State Park, South Dakota.

Predicted effectiveness	Area (ha)	Observed elk use	Expected elk use	Selection ratio	Bonferroni adjusted p-value (H_0: w = 1.0)
Summer					
Forage effectiveness (χ^2 = 20.91, P < 0.001)					
Good	10,020	2,280	2,268	1.005	1.000
Fair	6,397	1,543	1,448	1.067	0.006
Poor	3,663	722	829	0.871	0.001
Cover effectiveness (χ^2 = 5.25, P = 0.113)					
Good	3,232	676	731	0.924	0.075
Fair	7,162	1,655	1,621	1.021	0.881
Poor	9,686	2,214	2,192	1.010	1.000
Winter					
Forage effectiveness (χ^2 = 285.14, P < 0.001)					
Good	11,520	2,811	2,356	1.193	0.001
Fair	4,034	764	825	0.926	0.052
Poor	4,525	532	925	0.575	0.001
Cover effectiveness (χ^2 = 66.42, P < 0.001)					
Good	3,096	474	633	0.748	0.001
Fair	4,035	764	825	0.926	0.052
Poor	12,949	2,869	2,648	1.083	0.001

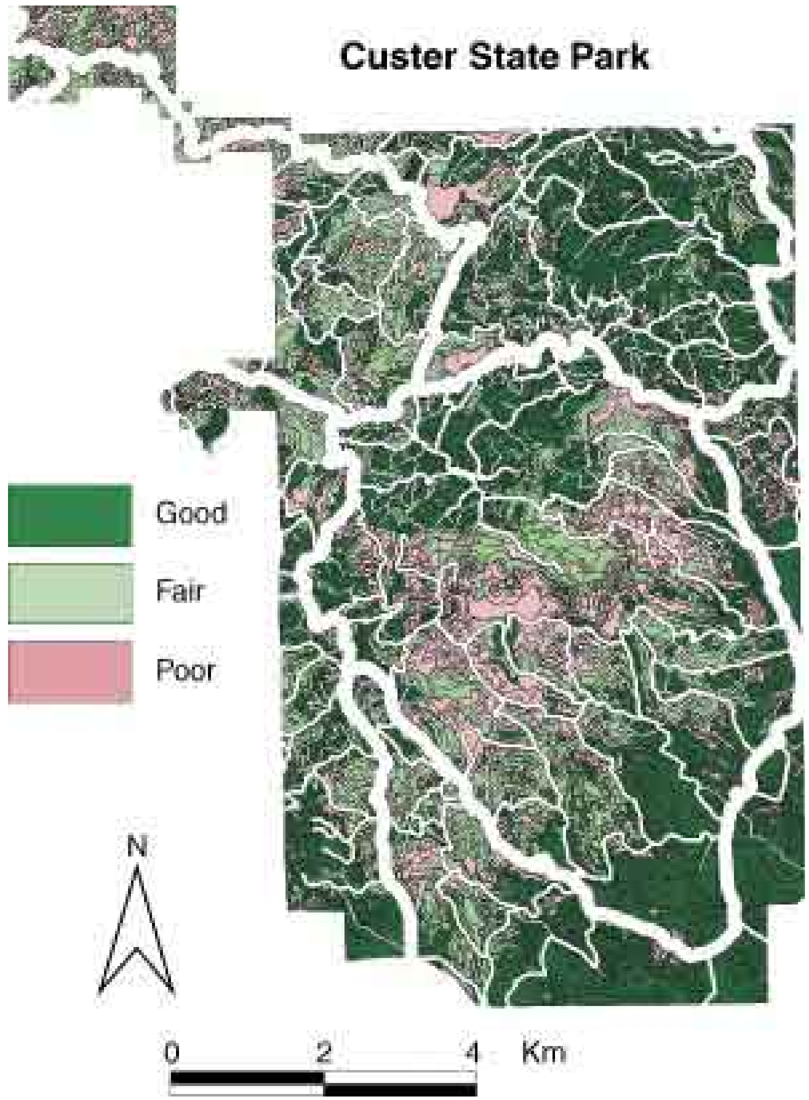


Figure 1—Arc-Habcap model predictions of summer forage effectiveness (FV) for elk in Custer State Park, South Dakota.

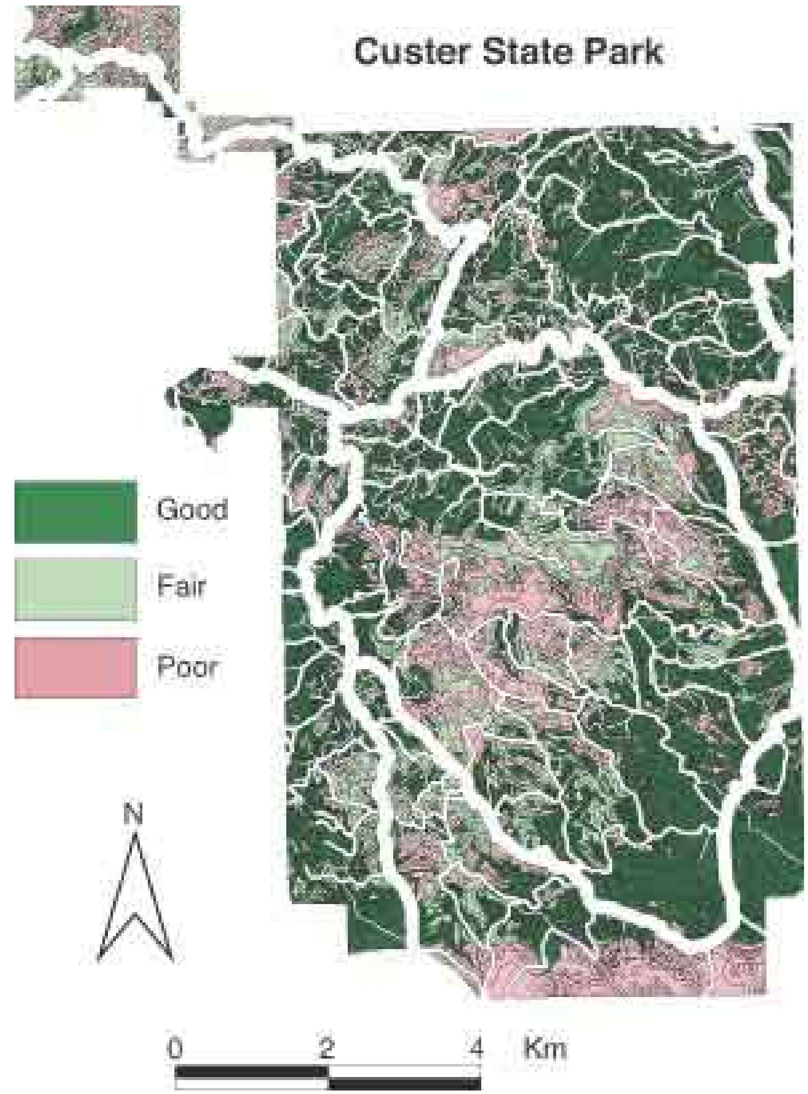


Figure 2—Arc-Habcap model predictions of winter forage effectiveness (FV) for elk in Custer State Park, South Dakota.

table 6). Selection ratios indicated elk used forage areas classified good as expected ($w = 1.01$, $P = 1.0$), areas classified fair more than expected ($w = 1.07$, $P < 0.01$), and areas classified poor less than expected ($w = 0.87$, $P < 0.01$). These selection ratios were all significantly different from each other ($P < 0.01$).

During winter, the area of CSP predicted to be good effectiveness for forage increased slightly relative to summer. Fifty-seven percent of CSP was good forage effectiveness for elk, while 20% and 23% were fair or poor, respectively (figure 2, table 6). Dispersion patterns of elk among areas of winter forage categories differed ($\chi^2 = 285.14$, $P < 0.01$). Elk used areas predicted to be good forage effectiveness more than expected ($w = 1.19$, $P < 0.05$), used areas predicted to be fair forage effectiveness less than expected ($w = 0.93$, $P > 0.05$), and avoided areas predicted to be poor forage effectiveness ($w = 0.58$, $P < 0.05$). These selection ratios also differed from each other ($P < 0.01$).

Cover effectiveness

During summer, the model predicted 48% of CSP had poor cover effectiveness, 36% as fair cover, and only 16% as good cover effectiveness. Dispersion of elk during summer relative to cover was similar to that predicted by Arc-Habcap ($\chi^2 = 5.25$, $P = 0.073$) (figure 3, table 6). Elk may have selected areas of good cover effectiveness less than expected ($w = 0.92$, $P = 0.08$), but elk use of areas of fair or poor cover effectiveness did not differ from 1.0 ($w = 1.02$, $P = 0.9$; $w = 1.01$, $P = 1.0$). Selection ratios for fair and poor cover were similar ($P = 1.0$) but differed from the selection ratio for good cover ($P < 0.01$).

During winter, most of CSP was predicted as poor cover effectiveness for elk by Arc-Habcap. About 15% of CSP was predicted good cover effectiveness during winter, 20% fair, and 64% poor cover effectiveness for elk (figure 4, table 6). Dispersion patterns of elk among cover effectiveness categories during winter differed from those predicted by Arc-Habcap ($\chi^2 = 66.42$, $P < 0.01$). Elk avoided areas predicted to be good cover ($w = 0.75$, $P < 0.01$) and areas predicted to be fair also were used less than expected ($w = 0.93$, $P = 0.05$), but areas predicted to be poor cover were selected more than expected ($w = 1.08$, $P < 0.01$). Selection ratios for these cover effectiveness categories all differed from each other ($P < 0.01$).

Cover-forage proximity effectiveness

During summer, elk dispersion among cover-forage proximity categories differed from that predicted by Arc-Habcap ($\chi^2 = 281.67$, $P < 0.01$). Forage and cover areas in CSP were well interspersed (figure 5). More than 70% of the park was classified as good effectiveness for cover-forage proximity (table 7). All sapling-pole and mature stages of ponderosa pine meet the criteria for being cover and forage (e.g., CV ≥ 0.5 and FV ≥ 0.2). Consequently, HDV for these stands was predicted to be 1.0. Elk used areas predicted as good and fair effectiveness for cover-forage proximity more than expected ($w = 1.07$, $P < 0.01$; and $w = 1.20$, $P < 0.01$). However, elk selected against areas predicted as poor effectivenessofcover-forageproximity($w = 0.46$,$P < 0.05$)during summer (table 6). These selection ratios differed from each other($P < 0.01$).

During winter, elk dispersion among cover-forage proximity categories differed significantly from that predicted by Arc-Habcap ($\chi^2 = 162.82$, $P < 0.01$). Arc-Habcap predicted that 56% of the park consisted of good effectiveness for cover-forage proximity, 20% was fair, and 24% was poor (figure 6, table 7). Areas predicted to be good or fair effectiveness of forage-cover proximity were selected more than expected ($w = 1.04$ and 1.27, respectively, $P < 0.05$), while areas predicted to be poor effectiveness for cover-forage proximity were selected less than expected ($w = 0.69$, $P < 0.01$). All winter selection ratios for cover-forage proximity differed from each other ($P < 0.01$).

During summer (figure 7), forage areas within 400 m from cover are likely to be selected as expected ($w = 0.9$-1.1, $P > 0.05$). Selection ratios associated with forage areas >400 m from cover suggested a non-significant avoidance ($w < 0.73$, $P > 0.05$). The significant difference between observed and expected use by elk of areas beyond 400 m from cover appeared to be precluded by the small sample size. Elk use of forage areas relative to cover-forage proximity was not random for the first 200 m ($P < 0.05$), but it became random beyond 200 m ($P > 0.05$). During summer, elk selected for cover within the first 100 m from forage more than expected ($w = 1.21$, $P < 0.01$). Elk generally used cover areas 200-400 m from forage equal to availability ($w = 0.9 - 1.1$, $P > 0.14$), and used cover >400 m from forage less than expected ($w < 0.70$, $P < 0.08$).

During winter elk generally stayed close to cover and forage edges (figure 8). Elk selected forage areas ≤ 100 m from cover more than expected (w = 1.1, P < 0.01). There appeared to be an overall avoidance of forage areas ≥ 200 m from cover, but not all were significant (w = 0.9 - 1.0, P = 0.03 – 1.0). Elk selected cover areas ≤ 100 m from forage more than expected (w = 1.38, P < 0.01). Beyond 100 m from forage, elk used cover areas less than expected, but not all selection ratios were significantly different (w ≤ 0.9, P = <0.01 – 0.3).

Habitat effectiveness

During summer, Arc-Habcap predicted that habitat effectiveness (HE) for elk was fair or poor for most of CSP. Only 4% of CSP was classified as good HE for elk (figure 9a and 9b, table 7). Elk dispersion patterns differed from predicted HE by the model ($\chi^2 = 24.45$, $P < 0.01$). Elk selected areas classified as good HE less than expected ($w = 0.66$, $P < 0.01$), but selected areas predicted as fair and poor HE as expected ($w = 1.0$, $P > 0.7$). Selection ratios for fair and poor HE were similar ($P > 0.05$), but both differed from that of good HE ($P < 0.05$). During winter, Arc-Habcap classified 20% of the park as good HE for elk, 27% as fair, and 53% as poor (figure 10a and 10b, table 7). Elk dispersion patterns among categories of HE differed from predicted use ($\chi^2 = 113.49$, $P < 0.01$). Elk used areas predicted to be good and fair HE less than expected ($w = 0.77 - 0.93$, $P = 0.05$), but used areas of poor HE more than expected ($w = 1.15$, $P < 0.01$). Winter selection ratios for HE all differed from each other ($P < 0.05$).

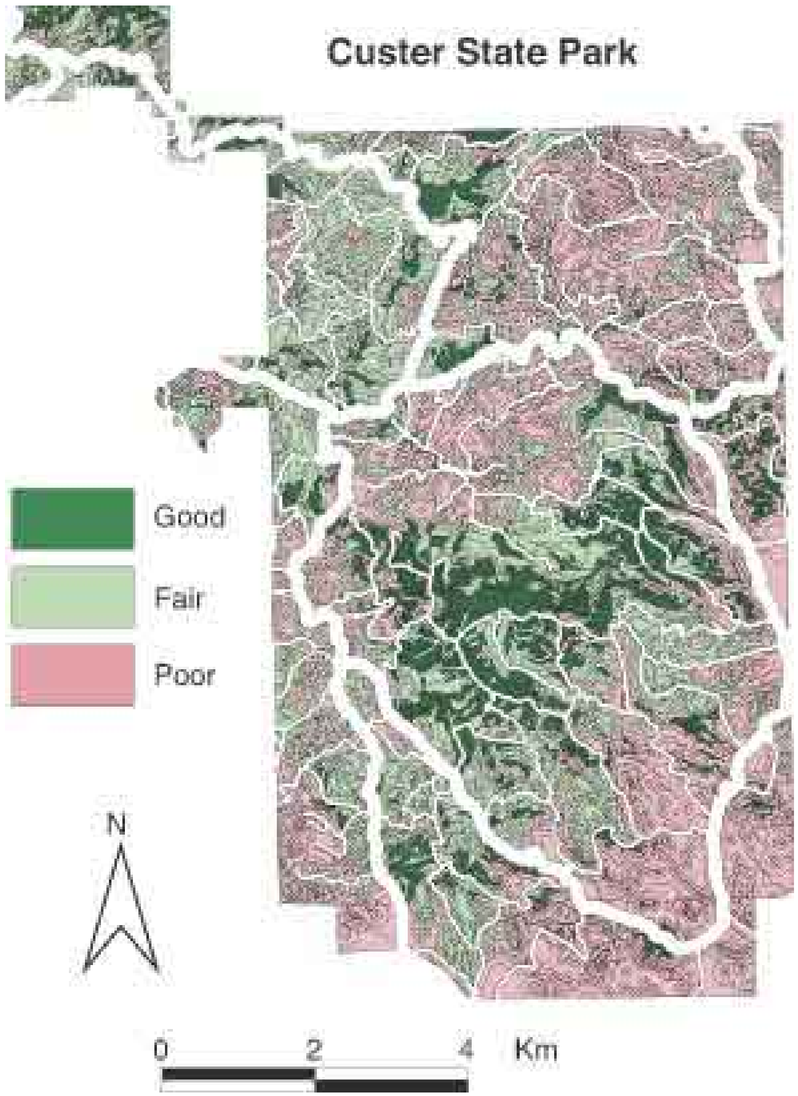


Figure 3—Arc-Habcap model predictions of summer cover effectiveness (CV) for elk in Custer State Park, South Dakota.

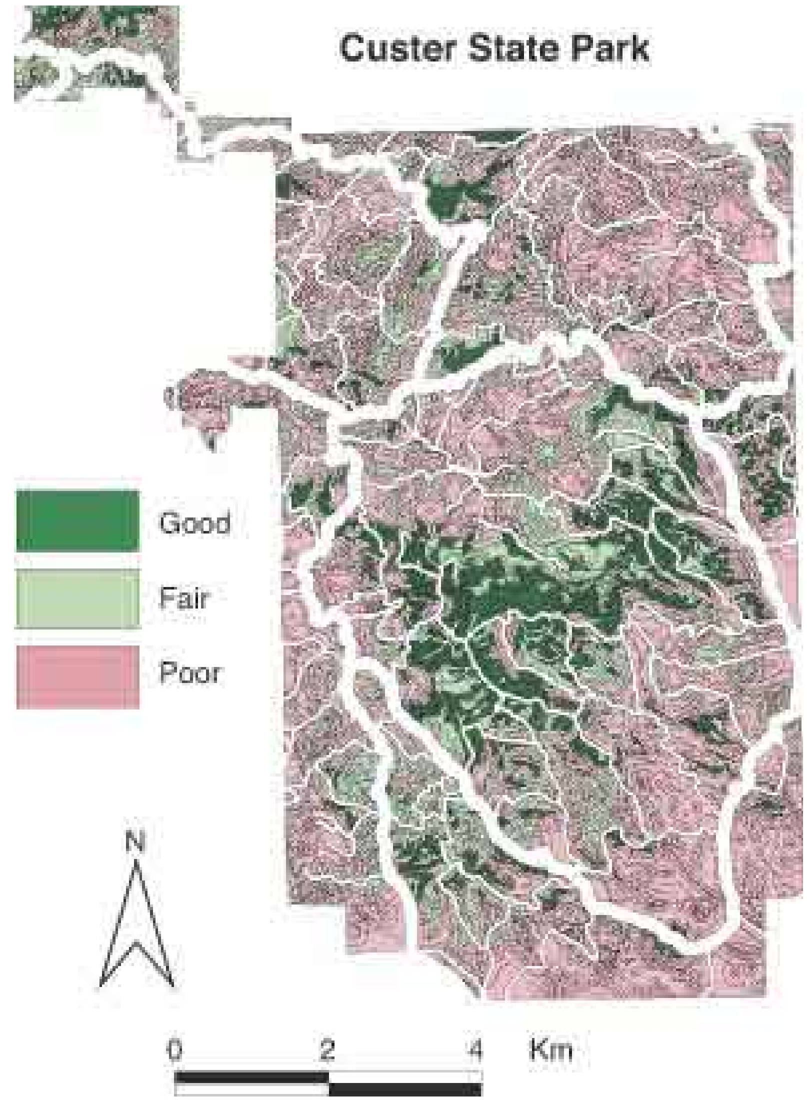


Figure 4—Arc-Habcap model predictions of winter cover effectiveness (CV) for elk in Custer State Park, South Dakota.

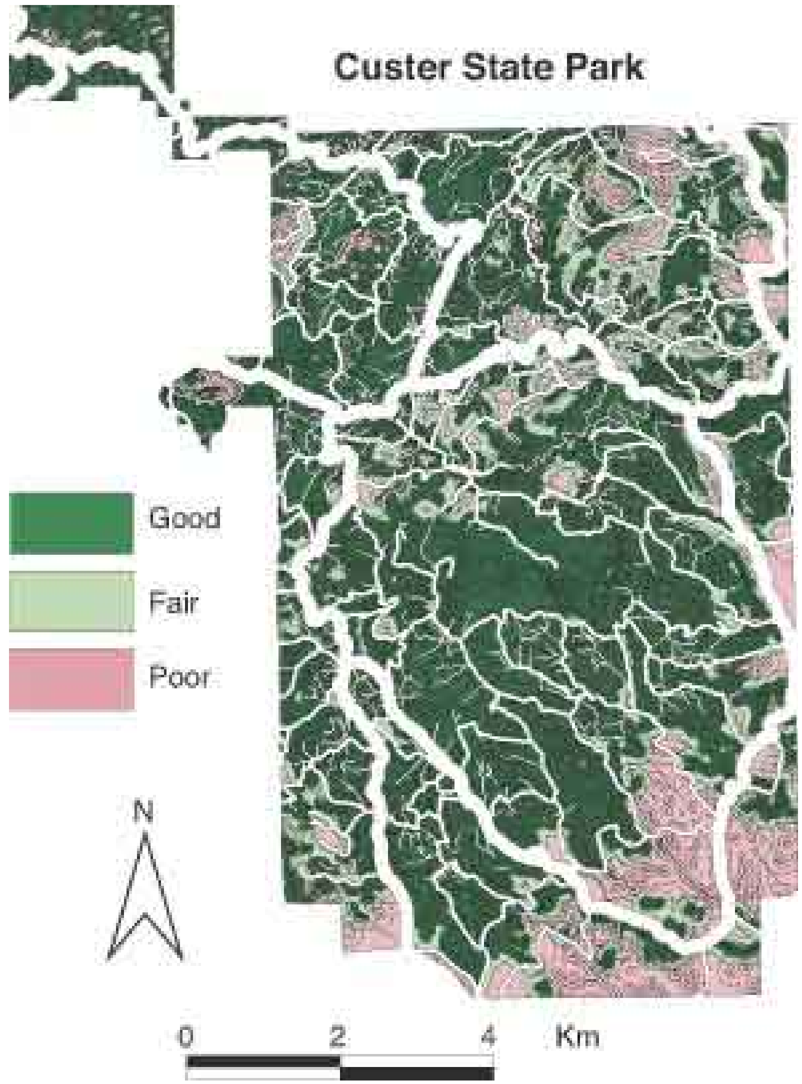


Figure 5—Arc-Habcap model predictions of cover-forage distribution effectiveness (HDV) for elk during summer in Custer State Park, South Dakota.

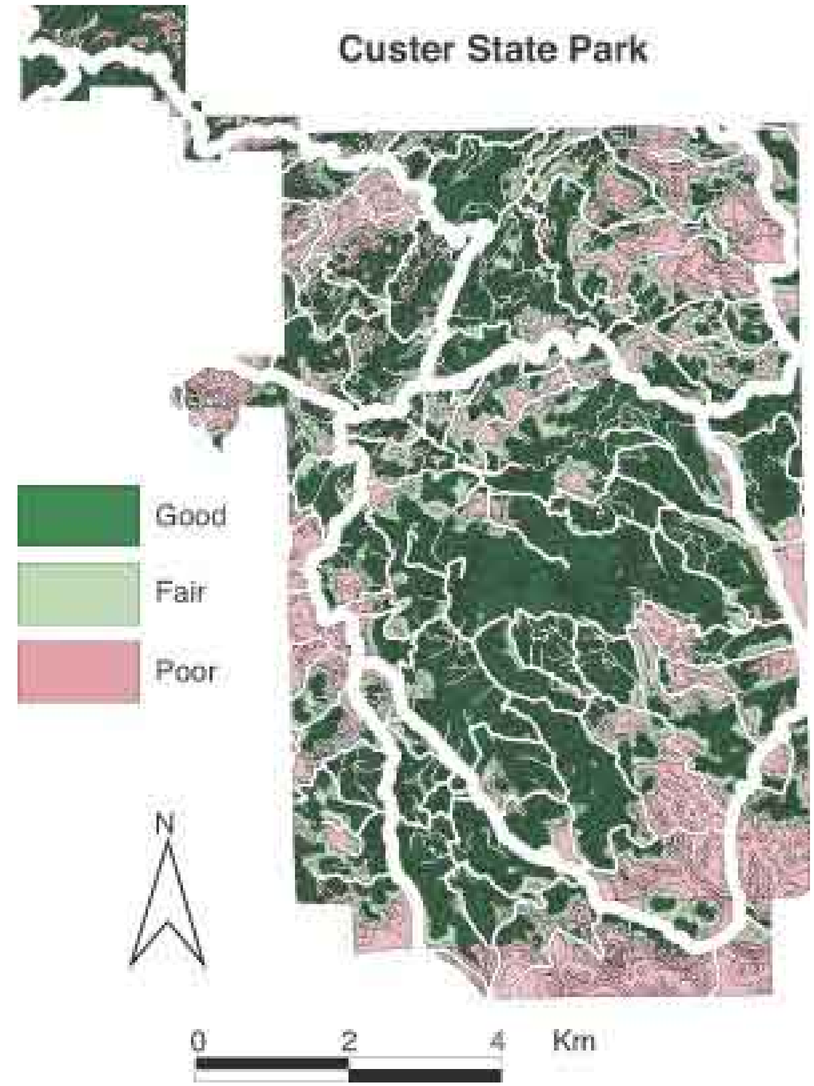


Figure 6—Arc-Habcap model predictions of cover-forage distribution effectiveness (HDV) for elk during winter in Custer State Park, South Dakota.

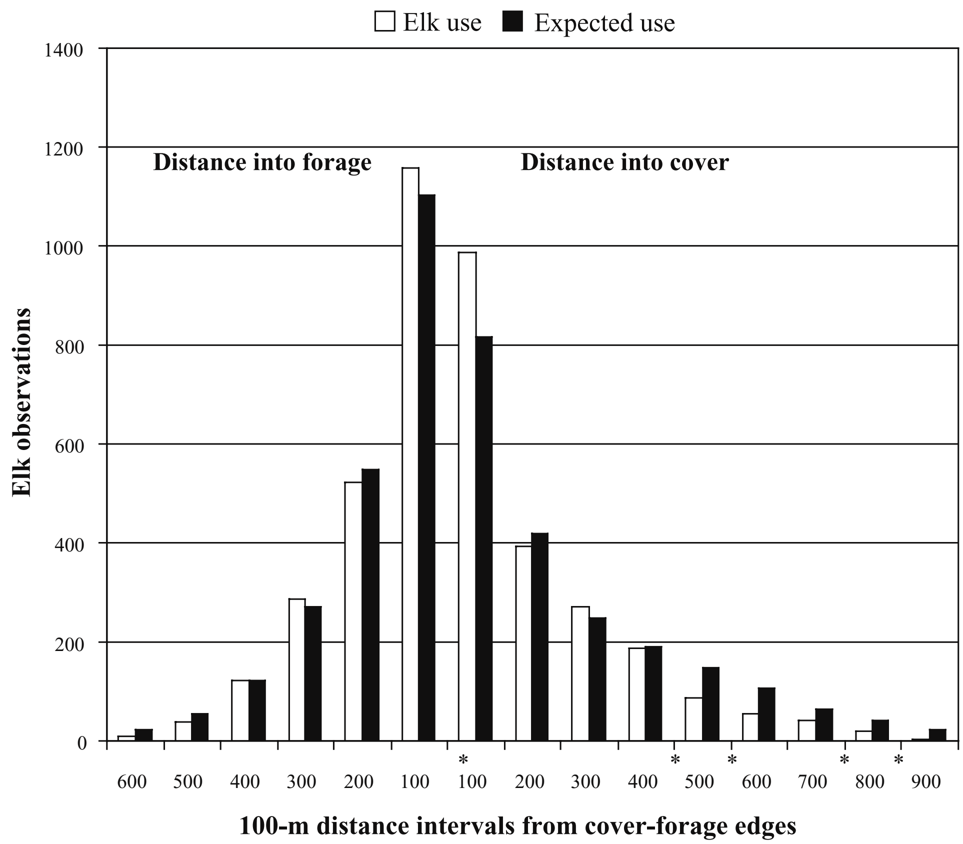


Figure 7—Elk use of areas within 100-m intervals from cover-forage edges during the summer as compared to expected use in Custer State Park, South Dakota. Bars in each pair with an asterisk are significantly different (*P* < 0.05).

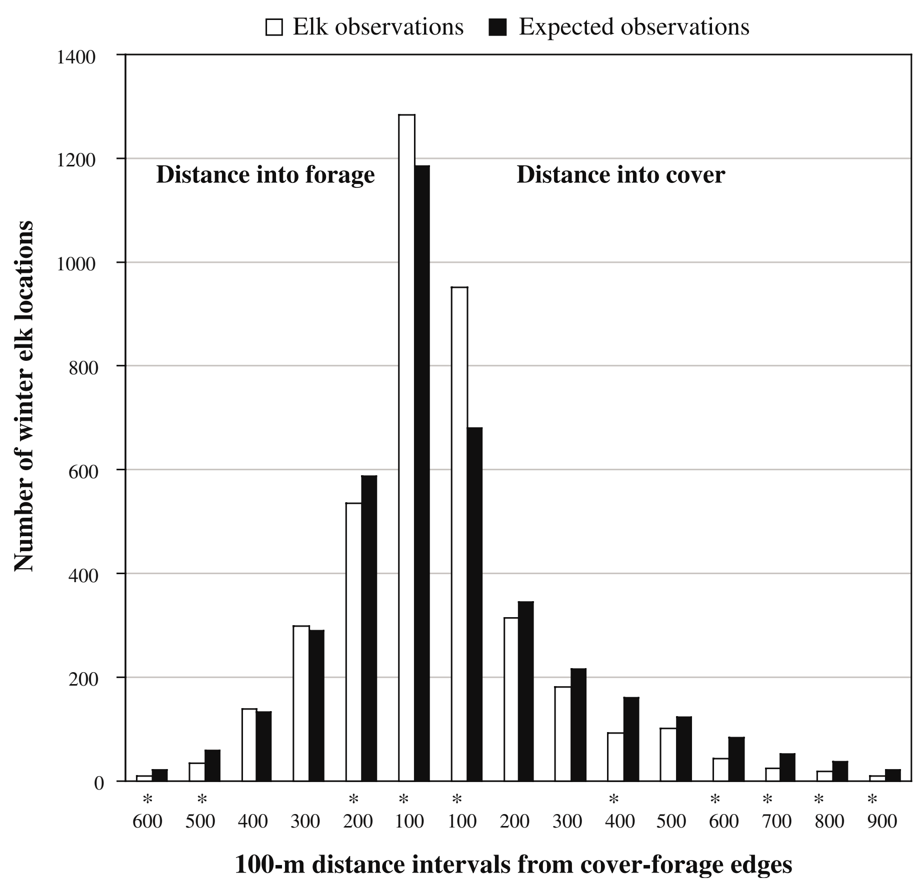


Figure 8—Elk use of areas within 100-m intervals from cover-forage edges during the winter as compared to expected use in Custer State Park, South Dakota. Bars in each pair with an asterisk are significantly different (*P* < 0.05).

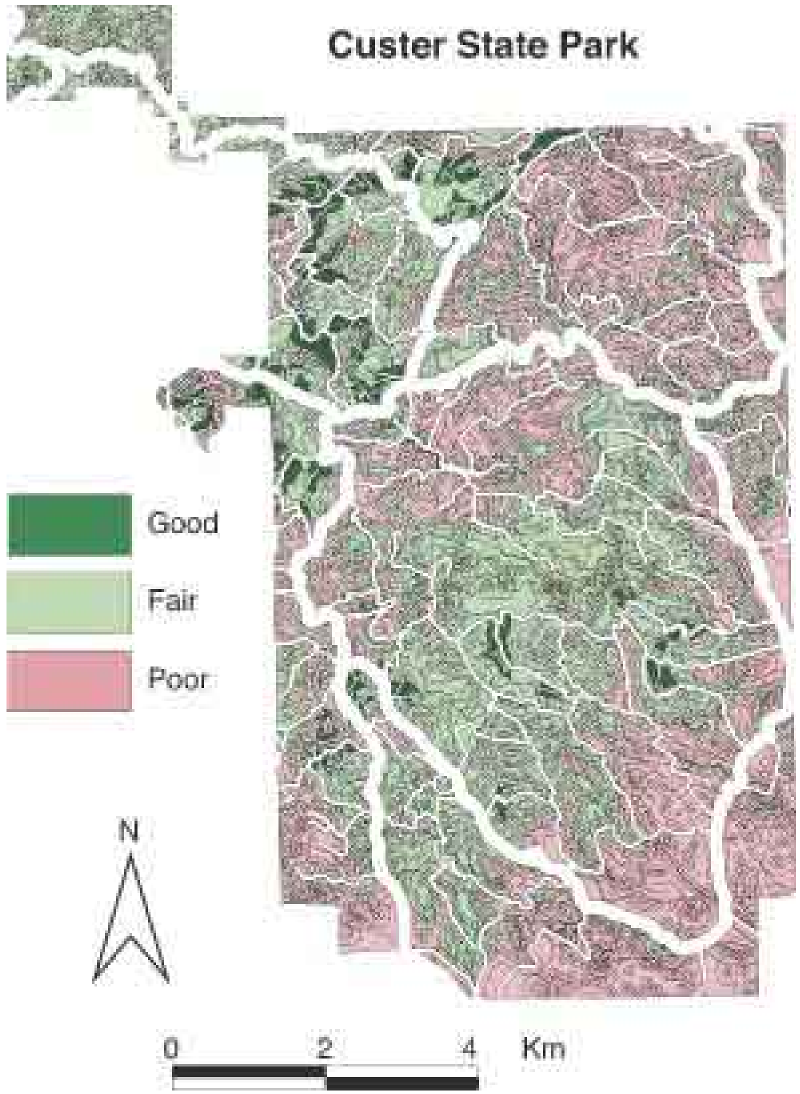


Figure 9a—Arc-Habcap model predictions of summer habitat effectiveness (HE) for elk in Custer State Park, South Dakota.

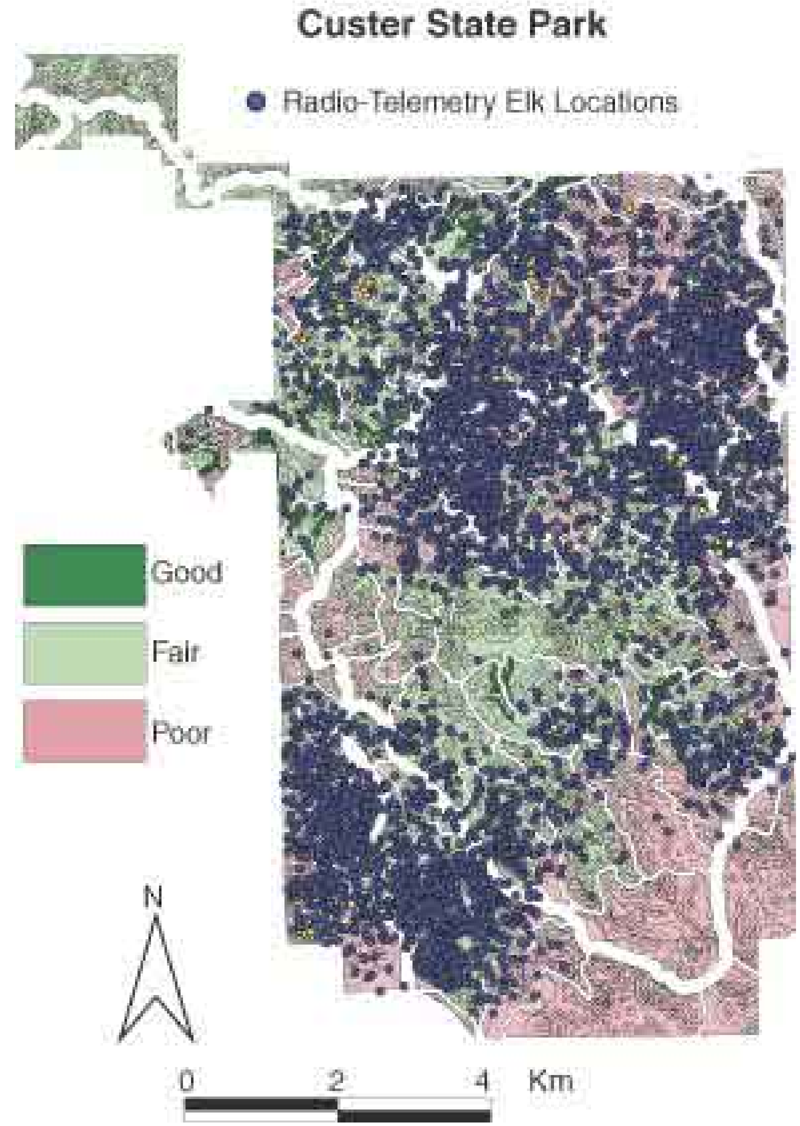


Figure 9b—Arc-Habcap model predictions of summer habitat effectiveness (HE) for elk along with radio-telemetry elk locations in Custer State Park, South Dakota.

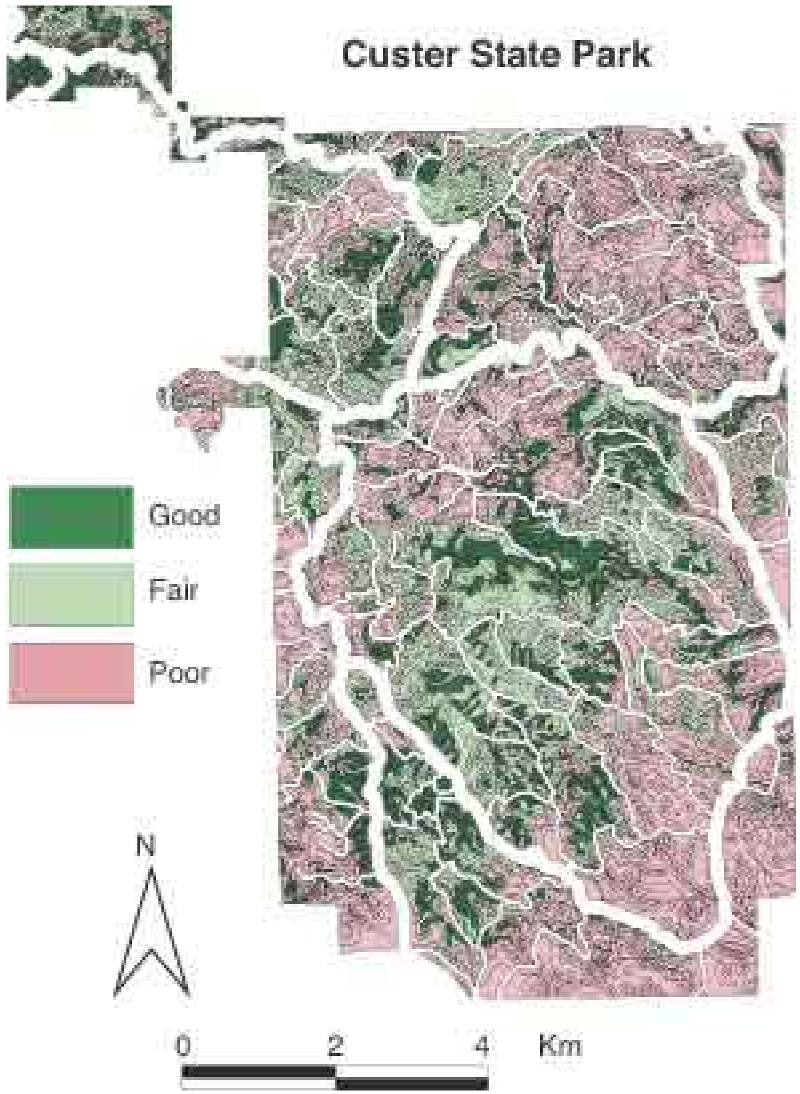


Figure 10a—Arc-Habcap model predictions of winter habitat effectiveness (HE) for elk in Custer State Park, South Dakota.

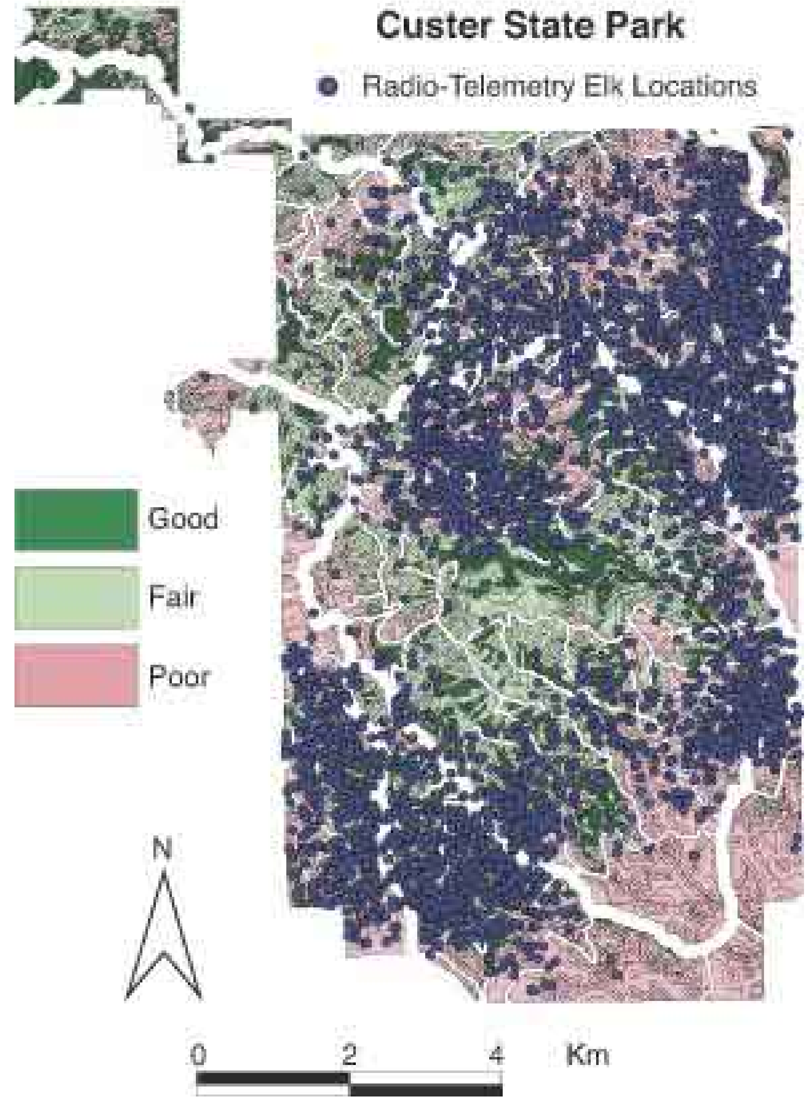


Figure 10b—Arc-Habcap model predictions of winter habitat effectiveness (HE) for elk along with radio-telemetry elk locations in Custer State Park, South Dakota.

Table 7—Elk use (no. of locations) compared with expected use in areas classified by Arc-Habcap as good, fair, and poor habitats for elk in Custer State Park, South Dakota.

Predicted effectiveness	Area (ha)	Observed elk use	Expected elk use	Selection ratio	Bonferroni adjusted p-value (H_0: w = 1.0)
			Summer		
Forage-cover distribution (χ^2 = 281.67, P < 0.001)					
Good	14,152	3,426	3,203	1.069	0.001
Fair	3,013	816	682	1.196	0.001
Poor	2,914	303	660	0.459	0.001
Habitat effectiveness (χ^2 = 24.45, P < 0.001)					
Good	790	118	179	0.661	0.001
Fair	9,603	2,213	2,174	1.018	0.729
Poor	9,686	2,214	2,192	1.015	1.000
			Winter		
Forage-cover distribution (χ^2 = 162.82, P < 0.001)					
Good	11,256	2,391	2,302	1.038	0.016
Fair	3,963	1,028	810	1.268	0.001
Poor	4,860	688	994	0.692	0.001
Habitat effectiveness (χ^2 = 113.49, P < 0.001)					
Good	4,035	764	825	0.926	0.051
Fair	5,414	851	1,107	0.769	0.001
Poor	10,631	2,492	2,174	1.146	0.001

Road effects on elk

Approximately 24% of CSP was predicted by Arc-Habcap as ineffective habitat for elk due to the proximity of roads. Elk used these areas of ineffective habitat in nearly the same proportion as the area they comprised in CSP. Areas adjacent to roads comprised 21% of elk locations during summer (figure 11) and 24% of elk locations during winter (figure 12). During summer, elk used areas adjacent to primary roads less than expected ($w = 0.77$, $P < 0.01$) and used areas adjacent to primitive roads more than expected ($w = 1.41$, $P < 0.01$, table 8). Selection ratios for primary and secondary roads during summer were similar, but differed from the selection ratio for primitive roads ($P < 0.01$). During winter, elk used areas adjacent to primary and secondary roads less than expected ($P < 0.01$) and areas adjacent to primitive roads more than expected ($P < 0.01$). All selection ratios associated with road categories during winter differed ($P < 0.01$). Negative effects of primary roads on elk extended to 350 m during summer and 60 m for secondary roads; primitive roads did not appear to negatively affect elk during winter (figure 13, table 8). Negative effects of primary roads on elk extended to 300 m during winter. The negative effect of secondary roads during winter was constrained to 60 m and primitive roads had no real effects on elk dispersion patterns (figure 14, table 8).

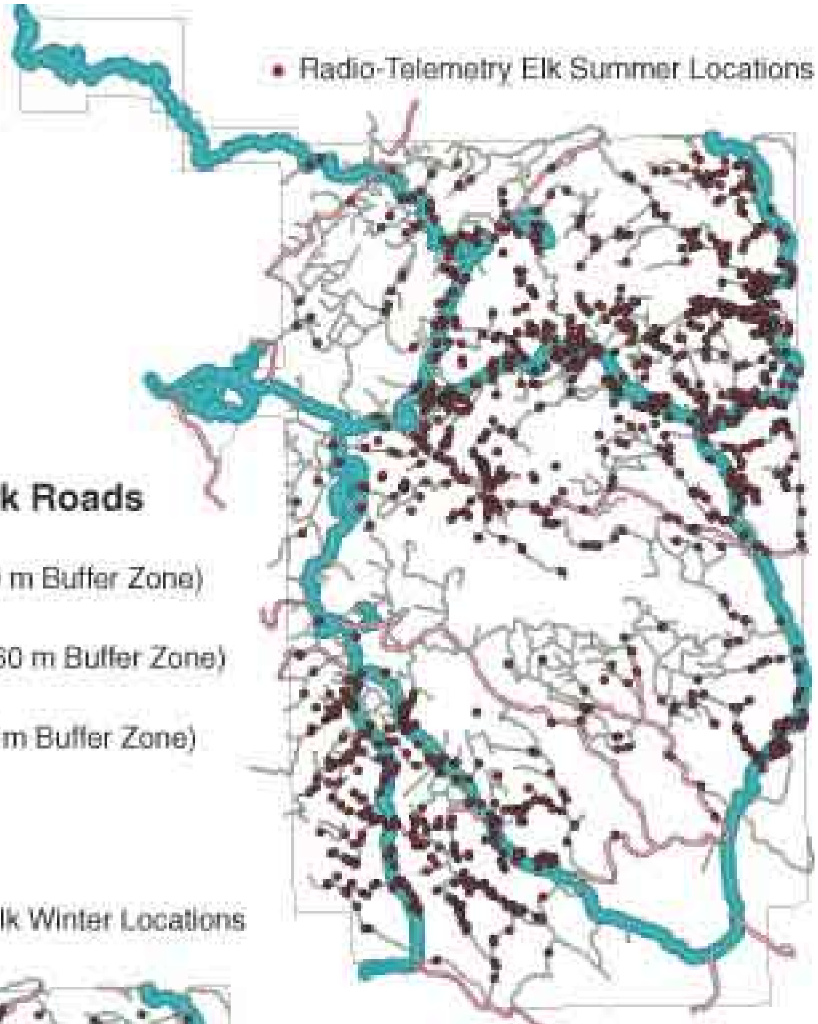
Discussion

The primary improvement of Arc-Habcap over previous Habcap models was the ability to spatially evaluate the proximity of cover and forage and incorporate their juxtaposition effects into the calculation of habitat quality. Another improvement is the ability to display the model output in a GIS map. Based on Arc-Habcap model predictions, CSP was better foraging habitat than cover habitat. We did not know the actual activity of elk so we assumed feeding and bedding (cover) were equally distributed among radio-telemetry locations. Correctly assigning elk activity was not critical to our hypothesis that predictions of habitat effectiveness with Arc-Habcap would reflect dispersion patterns of elk across the landscape in CSP. Because the elk population in CSP was managed below elk carrying capacity, elk should preferentially select good habitats or avoid poor habitats (Fretwell 1973), thus significant deviations from the proportional use would be expected from a model that accurately depicts elk distributions (e.g., elk would use areas predicted as good more than expected and poor less than expected).

Predictions of Arc-Habcap suggested that some components of the model reflected elk responses to habitat conditions. Predicted proportional use for FV and HDV generally reflected elk dispersion patterns we expected in CSP. However, the model performed poorly for CV and HE. The greater selection ratio for forage habitat during winter versus summer was consistent with our expectations as quality and quantity of forage are more likely to limit elk during the winter dormancy of grasses than during summer (Thomas et al. 1988).

Arc-Habcap restructured spatial land units into smaller units and assigned HDV values based on the proximity of cover and forage. Our data support a slightly different decline in effectiveness of the HDV coefficients than were reported by Wisdom et al. (1986) and Thomas et al. (1988). By examining elk locations in 100-m intervals from cover-forage edges, new

Figure 11—Summer elk locations relative to open roads and ineffective areas due to roads in Custer State Park, South Dakota.



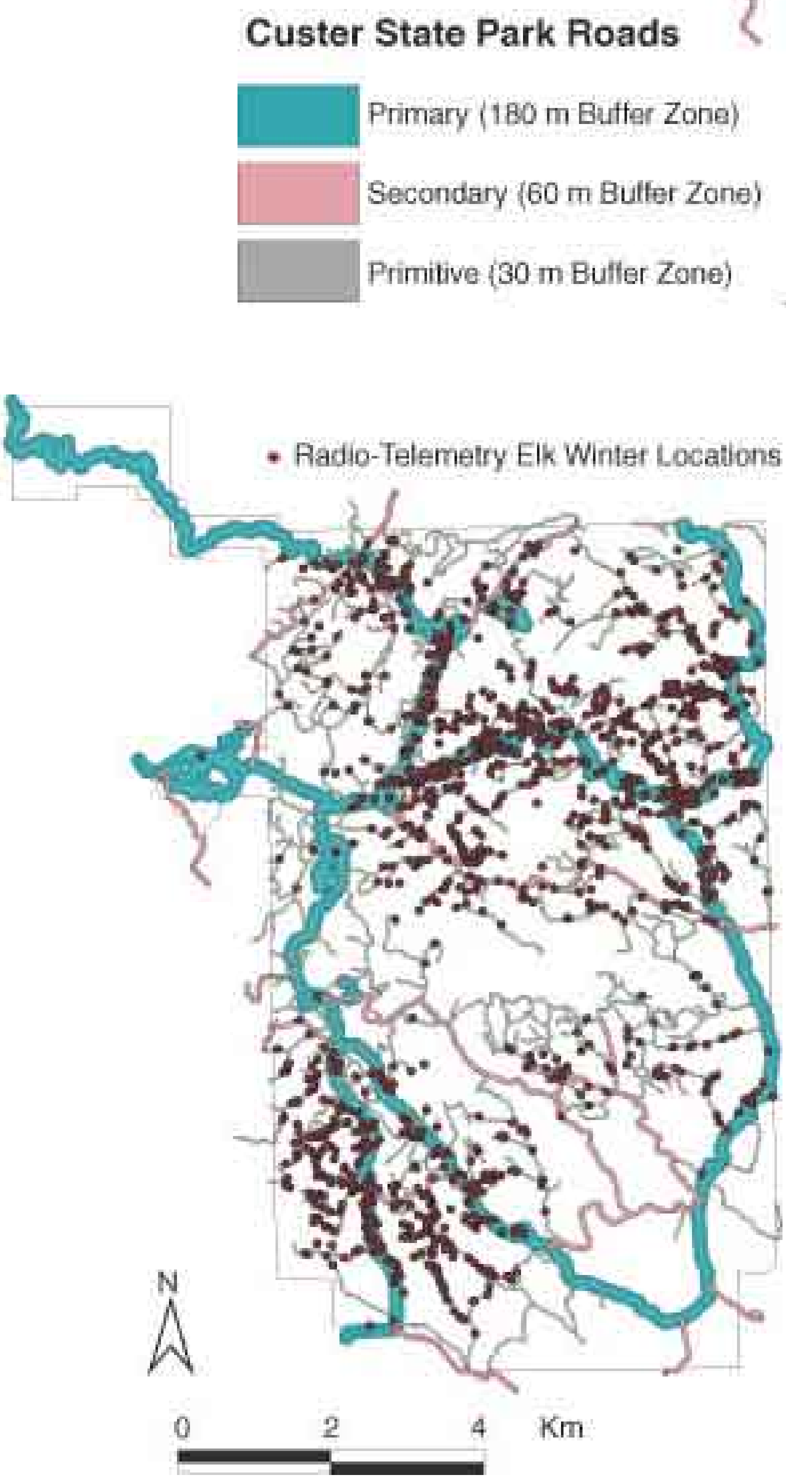


Figure 12—Winter elk locations relative to open roads and ineffective areas due to roads in Custer State Park, South Dakota.

Table 8—Elk use (no. of locations) of areas adjacent to roads as compared with expected use. These areas were ineffective habitats for elk by Arc-Habcap due to proximity to roads in Custer State Park, South Dakota[1].

Road category	Area (ha)	Observed elk use	Expected elk use	Selection ratio	Bonferroni adjusted p-value (H_0: w = 1.0)
			Summer		
(χ^2 = 104.58, P < 0.001)					
Primary	3,780	524	681	0.770	0.001
Secondary	734	116	132	0.878	0.410
Primitive	2,317	590	417	1.413	0.001
			Winter		
(χ^2 = 237.13, P < 0.001)					
Primary	3,780	521	723	0.721	0.001
Secondary	734	74	140	0.527	0.001
Primitive	2,317	711	433	1.605	0.001

[1] Areas adjacent to primary roads extended 180 m, areas adjacent to secondary roads extended 60 m, and areas adjacent to primitive roads extended 30 m.

HDV coefficients were calculated from derivative estimates at the midpoint between two distance intervals. We recommend an HDV of 1.0 for areas 100 m or less from cover-forage edges, 0.5 for areas between 100 and 200 m, 0.1 for areas between 200 and 500 m, and 0.01 for areas beyond 500 m from forage-cover edges. Elk use some habitats as both forage and cover (Wisdom et al. 1986), but the characteristics of these habitats need quantification such as kind and amount of the herbaceous or shrub vegetation. A problem associated with Arc-Habcap was that all structural stages of ponderosa pine > 2.5 cm dbh qualified as forage and cover (HDV = 1.0) except "old-growth" during summer and those structural stages with over-story canopy cover ≤ 40% during winter. As a result, some forest stands fell under the category described above despite the lack of adequate amount of forage. Consequently, we recommend redefining the vegetation conditions for stands that provide both forage and cover for elk.

Predictions of HE by Arc-Habcap did not depict elk dispersion patterns in CSP. Wisdom et al. (1986) advocated the geometric mean as a method that integrates all components of the habitat model with equal weight, and the geometric mean appeared to best represent their expectations of elk responses to habitat conditions. The geometric mean method of calculating HE resulted in most of CSP predicted to be poor for elk. Areas where vegetation conditions resulted in coefficients of 0 for FV, CV, or HDV, resulted in HE = 0. Approximately 40% of elk locations occurred in areas predicted as poor HE. A potential solution would be not to allow HE coefficients of 0. We believe there is value in allowing some coefficients to be 0 without driving HE to 0. Therefore, we recommend an alternative method for calculating the HE. The formula we propose was based on elk use of areas of good foraging habitat from the data and calculates a weighted average using forage, cover, and cover-forage proximity [HE = (3FV+CV+HDV)/5]. We selected a weight of 3 for FV because we found 3-6 times more use of good forage habitats than good cover habitats, and we believe that elk can compensate better for lack of cover with good forage than the reverse. Some biologists suggest that thermal cover is important to elk during winter (e.g., Hoover and Wills 1984; Wisdom et al. 1986), but others have questioned its importance (Hobbs 1989; Cook et al. 1998). The original occupation of grassland biomes by elk in western North America (Guthrie 1966; Bryant and Maser 1982) tends to support our contention that forage is more important than cover. Calculations of HE using the weighted average in CSP resulted in model predictions that met our expectations of how elk used good and fair habitat categories better than when we used geometric mean to calculate HE. Using the geometric mean method, good and fair HE habitats were under utilized and poor HE habitats were heavily used (figure15a and 15b). The weighted average formula allows inclusion of land units with coefficients of 0 for any of the 3 components and also allows for compensation among components of the model. The rationale for using a geometric average by Wisdom et al. (1986) was that it allowed for compensation among model components.

Roads might be one of the best predictors of elk dispersion (Lyon 1984). Areas immediately adjacent to primary and secondary roads had relatively less elk use of habitats than areas farther away from roads, in CSP. The number of observed elk next to roads tends to be lower than expected up to 300 m from roads. This avoidance of areas adjacent to primary and secondary roads was evident despite the apparent attraction of elk at night during late summer to roadside management areas for feeding (e.g., Millspaugh 1999). The negative influence on elk noted around primary roads extended beyond the 180 m (current buffer distance in Arc-Habcap) to approximately 300 - 350 m. The negative influence of secondary roads extended to 60 m, the current buffer distance in Arc-Habcap. Primitive roads had very little effect on elk dispersion patterns in CSP. Eliminating areas adjacent to roads as ineffective habitat as predicted by Arc-Habcap was not supported in our data or the literature. Lyon (1979) suggested that roads alone would not reduce habitat effectiveness for elk below 10-15%. Elk use within 50 m of primary roads was approximately 60%

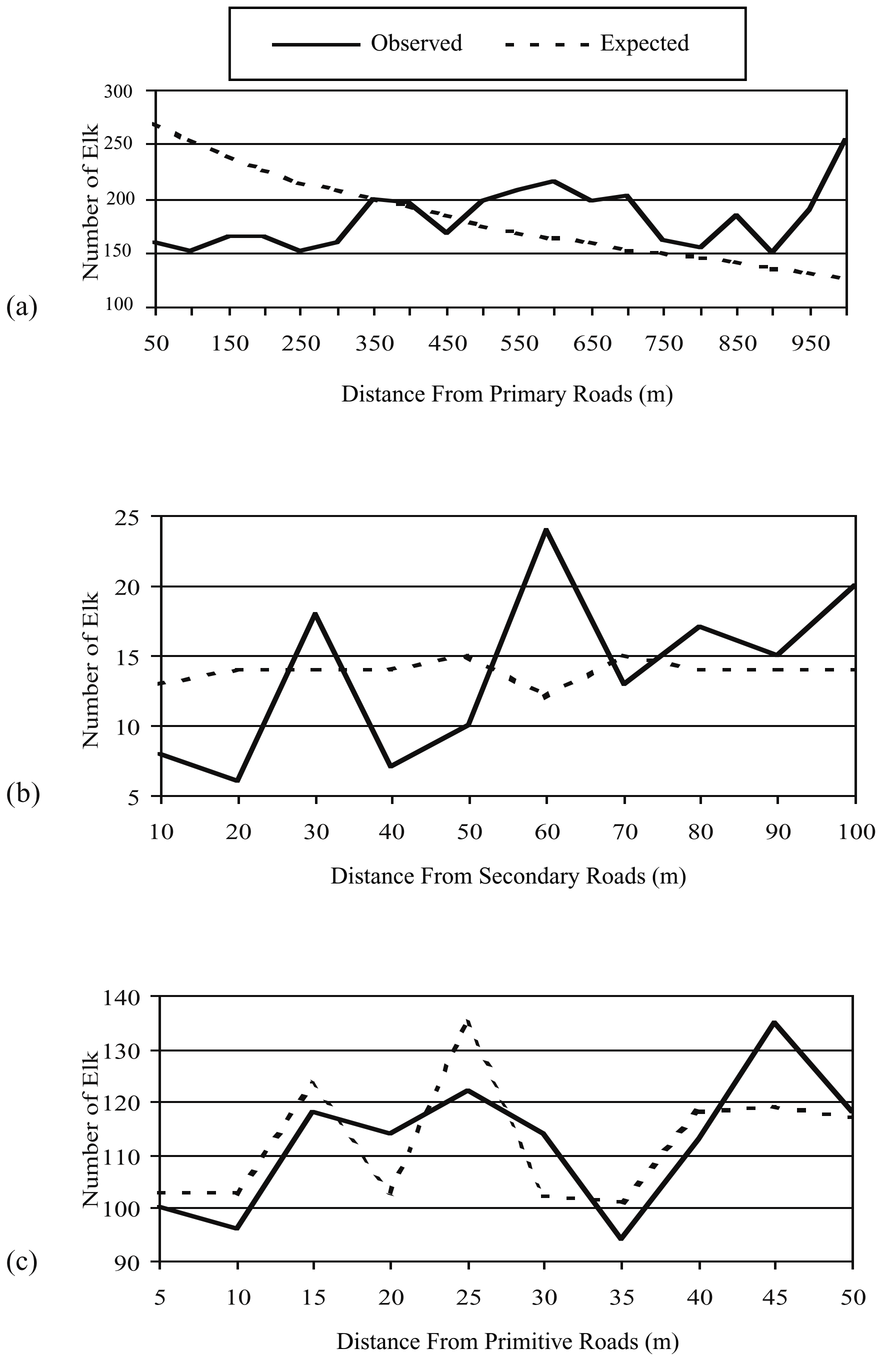


Figure 13—Elk summer use plotted against expected use along distance intervals from roads primary (a), secondary (b), and primitive (c).

of that expected. Negative effects of roads on elk were not evident beyond 300-350 m in CSP. However, elk in parks may not perceive roads the same as outside park boundaries. Rowland et al. (2000) reported increasing habitat selection ratios as distance from roads increased at least as far as 1.6 km. Future investigations on the effects of roads on elk can be studied in areas with high density of roads (> 2 km/square mile), using research designs that consider areas with road closures, open roads, and no roads, so that effects of traffic volume and noise can be measured and studied at several periods of the year.

Conclusion

The ability to develop spatial displays of elk habitat in GIS is an attractive feature. However, there are substantial modifications necessary for the Arc-Habcap model to reflect elk dispersion patterns in CSP. A simple modification of the formula calculating habitat effectiveness resulted in a better habitat classification that met our expectation of how elk should use habitats. Good and fair habitat categories received most of the use as compared to the geometric mean

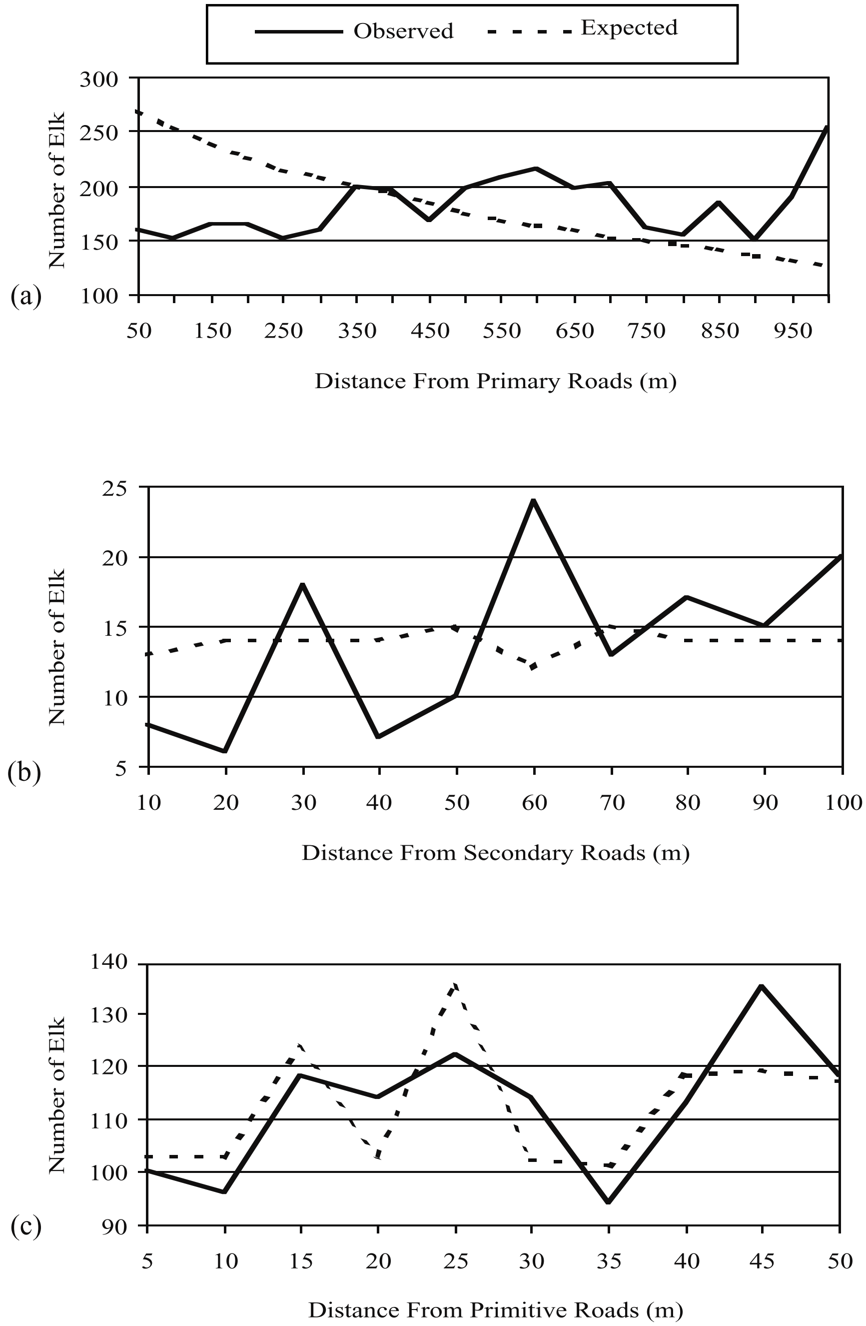


Figure 14—Elk winter use plotted against expected use along distance intervals from roads (primary (a), secondary (b), and primitive (c).

classification where the poor categories received most of the use by elk. With recommended modifications, Arc-Habcap will be a useful deterministic tool for biologists and managers.

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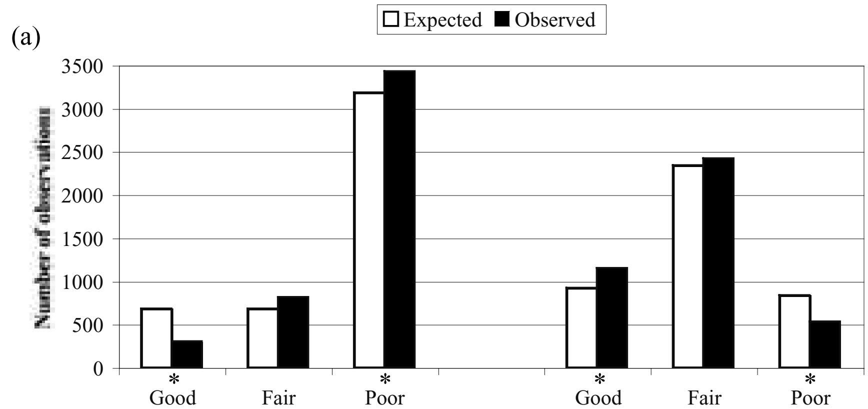

Figure 15a—Comparison of geometric mean habitat effectiveness (HE) with a weighted average HE during summer in Custer State Park, South Dakota. Bars of elk use and expected use of habitats with an asterisk below are significantly different (P < 0.05).

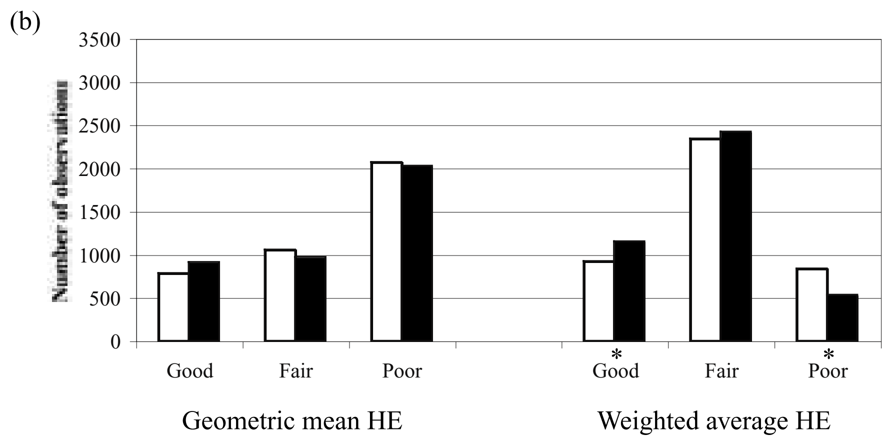

Figure 15b—Comparison of geometric mean habitat effectiveness (HE) with a weighted average HE during winter in Custer State Park, South Dakota. Bars of elk use and expected use of habitats with an asterisk below are significantly different (P < 0.05).

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