GIS Modeling of Elk Calving Habitat in a Prairie Environment with Statistics

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Abstract

In 1981, elk were first introduced to the prairie environment of the Cimarron National Grassland in Kansas. The lack of information regarding critical elk habitat in the prairie and the demand for integrated land use necessitated elk habitat studies in the grassland. A logistic regression model was developed to assess the relationship between observed calving sites and a set of biophysical and anthropogenic habitat variables. A GIS was used to solicit spatial information and implement the logistic model to predict the spatial distribution of calving probabilities in the grassland. Seep pits, the man-made water supply facilities along the river corridor, and cottonwood and salt cedar in the riparian areas were found statistically significant in explaining elk calving habitat; in contrast, highways and improved gravel roads appear to affect calving habitat in a negative fashion. The results also suggested possible adaptation of elk to human disturbance.

Introduction

American elk in the United States are predominantly located in mountainous areas, such as the Rocky Mountain Range and the Cascades (Van Wormer, 1969; Taber and Raedeke, 1987). In 1981, Rocky Mountain elk (*Cervus elaphus nelsoni*) were first introduced to the prairie environment in the Cimarron National Grassland of Kansas. Following several later introduction efforts, the population had risen to more than 100 individuals. Although the introductions have been successful, little is documented about elk habitat in prairie environments; virtually all published elk studies in the United States focus on mountainous environments. The lack of information regarding elk in prairie environments and the success of the Cimarron National Grassland as elk habitat necessitated an elk habitat study in a prairie environment.

Before their eradication from prairie environments by western settlers, American elk existed across the Great Plains and most of North America (Van Wormer, 1969). Biophysically, it is natural to reintroduce elk back to their former range on the plains; however, modern land use poses a major complication to today's wildlife management on the plains. Since its establishment in the early 1930s, the Cimarron National Grassland has supported an array of land uses such as petroleum extraction, development of roads, and cattle grazing, that coexist and compete with wildlife (USDA Forest Service, 1991). The federal and state agencies that manage the grassland and wildlife have made many efforts to maintain an integrated resource use (Hartman and MacDonald, 1988). These efforts have included controlled grazing, planting food plots for wildlife, and fencing supposed critical wildlife habitats. The requisite for the success of these efforts is locating critical habitat areas, so that limited management resources can be used most effectively.

The grassland as a whole is considered to be suitable for elk, but calving, which tends to require particular habitat, is key to the survival of the elk population. In the grassland, calving is the most pivotal and vulnerable activity that requires habitat protection (Cline, personal communication, 1994). Calving is observed to occur in riparian areas in the grassland (Robinson, 1992). Along the long stretch of the riparian areas, elk management efforts have focused on the southwestern portion, which was selected based on observations and assumptions. Information about biophysical habitat characteristics preferred by calving elk and the anthropogenic impacts on the habitat is paramount to locating the most critical habitat areas. Unfortunately, this information so far remains unknown or hypothetical. In recent years, the managing agencies have started collecting spatial data, thus providing a valuable basis for an in-depth understanding of elk calving habitat in prairie.

The objective of this research was to evaluate suitability of elk calving habitat in the Cimarron National Grassland. Biophysical and anthropogenic factors were accounted for in habitat evaluation and mapping. Using GIS and statistical methods, the study attempted to accomplish the following specific tasks:

- developing a statistical model that related known elk calving locations to habitat characteristics, and
- applying the model to the entire study area to map the probability of calving habitat using GIS.

The intent of this study was to provide a quantitative understanding of elk calving habitat in the prairie environment. This information is crucial to elk population and land-use management in the grassland. As one of the very early studies of elk in a prairie environment, this study will serve as a prototype for further and extended efforts in elk management on the plains and contribute to wildlife management in developed areas.

Background

Study Area

The Cimarron National Grassland covers approximately 438 square kilometres in Morton County in southwestern Kansas (Figure 1). Climate of the area is semi-arid with no more than 400 mm of annual precipitation. The intermittent Ci-

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marron River runs through the gentle terrain of the grassland. The river is usually dry, leaving a sandy river bed. The flood plain of the river forms a central corridor, with a shallow water table one or two metres below the surface. Ponds or other surface water pools are scarce. Along the river channel is the riparian woodland. On the vast, open land, a mixture of tall grass and short grass species typifies the climate and supports wildlife of many types (USDA Forest Service, 1991).

Riparian vegetation consists primarily of cottonwood trees (*Populus saryrntii*) and salt cedar shrubs (*Tamarix ramosissimu*). The vegetation south of the river corridor is sandsage prairie, named after the sandy soils and recognizable amount of sagebrush (*Artemisia filifolia*) on the landscape. The dominant grass species are sand lovegrass (*Erigrostis trichodes*), sand dropseed (*Sporobolus cryptandrus*), and big sandreed (*Calamouilfa gigantea*). North of the river corridor is short grass prairie on hardpan soils. The dominant grass species are blue gramma (*Bouteloua gracilis*), buffalo grass (*Buchloe dactylordes*), and western wheatgrass (*Agropyron smithii*) (USDA Forest Service, 1991). The grassland has provided elk with essential habitat needs of forage, water, and cover.

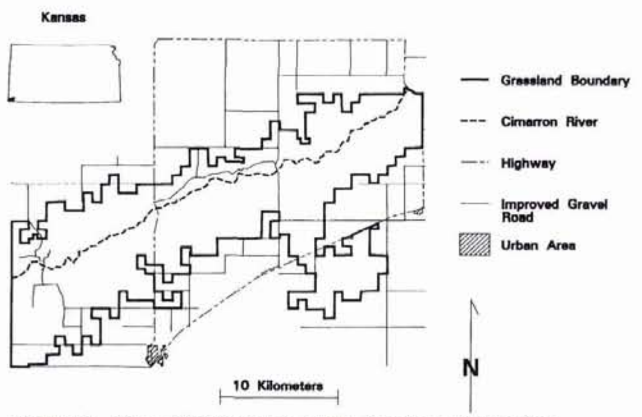

Figure 1. Map of the study area. Roads outside the grassland boundary are shown here because they were included in the analysis.

Biophysical Habitat Factors

Because little has been published regarding elk in the prairie, research based on a mountainous environment is an important reference for analyzing observed prairie habitat. Elk in the grassland have shown a similar forage preference to elk in mountains. Elk feed on a variety of grasses, forbes, and shrubs, which are abundant in the grassland. Furthermore, water is a crucial element of elk habitat. Researchers have suggested that elk prefer to remain within a certain distance to water, depending upon elk sub-species and the environment they inhabit (Skovlin, 1982). In the semi-arid grassland water seems to be critical to elk.

Cover is essential for hiding and helps elk maintain body heat in winter. Tall grass, thick brush, and trees have been used for cover in mountainous areas, but forested areas have been observed as the preferred cover type (Skovlin, 1982). Elk in the grassland seem to use similar cover types but are less dependent on trees. Unlike in the mountains where elk depend on the ecotone between forest and open forage areas, elk in the Cimarron National Grassland reside mainly on the open prairie, but rely on the riparian areas for calving (Cline, personal communication, 1994).

The Calving Habitat

Calving may require an optimal combination of required habitat factors (forage, water, and cover), but choice of cover may override other priorities. It is widely reported that calving season starts in spring, with a general movement of female elk. Pregnant elk leave their herd for a suitable area to calve, and remain close to their calves for several months the following summer. According to the existing literature regarding mountainous environments, calving tends to occur near the edge of forested areas for easy access to both forage and cover, thus minimizing travel and reducing vulnerability. In addition, it was also reported that calving elk prefer water within 400 metres (Skovlin, 1982).

In the Cimarron National Grassland, calving is observed to occur in riparian areas, which are forested with cottonwood and contain salt cedar shrubs. Cottonwood communities are normally associated with either grass or shrub understory. Salt cedar shrubs occur either as understory in cottonwood communities or as shrub communities in open areas. Forage is generally available in or near these communities. It was hypothesized that cottonwood trees provided vertical shelter for calving elk, while salt cedar shrubs provided horizontal protection from view. Cottonwood communities with salt cedar understory, therefore, were believed to be the optimal cover. Based on the reported and observed dependence of elk on water sources, it was also hypothesized that the shallow water table along the river corridor should be another determinant factor for calving habitat. These hypothesized effects of biophysical factors on calving habitat needed to be tested.

Anthropogenic Factors

Modern land uses modify the suitability of elk calving habitat. Human development is generally no further than 300 metres from any point in the grassland. Throughout the grassland (including the riparian areas), there are more than 400 oil and gas wells. Operation of these wells generates noise that may disturb calving elk. Associated with the wells and other facilities is an extensive network of roads: highways, improved gravel roads, and unimproved dirt roads. The slower traffic on the unimproved dirt roads was believed to be less predicable, thus causing significant impacts on elk. The effects of more predicable, high-speed traffic on highways and improved gravel roads were thought to be minimal.

Near or in the riparian areas are approximately 100 seep pits, which are open, shallow depressions dug into the ground. The seep pits are fed by the shallow ground water along the river corridor; the amount of water in the pits fluctuates seasonally with the groundwater. Because natural surface waters are extremely scarce in the grassland, the seep pits were believed to be a major water source for wildlife.

Windmills throughout the grassland may have provided elk another possible source of water although the windmills were erected primarily for cattle. During two months of each year, approximately 5,000 head of cattle are allowed to graze in the riparian areas. It is reported that cattle and elk do not stay in close proximity. Cattle grazing may have posed a threat to calving elk. The perceived impacts of the aforementioned anthropogenic factors have not yet been previously tested.

In recent years, the methods for analyzing wildlife habitat have become increasingly sophisticated. Integrating statistics and GIS has provided a powerful tool to capture relationships of environmental factors with habitat in a spatial context (Alldredge and Ratti, 1986; McCorquodale *et al.*, 1986; Agee *et al.*, 1989; Lowell and Astroth, 1989; Pereira and Itami, 1991; Breininger *et al.*, 1991; Johnston, 1992; Herr

Table 1. Basic Statistics of the Four Land-Cover Types for the Elk Calving Habitat Analysis.

Land-Cover Types	Number of Observations	
Types	Calving	Non-Calving
Cottonwood and Salt Cedar	56	7
Other Cottonwood Communities	94	21
Salt Cedar	11	0
Others	25	146
Total	186	174

and Queen, 1993; Clark *et al.*, 1993; Jager and Overton, 1993; and Mladenoff *et al.*, 1995). This integrated approach should be most appropriate for the intended study.

Methods

Spatial Data Collection

Spatial data were collected to support variable significance tests, model development, and calving habitat suitability assessment. Data themes were organized around three categories: elk activities, biophysical habitat factors that form the basis of natural habitats, and the anthropogenic factors that have modified the natural habitats in the grassland.

Elk activity information was obtained mainly from a telemetry data set (Robinson, 1992), sponsored and supported by the Rocky Mountain Elk Foundation, Kansas Department of Wildlife and Parks, and the USDA Forest Service as one of the data collection initiatives in the grassland. The telemetry data tracked daily activities of a group of female elk for over one full year, including calving and non-calving seasons. The recording began in 1991. By receiving radio signals sent from collared elk, a field staff member recorded elk ID numbers, the dates of observation, the locations of the elk, and information regarding elk activity and physical environment (Robinson, 1992). Location information was in the UTM coordinate system. The telemetry data, including a total of 360 point locations and associated attributes, were converted to a point coverage in Arc/Info format.

The elk activity data were further coded into two groups: calving or non-calving. The coding was primarily based on the migration of collared elk toward or away from riparian areas; such movements were assumed to mark the beginning and ending of the calving season, normally from May to August. The beginning of the calving season was identified as the date when the general movement of the elk toward the riparian areas became localized; the calving season was assumed to have ended when the elk started a general movement again. All records that fell within the so defined calving season were coded as calving, and otherwise as non-calving.

The primary biophysical factors were land-cover types that provided hiding cover and forage for elk. The information was interpreted from 1988 USDA Forest Service 1:24,000-scale orthophotographs. Several field surveys were made to update and verify the land-cover types. The basic mapping unit was equivalent to Level III of Anderson Classification System (1976). The land-cover types identified in the riparian areas were cottonwood trees with salt cedar shrubs, cottonwood with sagebrush, cottonwood with grass, cottonwood with sand, salt cedar shrubs, sagebrush, grasses, sand, food plots, and water bodies (natural surface waters). The grassland outside the riparian areas was classified into short grass prairie, wooded draw (brush thickets), and sandsage prairie. These identified land-cover types were digitized into a polygon coverage.

Human land-use features were identified as roads, oil and gas wells, seep pits, and windmills. All of the roads (highways, improved gravel roads, and unimproved dirt roads) were digitized from 1993 USGS 1:24,000-scale planimetric quadrangles and included in a line coverage. Oil and gas wells were digitized from the same set of USGS planimetric quadrangles and stored in a point coverage. The windmills were digitized from the planimetric quadrangles and stored in a separate point coverage. Changes in roads and wells were minimal from 1991 to 1993, and no change was observed for windmills. The seep pit locations were available through another data collection effort in the grassland by the USDA Forest Service in 1993 and digitized into a point coverage. All of the aforementioned data were referenced to the UTM coordinate system and prepared in Arc/Info format.

Calving Habitat Model Development

Because the primary focus of the study was to identify calving habitat, logistic regression was considered most appropriate for the intended modeling. Logistic regression regresses a dichotomous dependent variable on a set of independent variables which can contain numeric as well as categorical data. The results of the regression predict probabilities of one state of the dependent variable. The method has been successfully used in wildlife habitat studies (Pereira and Itami, 1991; Johnston, 1992; Mladenoff *et al.*, 1995). In this study, elk activity (calving or non-calving) was the dependent variable. The independent variables included the biophysical variables (the land-cover types) and the anthropogenic variables.

The land-cover types at each of the 360 elk locations were identified using a point-in-polygon overlay operation and confirmed by the telemetry data records. Human disturbance was represented by the shortest distances from each elk location to the three types of roads and to the nearest oil or gas well. Availability of water sources was represented by two variables: shortest distance to a seep pit and shortest distance to a windmill. Using GIS functions, the distances were measured in metres between elk locations and the anthropogenic features.

Before the logistic regression analysis, each of the independent variables (13 nominal and six numeric) was tested to screen statistically significant variables in explaining habitat preference of calving elk. Because the habitat variables were selected empirically, such a procedure is preferred before full-scale model development (Pereira and Itami, 1991).

The land-cover types, adjusted by their availability in the grassland, tested significant using Chi-square statistics. Elk use of cottonwood communities, and especially the salt cedar community, showed high departures from their expected occurrence for calving while other types were close to occurrences expected by chance. The original 13 land-cover types were then regrouped into four categories for logistic modeling: cottonwood community with salt cedar understory, all other cottonwood communities, salt cedar shrub, and an "others" category containing the remaining cover types. Although the "cottonwood with salt cedar understory" land-cover type showed a departure similar to other cottonwood communities, it was treated as a separate category in order to further examine its hypothesized role in calving habitat. Table 1 shows the basic statistics of the four land-cover types.

The descriptive statistics of the six numeric independent variables are given in Table 2. Either a T-test or Mann-Whitney test was used for each variable with α values adjusted for multiple testing. The results showed that the distance to unimproved dirt roads and the distance to wells were not statistically significant. The indifference of the calving elk to the two anthropogenic features suggested possible adaptation of the elk to human disturbance in the grassland. Even though the dirt roads and wells generate traffic and noise, they are widely spread over the grassland and likely become unavoidable for the elk. The remaining four variables — distances to highways, improved gravel roads, seep pits, and windmills — were statistically significant. The spatial locations of elk, roads, seep pits, and regrouped land-cover types are displayed in Plate 1.

The significant variables, four nominal and four numeric, were entered into the logistic regression to model the elk-calving habitat relationship. Logistic regression requires coding n nominal variables into $n - 1$ dichotomous dummy variables and an additional reference category (Wrigley, 1976; Clark and Hosking, 1986; Demaris, 1992). In this case, the "others" was used as the reference category and the other three land-cover types were converted into three dichotomous (cases associated with presence of a particular land-cover type as 1 and absence as 0) dummy variables. Out of the total 360 locations, two-thirds (240) were randomly selected to develop the logistic model, and the remaining one-third (120) was set aside for model validation at a later time.

TABLE 2. BASIC STATISTICS OF THE SIX NUMERIC INDEPENDENT VARIABLES FOR THE ELK CALVING HABITAT ANALYSIS. ALL DISTANCES ARE MEASURED IN METRES.

Calving Locations (186 observations) Variables	Mean	Standard Deviation
Distance to gravel roads	2136.7	1482.4
Distance to highways	5890.0	2390.0
Distance to dirt roads	316.1	185.5
Distance to seep pits	425.0	239.5
Distance to wells	677.3	369.9
Distance to windmills	1139.9	411.9

Non-Calving Locations (174 observations) Variables	Mean	Standard Deviation
Distance to gravel roads	1616.9	1034.9
Distance to highways	3582.3	2234.3
Distance to dirt roads	345.7	239.4
Distance to seep pits	3325.5	3462.9
Distance to wells	802.6	502.3
Distance to windmills	974.0	431.2

Results and Discussion

The Logistic Model

Using a weighted linear combination of the independent variables, the logistic model predicted the probability of calving habitat at individual locations. The logistic model developed in this study was represented by the following:

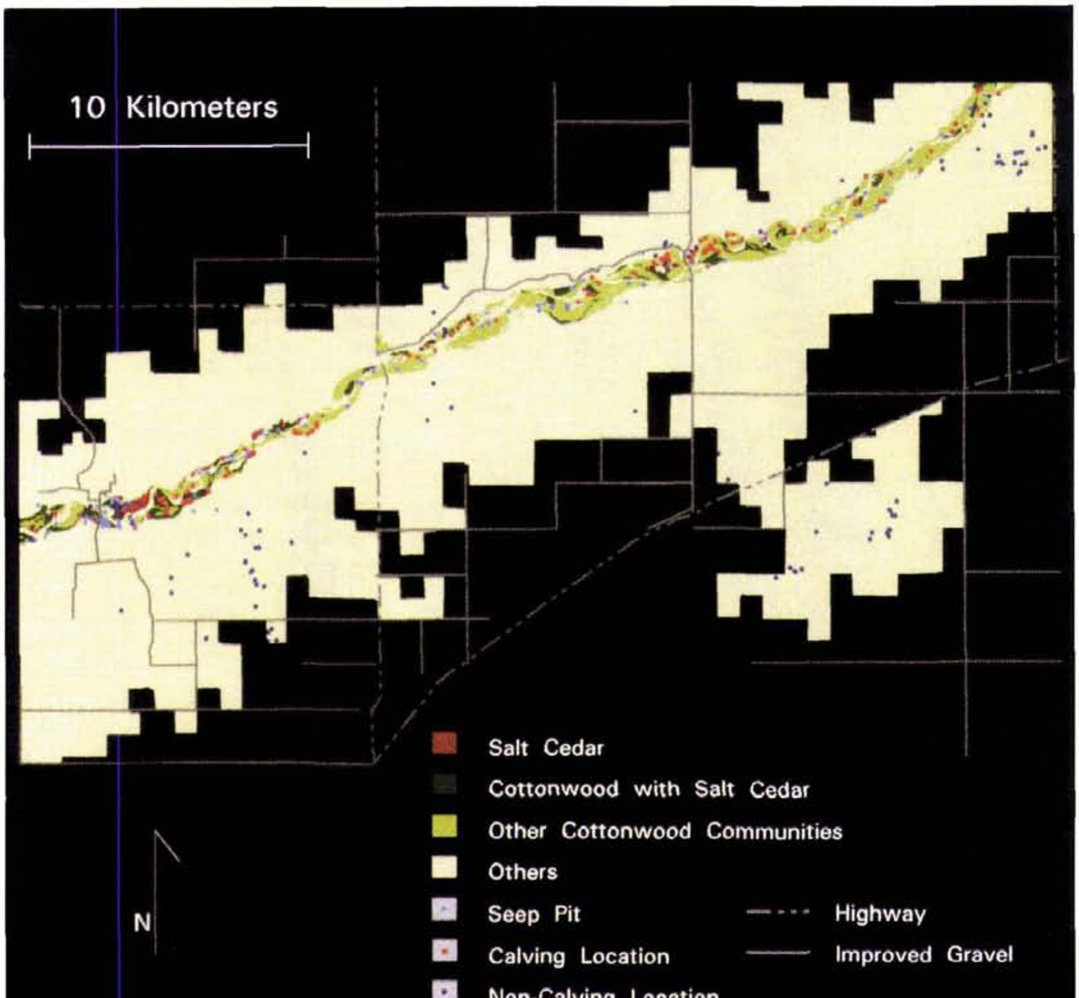

Plate 1. The spatial locations of elk telemetry points, roads, seep pits, and regrouped land-cover types in the Cimarron National Grassland.

Table 3. Classification Accuracy of the Logistic Model for the Sample Data Set (the Two-Thirds Data for Model Development and Calibration).

True Categories	Predicted Categories: Calving	Non-Calving	Accuracy (%)
Calving	116	8	93.6
Non-Calving	20	96	82.76

$$
\begin{aligned}
Y = & -2.583752 \\
& + 0.000706 \text{ distance to gravel roads} \\
& + 0.000343 \text{ distance to highways} \\
& - 0.001867 \text{ distance to seep pits} \\
& + 2.222704 \text{ presence of cottonwood} \\
& + 2.251458 \text{ presence of cottonwood and salt cedar} \\
& + 7.936381 \text{ presence of salt cedar}
\end{aligned} \quad (1)
$$

and

$$P = \frac{e^{y}}{e^{y} + 1} \quad (2)$$

where P is the probability of suitable calving habitat at a particular location, and Y is the exponent of the logistic equation, also the weighted linear combination of the independent variables. The output probability values range from 0 to 1, with 0 indicating a 0 percent probability of calving habitat and 1 indicating a 100 percent probability. The default threshold of 0.5 implies that probabilities above 0.5 are calving habitat and below 0.5 are non-calving habitat. The model correctly predicted 93.6 percent of the calving locations and 82.8 percent of the non-calving locations in the sample data (the two-thirds of total data for model development). The detailed counts are shown in Table 3. When the logistic model was applied to the validation data set, 85.5 percent of the calving locations and 79.3 percent of the non-calving locations were identified correctly (Table 4). These results were quite satisfactory.

According to the model, a location's probability for calving increased with distance to gravel roads and highways. This interpretation agreed with the hypothesis that roads may have negative impacts on calving habitat. The regression coefficient of gravel roads was higher than that of highways; when adjusted by standard deviation, the standardized regression coefficients suggested that gravel roads ($\beta = 0.93$) seemed to have impacts similar to those of highways ($\beta = 0.88$). In comparison to the unimproved dirt roads, which were not significant for the model, gravel roads and highways have more traffic at higher speeds and generate more dust or noise, which all could be perceived as a greater threat by elk.

The negative regression coefficient of distance to seep pits indicated that shorter distances to the pits tended to increase calving probability. Note that the average distance to seep pits (425 m, Table 2) for calving was similar to that reported for elk in the mountains. Seep pits as a factor ($\beta = -5.7$) may be more important than the roads factor for calving elk. In contrast to seep pits, distance to windmills was not significant in the model. A possible explanation is that farmers terminate water flow at windmills when cattle are not grazing in the surrounding area. When windmills provide water, elk may rather distance themselves from the windmills around which cattle often congregate. These circumstances may have complicated the role windmills play in calving.

The presence of cottonwood, salt cedar, and combined cottonwood and salt cedar increased the probability of suitable calving habitat in comparison to the "others" land-cover category. Cottonwood with salt cedar did not outperform either cottonwood or salt cedar communities in the model; this is consistent with the Chi-square test but conflicts with the hypothesis that cottonwood with salt cedar should be the optimal calving habitat. The salt cedar communities seemed to account for the calving habitat more than the other two types. In the grassland, pure salt cedar communities are few; this perhaps biased the statistics, and the importance of salt cedar may be over-estimated by the model.

Although the model performed well, there were 21 misclassified cases in the validation data set. Nearly one-half (nine) of them were marginal cases with calving probabilities between 0.475 to 0.525, very close to the exact threshold probability 0.5. Most of the actual calving sites that were misclassified as non-calving were in other types within the riparian areas but near various cottonwood communities. The actual non-calving cases misclassified as calving habitat were because the elk were in the salt cedar or cottonwood areas. Most of these cases occurred in either February or early March; perhaps these elk were seeking thermal cover in the colder months.

Calving Habitat Probability Assessment

The calving probability of the entire study area was assessed by applying the logistic model (Equations 1 and 2) to the GIS coverages corresponding to the independent variables. A raster format, grid, was used for the operation, because it was more effective at presenting spatially continuous phenomena than was a vector format. The operation was conducted using GRID procedures of ARC/INFO. The cell size used, 30 by 30 metres, was the width of the smallest polygon of all coverages so as to retain the spatial information at a maximum level. The end result was a probability surface predicting the potential of calving habitat for all locations in the grassland (Figure 2).

The high probability calving habitats extended along riparian areas. The northeast portion showed high suitability. In these areas, gravel roads are few and highways are distant, but cottonwood or salt cedar are common. Another area with noticeably high probabilities was the southwestern portion of the riparian areas. The dominance of almost pure, thick salt cedar stands and higher density of seep pits may have contributed to the high probability in these locations. The abundance of pure sand westward along the river corridor and the presence of a network of gravel roads across the west end of the corridor may have decreased the probability slightly. The two high probability portions faded into the central portion of the riparian areas. In these areas, gravel roads and highways spreading either adjacent to or across the riparian areas may have created a bottleneck for calving habitat.

Conclusions

A predictive model was developed using statistics and GIS to assess the probability of elk calving habitat in the Cimarron National Grassland. Two types of habitat variables were found statistically significant in affecting the spatial distribution of calving habitat. The biophysical factors, mainly land-cover types, formed the natural basis for elk habitat in the prairie environment. Anthropogenic variables, including

Table 4. Classification Accuracy of the Logistic Model for the Validation Data Set (the One-Third of the Data Reserved for Model Validation).

True Categories	Predicted Categories: Calving	Non-Calving	Accuracy (%)
Calving	53	9	85.5
Non-Calving	12	46	79.3

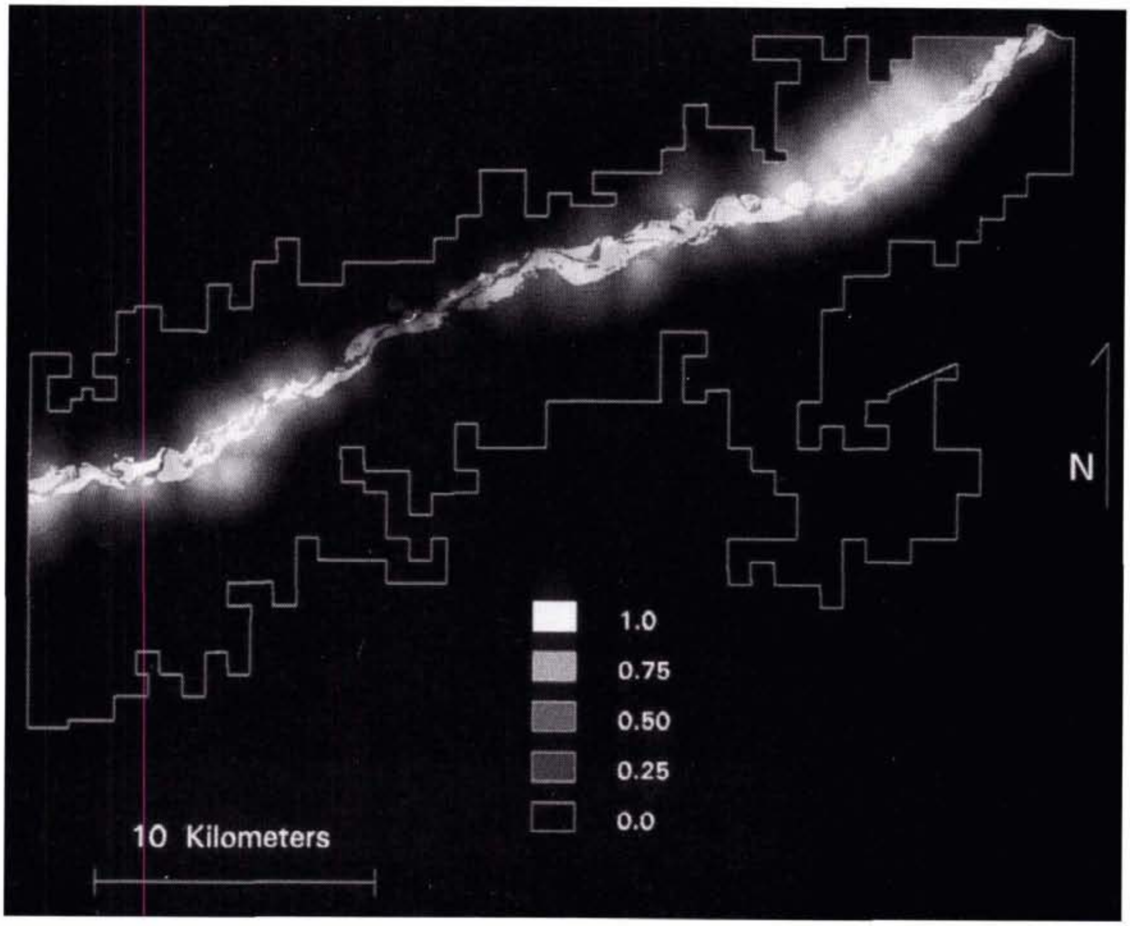

Figure 2. Probability surface predicting the suitability of elk calving habitat in the Cimarron National Grassland.

roads and water supply facilities, further modified the probability of calving habitat.

In general agreement with the long term observations of the USDA Forest Service field staff, the model suggested that cottonwood and salt cedar communities provided important cover and forage for calving elk. Close proximity to water sources, the seep pits, seemed to be significant for calving habitat in the semi-arid grassland. As hypothesized, the model indicated that improved gravel roads and highways likely exerted negative influences on calving. The unimproved dirt roads and wells, however, were not statistically significant. This may suggest possible adaptation of the elk to human disturbances that are widely spread and unavoidable.

The probability model could be used to prioritize management practices to obtain the most effective improvement from limited management resources. Controlling human use and adding forage near or in the calving habitat areas, maintaining seep pits, or controlling certain roads are examples of such practices. By identifying different probability areas, such as the high probability northeast and the bottleneck in the central area, various priorities may be assigned at the critical areas to maintain and improve the integrity of the calving habitat. Recently, elk have been introduced into other prairie locations which are characterized by intensive human development. This study should contribute to developing comprehensive management strategies for the best use of prairie resources by both humans and wildlife.

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