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Ecology of Elk in Northwestern Nebraska: Demographics, Effects of Human Disturbance, and Characteristics of Calving Habitat

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ECOLOGY OF ELK IN NORTHWESTERN NEBRASKA: DEMOGRAPHICS, EFFECTS OF HUMAN DISTURBANCE, AND CHARACTERISTICS OF CALVING HABITAT.

by

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ECOLOGY OF ELK IN NORTHWESTERN NEBRASKA: DEMOGRAPHICS, EFFECTS OF HUMAN DISTURBANCE, AND CHARACTERISTICS OF CALVING HABITAT.

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We radio-tracked 21 female Rocky Mountain elk (Cervus elaphus) in the Pine Ridge region of northwestern Nebraska for 5,789 elk-days from April 1995 to August 1997. Radio-collars were placed on female elk in 2 distinct herds; the Bordeaux Creek herd located east of Chadron and the Hat Creek herd, which is located west of Crawford.

We used 522 visual observations of elk to estimate the populations in the Bordeaux Creek and Hat Creek areas. The estimated number of elk in the Bordeaux Creek herd ranged from 59-77, with calf:cow ratios of 0.42-0.57:1 and bull:cow ratios of 0.29-0.42:1. The estimated number of elk in the Hat Creek herd ranged from 61-72, with calf:cow ratios of 0.43-0.51:1 and bull:cow ratios of 0.44-0.51:1. We developed a simulation model using STELLA for each herd from demographic rates determined from field observations and the scientific literature.

Habitat selection by elk in the Pine Ridge is largely determined by human disturbance factors and land-use patterns. Active timber harvest was found to temporarily displace elk. The distance between home range centers of elk exposed to logging ($\bar{x}$ = 5554 m) was larger than the distance moved of elk not exposed to logging ($\bar{x}$ =3337 m). Elk responded to summer agricultural crops by reducing and shifting

home ranges approximately 2.5 km toward crops after the second cutting of alfalfa and maturation of oats and millet during the late dough-stage. Winter elk distribution in the Bordeaux area was driven by the initiation of supplemental feeding. The elk calving season occurred at the same time as the initial stocking of cattle. Elk responded to cattle by moving out of recently stocked pastures and reducing the size of their home ranges. Road density and amount of travel were the 2 most important variables quantifying differences between elk-use and non-use areas. Areas with greater than 0.51 km road/km^2 and a road use index larger than 1650 are predicted to be avoided by elk.

Selection of calving areas by elk is an important component to the growth of a population. We located 22 elk calving sites and 42 random locations and measured 10 micro- and 9 macro-habitat variables between mid-June and July 1996 and 1997 to determine factors that affect habitat selection during the calving season. Seventy-three percent ($n = 16$) of elk calving areas were located in ponderosa pine (Ponderosa pinus) forest. The logistic regression model that best described elk use and fit the independent variables using a manual selection procedure, included: presence of cattle, average slope, habitat type, and distance from a road ($AIC = 49.57$, $R^2 = 0.65$).

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INTRODUCTION TO THESIS

Early Records of Elk in Nebraska

Elk (Cervus elaphus spp.) were native to Nebraska and roamed the Great Plains in the early 1800s. Jones (1962) reviewed records of 19th Century sightings of elk in Nebraska and reported the first documented elk sighting by Lewis and Clarke in 1803 and reports of sightings as late as the 1880s. Elk and bison (Bison bison) were nearly eliminated during the 1830s -1860s by market hunters. Swenk (1908) reported that elk were extirpated from Nebraska about the same time as the Plains bison (B. b. bison) in the early 1880s.

Return of Elk in Nebraska during the 20th Century

Rocky Mountain elk (C. e. nelsoni) were transplanted from Yellowstone National Park to the Rawhide Buttes, near Lusk, Wyoming in the 1960s. Elk reappeared in the Pine Ridge area of northwestern Nebraska during the 1960s. The reoccurrence of elk in Nebraska is best explained by elk that were transplanted to the Rawhide Buttes migrated into the Pine Ridge region of Nebraska. Evidence supporting this claim includes two tagged elk from the translocated herd that were of several in Nebraska. One collared spike bull was released in February 1967 and was found in August 1967, 15 km north of Hay Springs, Nebraska. The young bull had traveled at least 115 km. The second collared elk, a 9-year old bull, was released in the Rawhide Buttes during January 1968 and its skeleton was recovered in September 1969 south of Harrison, Nebraska (Helms, B., Wyoming Game and Fish Department, pers comm.).

Elk Management in Northwestern Nebraska

The resurgence of elk in the Pine Ridge area proves that Nebraska still has adequate habitat to support elk. Elk contribute to the State's biodiversity and provide hunters and wildlife viewers recreational opportunities, resulting in additional income for local economies and natural resource agencies.

Elk provide benefits to the people of Nebraska, but also provide a management challenge to natural resource agencies. Elk in Nebraska, unlike the western states, spend the majority of their time on private land. Elk cause damage to ranchers' agricultural crops, fences, and hay stacks. Habitat on private land provides the majority of cover and food that elk need to survive. Landowners can compensate for monetary losses caused by elk by charging access fees for hunting or viewing elk on private land. By allowing elk hunting, ranchers may disperse elk from sensitive areas, such as agricultural fields or haystacks. Natural resource agencies must consider these factors in their elk management program. Communication and interaction between the Nebraska Game and Parks Commission (NGPC) and area landowners will be essential for successful management of elk in the Pine Ridge.

The NGPC started managing elk in the Pine Ridge area in 1986. Management was triggered by complaints from Bordeaux Creek landowners, located east of Chadron. Concerns and complaints of crop and hay damage by elk were reported by area ranchers. The NGPC implemented a hunting season starting in the fall of 1986 to reduce the herd of approximately 40 elk. A second season was held in 1987. Thirty elk were harvested in the Bordeaux Creek area during the two seasons. Elk numbers and related damage were reduced to a level that was tolerable to landowners and hunting was ceased. By 1994, elk numbers and depredation complaints were increasing in the Hat Creek and Cottonwood Creek drainages, northwest of Crawford, and again in the Bordeaux Creek drainage. The NGPC held a series of public meetings to address the future of elk and elk management in the Pine Ridge. After reviewing the comments at each meeting, the NGPC developed an elk management plan (Nebraska Game and Parks Commission 1995) that identified the following objectives: 1) determine the status of the elk population and maintain a minimum population of 100 elk, with at least six mature (6+ points) bulls, 2) respond to all depredation complaints, 3) implement prescribed hunting seasons, starting in 1995, 4) monitor the overall health of the elk population and prevent contamination of domestic livestock through removal or treatment of infected elk, and 5) provide informational and educational materials to the public, that promotes free-ranging elk as a valuable component of our native fauna. Hunting seasons were implemented in 1995-1998 to help control population growth and reduce depredation problems. The 1995-1998 seasons resulted in the harvest of 57 elk in the Bordeaux Creek Unit and 38 in the Hat Creek Unit.

Elk Research in Northwestern Nebraska

Research on elk in the Pine Ridge is needed to support evaluation and continuation of the NGPC management plan. Information on the estimated number of elk, sex/age structure, distribution, critical calving and wintering areas, effects of human disturbance, and the herd health of the Pine Ridge elk population is needed to enable the NGPC to conduct an ecologically sound elk management program.

A project to gather baseline information on the Pine Ridge elk herd began in April 1995 with funding from the NGPC, Rocky Mountain Elk Foundation (RMEF), United States Forest Service (USFS)-Nebraska National Forest, and University of Nebraska-Lincoln (UNL). Baseline information on population size, herd health, distribution, and sex/age structure have assisted the NGPC with establishing season zones and harvest recommendations. To improve overall management, biologists need to understand the effects of land-use patterns on the elk population and identify areas where elk may cause problems with agricultural production. Understanding the impacts of cattle grazing, logging, road construction, and land development on the elk population will assist managers in making sound recommendations in the Pine Ridge. Identifying and characterizing critical habitats will enable managers to select sensitive areas for protection or acquisition and to manipulate these areas to attract or disperse elk. Thus, our objectives were to estimate the size and sex/age structure of the population of elk in the Pine Ridge, determine the distribution of elk relative to timber harvest, agricultural crops, livestock, roads and houses, and determine the distribution and habitat characteristics of elk calving areas.

CHAPTER 1: LITERATURE REVIEW

Population Estimation

Estimates of population size are often determined using herd composition counts, mark-recapture techniques, removal methods, mathematical models, or the use of thermal scanners. Often, game agencies will use a combination of these techniques rather than relying on a single technique to assess the population (Raedeke et al. 1999).

Herd composition, based on identification and enumeration of 4 or 5 age and sex classes in a population, and mathematical models of the population are the 2 levels of population structure analysis (Taber et al. 1982). Herd composition data are often collected during the late summer to determine composition of the pre-hunt population and provide a relative index of population size. Subsequent counts are conducted in the winter to assess the level of harvest to different segments of the population and provide an estimate of the composition of the post-hunt population (Raedeke et al. 1999). An independent estimate of population size should be conducted in addition to herd composition counts to increase confidence in survey results (McCullough 1994).

Mark-recapture techniques, known as the Peterson or Lincoln index, have also been used to assess big game populations (Raedeke et al. 1999). All mark-recapture methods have the same basic format. A sample of elk are captured, marked, and released. A second sample of elk is then collected and the number of marked and unmarked elk is recorded. The recapture is usually based on visual observations rather than physically capturing the elk (Raedeke et al. 1999). The population can be estimated based on the equation: $N = (M)(n)/(m)$, where N is the population size, M is the number of elk marked during the initial capture, n is the total number of elk recaptured, and m represents the number of marked animals during the recapture.

In big game populations, the most commonly used estimation technique is the change-in-ratio (CIR) method (Kelker 1940). It is based on the concept that if one identifiable sex or age class (antlered males) is hunted more heavily than another, selective removal will be reflected in differences in the pre-hunt and post-hunt sex ratios. If pre-hunt and post-hunt sex ratios can be estimated, along with the number of animals killed, both the pre-hunt and post-hunt populations can be determined (Raedeke et al. 1999). Population estimates are based on the equation: $N_1 = K (P_1 - b)/P_1 - P_2)$, where N is the pre-hunt population estimate, K is the total number of elk harvested, P_1 is the proportion of males in the post-hunt counts, P_2 is the proportion of males in the pre-hunt counts, and b is the proportion of males in the total harvest.

The use of population modeling has increased recently as a tool for estimating population size, analyzing proposed harvest recommendations, and determining the effects of predation and weather on the demographics of elk herds (Raedeke et al. 1999). The computer program, POP-2 (Bartholow 1995), is a simulation model that is commonly used by wildlife agencies. An initial population estimate, sex ratio, and reproductive and mortality rates are needed for simulations.

Another type of modeling that aids in the comprehension and conceptualization of the varying and interacting demographic rates that drive populations is system dynamic (Richmond 1993, Forrester 1994). The system dynamic modeling software, STELLA (STELLA, High Performance Systems, Hanover, New Hampshire, USA) allows the user to be flexible and incorporate important variables in their situation, which in turn can be manipulated giving the user a better understanding of the dynamics of the system. System dynamics and systems thinking aids in the comprehension and conceptualization of the varying and interacting demographic rates that drive populations (Richmond 1993, Forrester 1994).

Thermal scanners have also been used to estimate big-game populations. Currently, the accuracy of this technique is not at the level needed by most wildlife agencies. Computer-assisted analysis of infrared imagery recorded 52% fewer deer than drive counts, and densities of moose were 5 times greater than results obtained using conventional aerial methods (Garner et al. 1995).

Human Disturbance

Several papers have been written on the impacts of human disturbance on wildlife populations (e.g. Czech 1991). Human disturbance may have detrimental impacts on elk distribution (Morgantini and Hudson 1979). A result of persistent human disturbance can be the movement of elk from preferred habitat to smaller, less favorable areas (Batcheler 1968, Morgantini and Hudson 1979). Calves may imprint on less favorable, marginal habitat throughout life. Cow/calf pairs abandoned traditional calf-rearing areas under simulated mining disturbances (Kuck et al. 1985). Red deer (C. elaphus) and chamois (Rupicapra rupicapra) populations exposed to intense hunting restricted their distribution to marginal habitat, resulting in reduced productivity (Batcheler 1968). Elk in Yellowstone National Park responded to cross-country skiers by moving a median distance of 400-m in remote drainages when skiers approached, compared to a median distance of 15-m in areas where elk were conditioned to high human use (Cassirer et al. 1992). Skiers may affect elk survival or reproduction by increasing energy expenditures or displacing elk to less suitable winter habitat. Energy expended while moving away from skiers represented 5.5% of the estimated average daily energy expenditure of 6,035 kcal for elk in the winter, which is more than the normal estimated daily expenditure for movement (Nelson and Leege 1982). Additional energy must be expended in feeding to compensate for energy lost during movements that occur during flight responses to skiers. Increased metabolic rates may lead to reduced vigor, reduced reproduction, or death (MacArthur et al. 1982).

Security cover appears to be required by elk in the presence of human disturbance (Peek et al. 1982). Security is defined by Lyon and Christensen (1990) as "the protection inherent in any situation that allows elk to remain in a defined area despite an increase in stress or disturbance associated with the hunting season or other human activities." Hiding cover consists of vegetative or topographic terrain features, or a combination of these features, that allow elk to avoid detection by predators and other disturbances, or to escape when detected (Brown 1987). Lyon and Christensen (1990) defined hiding cover as vegetation sufficient to screen 90% of a standing elk from the view of a human at ≤ 61-m. Specific forms of human disturbance that will be further discussed and researched includes: timber harvest, agricultural crops, livestock, and roads.

Timber Harvest

Timber harvest and associated roads have an impact on elk hiding and security cover (Lyon et al. 1985). Security for elk can be met in any habitat that elk feel safe and will remain in during a disturbance (Lyon et al. 1985). Timber harvests should be managed to minimize loss of critical hiding and security cover. Elk avoided areas within 500-1000 m of active logging in Montana (Edge and Marcum 1985), whereas elk in south-central Wyoming preferred to be at least 800-m from active clear-cutting operations (Ward 1973). This displacement may reduce use of available habitat. Lyon and Jensen (1980) studied the use of clear-cuts in Montana and found that an animal's willingness to enter openings is influenced by the proximity to security cover and past experience in the available environment. Elk were observed in areas where timber harvest had occurred in previous years (Ward 1973). Hershey and Leege (1976) found that elk preferred clearcuts larger than 81 ha and were observed within 46 m of a timbered edge 80% of the time. Elk avoided areas within 400 m of a primary or secondary roads. Clearcutting, shelterwood, and selective harvest methods removed approximately 60% of an elk herd's summer and fall range in Idaho. The extensive logging and road system of 11.2 km road/km^2 reduced elk by 80% on their winter range and caused the elk to seek alternative habitats (Leege 1976). Cow elk exposed to timber activities did not abandon traditional home ranges when adequate cover was available within in their home ranges (Edge and Olson 1985). Logging disturbance may alter distribution to areas that are disturbance-free and provide cover within the traditional home range. Elk in Idaho preferred pole-timber habitats located more than

400 m from traveled roads with >75% canopy cover during the fall (Irwin and Peek 1983). Black et al. (1976) conducted research in Oregon and Washington that produced guidelines for managing forests and concluded that optimal habitat consists of 40% cover to 60% foraging areas. Cover should be managed in 12-24 ha blocks.

Agricultural Crops

Data are lacking that quantify the effects of agricultural crops on elk distribution. Areas with intensive agriculture are the least compatible with elk. Landowners may be willing to tolerate damage to haystacks or use of pastures, but are intolerant of losses to grain crops (Lyon and Ward 1982). The most common complaint concerning elk in Michigan was damage to oats (Moran 1973). Eight out of 10 elk reintroductions in the eastern United States failed due to incompatibility with agricultural crops (Witmer 1990).

The increased cultivation of alfalfa in Montana and Wyoming resulted in elk shifting home ranges and increasing use of land with lower elevations during the spring and fall (Van Dyke et al. 1998). Mule deer (Odocoileus hemionus) in Utah shifted their diets to include more alfalfa when other preferred forages became limited (Austin et al. 1984). Mule deer consumed an average of 2.2 kg of alfalfa/deer-night during April through September (Austin and Urness 1993). Elk in a confined environment with alternative forage preferred alfalfa and consumed a daily average of 1.06 kg oven-dry hay/100 kg live animal during June and July (Austin and Urness 1987). White-tailed deer (Odocoileus virginianus) at Desoto National Wildlife Refuge shifted their home ranges toward cornfields during the silking and tasseling stage of development

(VerCauteren and Hygnstrom 1998), whereas deer in Pennsylvania reduced alfalfa yields by 9-33% (Palmer et al. 1982). Adult male white-tailed deer in Illinois selected row crops during June through September (Nixon et al. 1991).

Elk damage to winter haystacks was first recorded in Utah about 1930 (Low 1955). The Utah Fish and Game Department attempted to ameliorate the damage by providing materials and building fences around highly impacted winter haystacks (Austin and Urness 1987). Damage caused by elk to haystacks and winter wheat fields in the Pine Ridge region of northwestern Nebraska increased in the mid-1980's (Schlichtemier, G., NGPC, pers comm.). Similar damage management techniques were initiated to alleviate damage caused by elk in Nebraska. Brelsford et al. (1998) reported that winter wheat field yields did not decline when <20 elk fed on fields during winter and spring and grazing diminished by early April.

Livestock

Elk tend to avoid cattle in summer if suitable habitats exist, and may change habitat use patterns as a result of livestock grazing (Christensen et al. 1993. Elk avoided cattle on summer ranges and were twice as likely to use areas when cattle were absent than when cattle were present (Lyon et al. 1985). Elk and cattle are socially compatible, but elk prefer areas at least 800 m from sheep herds (Ward et al. 1973). However, Mackie (1970) reported that elk are socially subordinate to cattle and therefore are displaced when they come into contact. Elk prefer spatial separation from cattle, although there is limited evidence of elk intolerance to livestock under conditions of limited resources (Brown 1987). Elk in the Black Hills of South Dakota vacated pastures stocked with cattle or selected habitats that were lightly stocked (Rice 1988). Elk use steeper slopes, range farther from water and may prefer more closed canopy stands than cattle (Mackie 1970). Lyon (1985) noted that interrelationships are complex and may depend on stocking densities, habitat quality, and season of grazing.

Yeo et al. (1993) studied the influence of rest-rotation cattle grazing on elk and deer habitat use in east-central Idaho. They found that elk preferred rested pastures during the cattle-grazing period (June-October) and avoided areas frequented by cattle by selecting habitats with higher elevations and steeper slopes. Within grazed pastures, elk used slopes >20 degrees twice as often as in rested pastures. Elk also selected forested habitats more frequently in pastures with cattle than in pastures where cattle were absent.

Properly managed cattle grazing can be beneficial to elk habitats. Grover and Thompson (1986) found that cattle grazing the previous summer was the greatest positive influence on habitat selection of elk the following spring. The Wall Creek Wildlife Management Area in Montana is a prime example of managing cattle grazing to improve elk ranges. Pastures are divided into high elevation (summer range), mid-elevation (spring, fall, winter range), and low-elevation pastures (winter range). The 10 divided pastures are all grazed periodically by cattle, but also rested to ensure regrowth. Smooth brome (Bromus inermis) and crested wheatgrass (Agropyron cristatum) stands under no livestock grazing had a greater accumulation of residual growth. Residual vegetation was removed by using a rest-rotation grazing system that allowed for the regrowth of succulent forage. As a result, elk use of private land during the winter has been nearly eliminated (Alt et al. 1992). Baumeister et al. (1996) similarly reported that cattle grazing improved grassland productivity, redistributed elk away from privately-owned to publicly-owned land, and reduced fire risks in Montana. Fire suppression and deferred grazing reduces grassland productivity. Managers in Montana now recognize that the best habitat available to elk is found in areas seasonally grazed by cattle (Baumeister 1994).

Roads

Elk during the calving season were more likely to use areas with topographic barriers between the use area and roads, and locations closer to low-traffic roads than high-traffic roads or areas without topographic barriers (Edge and Marcum 1991). Rost and Bailey (1979) reported that elk and mule deer avoided roads, particularly areas within 200 m of a road, while Czech (1991) reported that Roosevelt elk (C. e. roosevelti) avoided a 500-m corridor centered around a U.S. Forest Service (USFS) road at the Mount St. Helens National Volcanic Monument. Deer and elk populations may decline from avoiding roads and using marginal habitat (Rost and Bailey 1979). Elk with a high degree of road access in their home range avoided areas within 200 m of open roads, but elk with few or no roads in their home range used all areas in proportion to availability (Hershey and Leege 1982).

Based on an 8-year study in Montana, Lyon (1979, 1983, 1985 et al.) quantified the effect of roads on habitat effectiveness (ability of habitat to meet elk requirements for growth and welfare). Habitat effectiveness severely declined with road densities greater than 0.61km road/km^2. The location of selected spring feeding sites in Montana was positively correlated with distance from the nearest visible road and negatively correlated with distance from cover (Grover and Thompson 1986).

Adult male mortality was directly correlated with road densities on heavily forested public land in Idaho, where cover was not limiting (Leptich and Zager 1991). Sex ratios increased from fewer than 10 bulls per 100 cows to 20 bulls per 100 cows in areas where roads were closed. Extensive road closures partially mitigated the loss of habitat and security cover, but security values were highest in unlogged, roadless areas (Lyon and Canfield 1991). Elk in Idaho were able to occupy preferred habitats longer during the hunting season because of road closures (Irwin and Peek 1979). Road closures in Oregon reduced movements of elk and increased survival during the hunting season (Cole et al. 1997).

Calving Areas

Limited research has been done to characterize the micro-habitat parameters of elk calving areas. Calving areas in Idaho were characterized by 1) gently sloping (usually less than 15%) and often in dips in steeper slopes, and 2) a juxtaposition of tree cover, shrubs, and succulent forage close to water (Phillips 1966, Roberts 1974). Black et al. (1976) provided the following criteria for calving areas: escape and thermal cover in the form of forests for the cows, hiding cover in the form of shrubs or fallen timber for new-born calves, succulent forage available for lactating females, water within 305 m, and gentle terrain. Elk in Idaho calved in conifer timber, mixed with aspen (Populus tremuloides), adjacent to open habitat dominated by sagebrush (Artemesia spp.) or meadow (Phillips 1974). Overhead canopy cover ranged from

20- 60%, with an average of 37%. Herbage production under the timber types appeared to have little or no influence on habitat selection of calving areas. Moderate slopes were preferred, ranging from 10-55%, with an average slope of 36%. Elk showed preference for north and east aspects. Calving sites were positioned at or near the head of drainages with an average elevation of 2,587 m.

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CHAPTER 2:

DEMOGRAPHICS OF ELK IN THE NEBRASKA PINE RIDGE: A MODEL FOR MANAGEMENT.

Abstract: We used 522 visual observations of Rocky Mountain elk (Cervus elaphus nelsoni) from April 1995 to August 1997 to estimate the populations in the Bordeaux Creek and Hat Creek areas of the Pine Ridge region of northwestern Nebraska. The estimated number of elk in the Bordeaux Creek herd ranged from 59-77, with calf:cow ratios of 0.42-0.57:1 and bull:cow ratios of 0.29-0.42:1. The estimated number of elk in the Hat Creek herd ranged from 61-72, with calf:cow ratios of 0.43-0.51:1 and bull:cow ratios of 0.44-0.51:1. We developed a simulation model using STELLA for each herd from demographic rates determined from field observations and the scientific literature. Adult female survival was 92% and apparent adult male survival was 81%. All of our demographic parameters indicated that density-dependent controls were not operating on the 2 herds. The population model simulations predict that without hunting, each herd will approach 300 elk after 10 years. Simulations run with an annual harvest of no calves and yearlings, 22% (n = 6) of adult females and 75% (n = 6-9) of adult males stabilized each population near current estimates. The use of the developed model with demographic data collected from ground and aerial surveys in August, and periods of complete snow cover will assist managers ability to estimate future elk populations and establish harvest goals.

Keywords: demographic rates, elk, Cervus elaphus, modeling, population dynamics, population estimate, STELLA.

Swenk (1908) reported that elk were extirpated from Nebraska during the early 1880s. Elk reappeared in northwestern Nebraska during the 1960's presumably from the Rawhide Buttes in northeastern Wyoming. By the mid-1980s, the herd of elk in the Bordeaux Creek area rose to an estimated 40 animals, and were causing damage to crops on private agricultural lands. The Nebraska Game and Parks Commission (NGPC) initiated a hunting season during 1986 and 1987 to reduce the herd. Thirty elk were removed in the 2 seasons, decreasing the Bordeaux Creek herd to around 15. By 1994, elk numbers and depredation complaints were increasing in the Hat Creek area, and again in the Bordeaux Creek area. The resurgence of elk in northwestern Nebraska has been a complex and emotional situation between the NGPC and private landowners in the region. The NGPC held a series of public meetings in the early 1990s to address the future of elk and elk management in the Pine Ridge. After reviewing the comments at each meeting, the NGPC developed an elk management plan (Nebraska Game and Parks Commission 1995), which includes a population objective of a minimum of 100 elk in the Pine Ridge, with at least 6 mature bulls.

The NGPC was unable to achieve satisfactory estimates of the population and sex/age structure using aerial and ground surveys in 1994 and 1995. The lack of information about seasonal and annual distribution made classifications laborious with limited results. Accurate population and sex/age structure estimates are critical to the management of big game animals. An accurate method to estimate the demographics and a tool to predict growth is essential due to the vulnerability of these small and isolated populations of elk. Research results from this study may assist other state agencies with similar isolated populations in less traditional habitat, while mismanagement of such herds could easily lead to local extirpations.

The basic information for understanding any population are birth and death rates, age and sex composition, numerical abundance, and the nature and form of regulatory mechanisms (Eberhardt 1985). We seldom have all of the information necessary about the dynamics of a population to make sound management decisions (Eberhardt 1985). Typically, information for some parameters are missing and is gathered from a subsample of individual animals and applied to the entire population.

Big game populations are estimated using a variety of methods. The most commonly used estimation techniques are the change-in-ratio (CIR) method, popularized for deer by Kelker (1940) and the modeling software, POP-2 (Bartholow 1995) that allows users to provide demographic input and receive only output. The Wyoming Game and Fish Department (WGFD) uses POP-2 by estimating herd demographics primarily from winter aerial classifications (Ryder, T., Wyoming Game and Fish Department, pers comm.). Total population counts are generally limited to populations with very limited geographic ranges occupying relatively open terrains (Raedeke et al. 1999). Total winter counts have been conducted on the National Elk Refuge in Wyoming since the early 1960's (Boyce 1989). Mark-recapture techniques, known as the Petersen or Lincoln index, have a long history of use in assessing big game populations (Raedeke et al. 1999). Other estimation techniques include life tables, sightability models, sex-age-kill (SAK) models, and use of thermal scanners (Raedeke et al. 1999).

System dynamics modeling is another technique that is used to simulate the dynamics of a population. Unlike general input models, such as POP 2, where the user provides input and receives only output, system dynamic models allow the user to be flexible and incorporate important site specific variables, which in turn can be manipulated, giving the user a better understanding of the dynamics of the system. STELLA is a system dynamic modeling program that is user friendly, a good tool for relating population projections to the general public, and can incorporate as many variables as thought to regulate the population. Habitat, predation, competition, and environmental variables, as well as the interaction can be modeled to determine the population response. System dynamics and systems thinking aids in the comprehension and conceptualization of the varying and interacting demographic rates that drive populations (Richmond 1993, Forrester 1994). A good model allows for a better understanding of the processes that regulate the population.

Our objectives were to estimate the number of elk and sex/age structure of each herd, establish demographic rates, develop a population model, and design a survey method for the 2 herds of elk in the Pine Ridge region of Northwestern Nebraska.

STUDY AREA

The Pine Ridge, which lies in the northwest corner of Nebraska, is approximately 160 km long and 1-8 km wide covering approximately 120,000 ha. Two distinct study areas were used for this project, the Hat Creek area, located between Crawford and Harrison, and the Bordeaux Creek area, located east of Chadron (Figure 1). The 2 study areas were determined from annual home ranges of the 21 radio-marked elk.

The region is dominated by rugged ponderosa pine (Pinus ponderosa) forest, interspersed with relatively flat grassland pastures and agricultural fields. Predominant hardwood species associated with riparian areas include green ash (Fraxinus pennsylvanica) and cottonwood (Populus deltoides). Predominant grass species include big bluestem (Andropogon gerardii), little bluestem (Schizachyrium scorparium, and Kentucky bluegrass (Poa pratensis).

The Hat Creek area encompasses 44,035 ha, consisting of 47% ponderosa pine forest (of which 14% was burned in 1989), 50% grassland, and 3% agricultural crops. The Bordeaux Creek area encompasses 48,398 ha, consisting of 51% ponderosa pine forest, 46% grassland, and 3% agricultural crops. Agricultural crops, including alfalfa, oats, millet, and winter wheat are available seasonally to elk, with baled hay being available throughout the year. The 2 study areas consist of privately-owned (94%) and publicly-owned (6%) land with a limited road system that provides access to ranches. The public land is the NGPC and United States Forest Service (USFS).

METHODS

Capture and Radio-telemetry

Twenty-one female elk were captured using a helicopter and net-gun (Helicopter Wildlife Management, Salt Lake City, Utah, USA), ear-tagged and fitted with 150-151 MHZ radio-collars (Advanced Telemetry Systems, Insanti, Minnesota, USA). Elk were located by radio-telemetry, primarily using a vehicle-mounted, 9 element Yagi antenna. Two to 3 azimuths were taken daily at fixed receiver locations to locate the elk.

Population Estimation - Visual

We used a known-alive-elk survey that relied on the location of the radio-marked females. We visually observed elk 522 times during 1995-1997. We determined the number of females and calves from combined classifications conducted in late-July-August and December- February during crepuscular periods when elk where grouped and using open habitat, such as agricultural fields. Visual classifications were also used to determine calf:cow and bull:cow ratios, as well as herd population demographic estimates during 1996 and 1997. Procedures used in this study were approved by the University of Nebraska Institutional Animal Care and Use Committee (IACUC # 94-09-075).

No male elk were radio-marked in this study, but we were able to use radio-marked females to locate herds that contained males. Classification of males was most successful during late July and August when pre-rut males were grouped in bachelor herds feeding on agricultural crops. Occasional observations of large groups with >5 males occurred during the winter months. We recorded males as either spikes (yearlings), or adults. When possible the number of antler points were recorded.

Population Estimation - Computer Modeling

Modeling Software

We used simulation modeling software (Stella, High Performance Systems, Hanover, New Hampshire, USA) to make the model of elk in the Pine Ridge (Figure 2). Variables that add to the population and increase the population (births and survival) are delineated by double-line arrows that point to the box representing the appropriate cohort. Double-lined arrows pointing away from the cohort box represent demographic variables that decrease the size of the population (natural or hunting mortality). Single-lined arrows represent feedback loops that determine the regulating process. For example, the number of calves produced is dependent on the number of females in the population and the recruitment rate. We conducted simulations with variable demographic rates and used sensitivity analysis to evaluate the population response of each herd to varying harvest rates.

Model Construction

Our population model is based on the general population equation:

$$N_{t+1} = N_t + N_t(b_t + i_t - d_t - e_t)$$

where N_t is the population size, while b_t, i_t, d_t, e_t are per capita rates of birth, immigration, death, and emigration at time *t*, respectively. We assumed that emigration rate was 0, based on the 2 years of data in which none of the 21 radio-marked female elk in the study areas emigrated from their established home ranges. In addition, we assumed that immigration rate was 0, based on the distance the Pine Ridge is from any established elk population. The Rawhide Buttes, Wyoming are approximately 50 km from the Pine Ridge and the Black Hills, South Dakota are approximately 120 km from the Pine Ridge. Based on size requirements, the Pine Ridge could support between 2,000-2,500 elk if only ponderosa pine forest is considered as suitable habitat (Schonewald-Cox 1986). The grazing of cattle reduces the number of elk that can be supported on the Pine Ridge. We believe that the Pine

Ridge can support between 500-1,000 elk after accounting for the decreased availability of forage due to cattle grazing. The current number of elk in the Bordeaux Creek and Hat Creek herds is approximately 150. Therefore, we did not incorporate a density-dependent function in the model because elk populations in the Pine Ridge were the low with high intrinsic rates of increase (r) and far less than carrying capacity (K). Further, examination of harvested animals indicated that elk were in excellent body condition.

The default values in the model are mean annual estimates of demographic rates. We allowed demographic rates of calving, and adult female and male survival to vary randomly within the 95% confidence interval. Yearling and calf survival remained constant because we obtained these rates from the scientific literature. We also incorporated sliders to allow users to set any rate before running a simulation.

Input Variables

We first began by dividing elk into 5 cohorts (calves, yearling females, adult females, yearling males, and adult males). We assumed a 50:50 sex ratio at birth based on results from Johnson (1951) and Picton (1961) in Montana. Reliable visual identification of yearling females in the winter is nearly impossible (McCorquodale et al. 1988, Eberhardt et. al 1996), therefore we estimated the initial number of yearling females in 1996 by counting the number of yearling males (spikes) and assuming that the 2 yearling cohorts were equal (McCorquodale et al. 1988, Eberhardt et. al 1996). The number of yearling males and females in 1997-1999 was estimated by the number of calves present the previous winter. Adult males were classified in late July-August when they were in small bachelor groups before the rut. The number of females and calves were determined from late summer (late July-August) and winter (December-January) classifications. We were interested in the number of calves expected to survive and add to the population. Therefore, we determined annual recruitment (calving rate) from the calf:cow ratios conducted in the late winter months during 1996-1999 (Eberhardt et. al 1996).

We used MICROMORT to estimate annual survival and cause-specific mortality for adult females (Heisey and Fuller 1985). At the end of the study we classified each radio-marked female as alive, dead, or censored. Censored individuals were those whose fate was unknown (Van Deelen et al. 1997). The only causes of mortality we identified were hunting or natural causes. We used the calf and yearling survival estimates determined by (Lowe 1969, Eberhardt et al. 1996) on lightly or unhunted herds. We calculated apparent adult male survival (excluding hunting mortality) by dividing the number of adults (including harvested males) by the previous year's adults and spikes (Eberhardt et al. 1996). We used ANOVA to determine if adult male survival could be pooled among years and between study areas.

Rate of Increase

We calculated finite rates of increase (λ) as $[N_{t+1}/N_t]$ and intrinsic rates of increase ($\underline{r}$) = $\ln [N_{t+1}/N_t]$ with harvested elk included in the N_{t+1} population size, assuming the elk harvested in September would have survived until winter counts in December and January. Rate of increase was an indicator used to determine whether density-dependent controls were operating on the 2 herds.

Population Model Simulations

We ran simulations with the estimated input variables to assess the accuracy of the model compared to visual estimates. Simulations were run without hunting mortality. We assumed that elk harvested in September or October would have survived to late December and January, thus harvested elk were added to the observed population estimate and compared to the model predictions.

We simulated the population growth of the Bordeaux Creek herd from January 1987 to January 1996 and compared it to the 1996 visual estimate, including elk harvested in September 1995. The best estimate of the number of elk in the Bordeaux Creek herd after the 1987 hunting season was 15 (Schlichtemeier, G., Nebraska Game and Parks Commission, pers comm.). We based the sex/age structure of the 1987 estimate on the current structure of the Bordeaux Creek herd. We simulated the population growth of 6 adult females, 2 yearling females, 1 adult male, 2 yearling males, and 4 calves. Simulations were run with a constant calving rate of 0.45, based on the 1996-1999 average, and by allowing the rate to vary within the 95% confidence interval. No simulations were run on the Hat Creek elk because no data were available for 1987.

We annually simulated the growth of field demographic estimates for 3 years beginning with the 1996 visual estimates in each herd. Annual model simulations were compared to the following year's estimate, including harvested animals. In addition, we ran 3 simulations with variable harvest rates for 10 years, starting in 1999. We wanted to determine the response of each herd to different harvest rates. The first was run without hunting mortality (no harvest), the second with an annual harvest of 22% of adult females and 75% of adult males (medium harvest), and third with harvest levels approximating the 1998 Bordeaux Creek harvest of 35% removal of adult females, 18% of calves, and 42% of adult males (high harvest).

RESULTS

Population Estimates and Sex/Age Structure - Visual

The number of elk in the Bordeaux Creek herd was estimated between 59-77, while the Hat Creek herd estimates ranged from 61-72, during 1996-1999 (Table 1). The Bordeaux Creek herd currently consists of 54% females, 23% males, and 23% calves, while the Hat Creek herd is comprised of 51% females, 26% males, and 23% calves. The age structure of the Bordeaux Creek herd is currently 42% adult females, 15% adult males, 20% yearlings, and 23% calves. The age structure of the Hat Creek herd is currently 39% adult females, 18% adult males, 20% yearlings, and 23% calves. The calf:cow ratios of the 2 herds were 0.31-0.57, while the bull:cow ratios were 0.29-0.51 (Table 2).

Demographic Rate Estimates

The survival rate of adult females was 92% (CI = 0.001). Cause-specific rates of mortality included: 5% hunting mortality (CI = 0.002), 1% natural causes (CI = 0.0001) and 2% censored (CI = 0.0001). The average calving rates were 45% (CI = 17) in the Bordeaux Creek herd and 46% (CI = 6) in the Hat Creek herd. The apparent adult male survival, excluding hunting mortality, averaged 81% and was similar between areas ($F_1 = 0.26$, $P = 0.62$), so the data were pooled. Yearling and calf survival were estimated to be 92%, based on (Lowe 1969 and Eberhardt et al. 1996).

Rate of Increase

The λ averaged 1.25 (range = 1.19-1.35) in the Bordeaux Creek herd and 1.22 (range = 1.17-1.25) in the Hat Creek herd during 1996-1999. The Bordeaux Creek $\underline{r}$ averaged 0.22, while the average $\underline{r}$ for the Hat Creek herd was 0.20. Herd growth is between 17% and 35%, but is being controlled by harvesting 7-33% of each herd.

Population Estimates - Computer Modeling

Bordeaux Creek - 1987-1996

Simulations run on the 1987 Bordeaux Creek estimate of 15, with an annual calving rate of 0.45 resulted in 55 elk in 1996, which was within 82% of the 1996 estimate that included visual observations and harvested animals. Adjustment of the calving rate to be randomly selected within the 95% confidence interval each year resulted in 73 elk in 1996, which was 8% higher than the visual estimate.

Bordeaux Creek and Hat Creek - 1996-1999

The population estimates based on computer simulations are very similar to those based on visual estimates for both herds (Table 3). Model simulations predicted the total number of females in the Bordeaux Creek herd between 39-50, during 1997-1999, while estimates from visual observations were 40-53. The total number of females in the Hat Creek herd were simulated between 38-42, while estimates from visual observations were 36-43. The model predicts that 72 elk will persist in the Bordeaux Creek Herd and 84 in the Hat Creek Herd during January 2000.

Variable Harvest Rates (Low-Medium-High) , 1999-2009

Simulations with no harvest (low) allowed both herds to increase in an exponential fashion with a doubling time of approximately 3.5 years. The model predicted that the Bordeaux Creek population would be 267, and the Hat Creek at 301, after 10 years (Figure 3).

Medium harvest rates, with removal of 22% of adult females, and 75% of adult males maintained the Bordeaux Creek and Hat Creek populations near current estimates. The simulations with a medium harvest rate predicted that the Bordeaux Creek population in 2009 (60) would be similar to the 1999 population estimate (61). The model simulated that the Hat Creek population would also be similar after 10 years.

The high harvest simulations with removal of 35% of adult females, 18% of calves, and 42% of adult males predicted that both herds will steadily decline. The Bordeaux Creek population simulation resulted in a decrease from 61 to 21, while the Hat Creek herd decreased from 72 to 23, during the 10-year period. Simulations indicated that both herds would contain fewer than 10 adult females.

DISCUSSION

Population Estimates and Sex/Age Structure - Visual

The population estimates generated from visual observations are expectedly low. The abundance of elk in the Pine Ridge is low, which increases the need for estimates to be as accurate as possible. We feel that conservative estimates were most appropriate because surveys that would overestimate this small population could lead to severe overharvest during hunting seasons. The current population estimates are above the NGPC objective of maintaining at least 100 elk in the Pine Ridge.

The sex ratios of both herds resemble those found in healthy herds in a National Park (DeSimone et al. 1993). Hines et al. (1985) concluded that 3 - 10 >2-year-old bulls:100 cows were necessary during the rut to ensure optimal breeding. At least 4 mature males are currently in each herd, which is above the NGPC objective and the required number of males necessary for optimal breeding. The calf:cow ratios of the Pine Ridge elk are similar to those reported by Eberhardt et al. (1996) in a small isolated herd in eastern Washington and to those seen across Wyoming (Ryder, T., Wyoming Game and Fish Department, pers. comm.).

Survival and Cause-Specific Mortality

Hunting is generally the major source of mortality in hunted elk populations (Peek et al. 1967, Kimball and Wolfe 1974, White 1985, Leptich and Zager 1991, Unsworth et al. 1993). Adult female survival (92%) in the Pine Ridge is similar to Colorado (91%, White 1985), Idaho (89%, Unsworth et al. 1993), and Oregon (89%, Stussy et al. 1994). The high survival of adult female elk in the Pine Ridge is likely due to the limited number of permits, difficulty obtaining permission to hunt on private land, lack of a significant density of a major predator, mild winters, and year-round availability of agricultural crops for forage. The highest mortality factor for adult female elk in the Pine Ridge was hunting (5%) and is likely the highest source of mortality for adult males. Mortality due to hunting is the demographic rate managers can most effectively manipulate to meet management goals.

Density Dependence and Rate of Increase

McCullough (1979) reported that density-dependent changes in white-tailed (Odocoileus virginianus) deer, like other K-selected species, occur at population levels close to carrying capacity. Research has shown that the more K-selected the species, the more constant the intrinsic rate of increase (r) is at low densities and slower the rate of population growth (e.g., elephant Loxodonta africana) (Woodberg 1964, Laws 1966, Craighead et al. 1974). On the other hand, life history strategies of the white-tailed deer are closer to a r-selected species with high rates of increase at low densities and rapid population growth (McCullough 1992). Our data indicated that elk in the Pine Ridge are not being affected by density-dependent controls. The current estimate of the elk populations in the Bordeaux Creek and Hat Creek areas is approximately 150 and likely no where near K. The herds exhibited low population sizes with high r, low mortality rates, no evidence of emigration, and individuals were in excellent condition. The average r for Pine Ridge elk herds was 0.21, which is similar to a colonizing herd in Washington that had a r of 0.20 during the first 11 years of growth (McCorquodale et al. 1988). Gogan and Barrett (1987) calculated r_m as 0.31 for an introduced elk population in California, whereas Murphy (1963) calculated r as 0.25 for a captive herd in Missouri. These r values likely approximate the maximum rate of increase for elk.

Population Modeling

Population estimates from visual observations validate our model predictions and associated assumptions - no density dependence, immigration, or emigration. The computer simulation of the Bordeaux Creek herd, 1987-1996 strengthens the 1996 visual population estimate. The population model developed from the demographic rates generated from field observations and scientific literature appear to simulate the Bordeaux Creek and Hat Creek herd dynamics very well.

The 1997-1999 annual simulations and field estimates also were very comparable in both herds. The system dynamics model will aid managers in estimating future elk populations and establishing harvest goals with a high degree of confidence. The model simulations indicate that to maintain the current number and sex/age ratio of each herd, 22% (n = 6) of the adult females and 75% (n = 6-9) of adult males should be harvested each year. Below these levels the populations will continue to increase. Simulations run with an annual harvest of 35% of adult females, 18% of calves, and 42% of adult males resulted in both herds decreasing to less than 25 animals after 10 years.

The model can also be adjusted to easily estimate the number of hunting permits needed to accomplish harvest objectives. For example, to sustain the number of elk in each herd based on the average hunter success rate from the 1995-1998 seasons, it will require issuing 13 antlerless and 9-13 either sex permits in the Bordeaux Creek Unit, and 20 antlerless and 8-12 either sex permits in the Hat Creek Unit. This assumes that hunters drawing an either sex permit will continue to select a male to harvest.

Minimum Viable Population

The current abundance of elk is low, and may pose long-term genetic problems. Schonewald-Cox (1986) suggested that the number of elk required to prevent population-wide loss of genetic diversity due to genetic drift is 1,500-2,000. The minimum viable population size, which is the smallest isolated population that has a relatively high probability of remaining extant for an extended period of time, for elk is 75, of which half should be breeding females (Towry 1984). According to current population estimates, both the Bordeaux Creek and Hat Creek herds are slightly below 75. Based on the lack of emigration of radio-marked female elk (n = 21), we feel that the 2 herds are currently functioning as discrete populations, rather than a metapopulation.

Population Survey Design

Unsworth et al. (1990) recommend surveying elk when group sizes are at a maximum and when they are using the most open habitats. This situation occurred in the Pine Ridge elk herds during late July-August when females were concentrated around alfalfa, oat, and millet fields, and late November-January when Bordeaux Creek elk increased use of winter wheat fields and the feedground, while Hat Creek elk fed in open grassland habitat and on stored hay (Stillings, ch. 3, 1999).

Male elk should be classified during 24 July - 31 August when they are congregated in small bachelor groups and feeding on alfalfa, oat, or millet during crepuscular periods. Elk typically exhibit a strong fidelity for seasonal and annual home ranges (Rudd et al. 1983, Edge and Marcum 1985, Edge et al. 1986, Smith and Robbins 1994). During the 3 summers of field work in the Pine Ridge, elk were observed on the same fields each year. Calf:cow groups also formed on these fields, allowing for initial classifications.

During the winter, elk in the Pine Ridge frequented the same areas year after year. Ground surveys should be conducted during December and January when sufficient snow cover is present to produce the best estimates of females, calves, and recruitment rates.

Wildlife departments in Wyoming and Colorado survey elk before and after hunting seasons to develop estimates of herd composition (Ryder, T., Wyoming Game and Fish Department, pers comm.). Aerial surveys are conducted with helicopters at low speeds and ground surveys are aided with spotting-scopes. Both states have large data sets that include the ages of harvested animals to assist with estimating herd composition. Population simulations are run using POP-2 (Bartholow 1995).

We recommend that the NGPC initiate annual surveys to improve and maintain elk population demographic estimates. We suggest 1 of 3 options: Option 1 -- ground observations of agricultural crop fields in August and core winter areas in December and January within the Bordeaux Creek and Hat Creek study areas, Option 2 -- ground observations and helicopter surveys of agricultural crop fields in August and core winter areas in December and January within the Bordeaux Creek and Hat Creek study areas, or Option 3 -- implement Option 2 with additional ground and helicopter surveys of alfalfa and grain crops and potential wintering areas outside of the Bordeaux Creek and Hat Creek areas.

Option 1 -- Ground Surveys -- Bordeaux Creek and Hat Creek Areas

The goal of Option 1 is to produce the best estimate of the maximum number of elk known to be alive in the Bordeaux Creek and Hat Creek areas before seasons are set by the NGPC. Managers will be able to simulate annual growth to estimate populations and make harvest recommendations.

Conduct summer ground surveys (24 July-31 August) during crepuscular periods by visually observing the agricultural fields within Sections 1, 2, 10, and 11 of T31N R48W, and 35 and 36 of T32N R48W in the Bordeaux Creek area, and Section 30 of T32N R54W, Section 1 and 7 of T32N R54W, Sections 5, 6, and 33 of T32N R55W, and Section 19 T33N R53W in the Hat Creek area.

During the winter, elk in the Pine Ridge frequented the same areas year after year. Ground surveys should be conducted during December and January with sufficient snow cover to maximize reliability of counts. Effort should be focused in Sections 19-33 of T33N R47W in the Bordeaux Creek area, and Sections 6-12 in T32N R55W, Sections 1-12 in T 32N R56W, and Sections 13-36 in T 32N R54W in the Hat Creek area.

The ground survey method has been used in Nebraska since 1996 to develop population estimates. They are reliable and provide the opportunity to communicate with landowners outside of public meetings. The time spent in the field surveying elk may provide additional data on bighorn sheep (Ovis canadensis), deer (Odocoileus spp.), and turkey (Meleagris gallopavo) populations.

Limitations associated with ground surveying include the amount of time needed to attain a true representation of the herd composition and land access. Summer classifications will require at least 20 surveys during crepuscular periods and approximately 60 hours to adequately classify the number of adult males and to gather initial calf and female estimates. Winter classifications will require at least 10 surveys and approximately 30 hours to estimate the number of females and calves in the 2 herds. Time must also be spent obtaining permission from landowners to conduct surveys. Option 1 will produce satisfactory estimates of the Bordeaux Creek and Hat Creek populations, but will not account for elk outside these areas.

Option 2 -- Ground and Aerial Surveys -- Bordeaux Creek and Hat Creek Areas

This procedure is very similar to Option 1 (Ground surveys) and methods used in western states. The goal of Option 2 is to estimate the maximum number of elk known to be alive within the entire Bordeaux Creek and Hat Creek study areas, and to decrease survey time and likelihood for double-counting elk.

Conduct surveys during 24 July - 31 August, and December and January. Ground survey areas defined in Option 1 to attain initial classifications and verify elk use. In addition, helicopter surveys should be conducted after elk have been observed using open agricultural fields during the late summer or areas of open habitat during the winter. Aerial survey all seasonal high-use areas (Figure 4) within herd home ranges over consecutive days, as long as conditions remain optimal, until each area is examined. Optimal conditions required for successful summer aerial surveys are the crepuscular period following nights without thunderstorms, and wind $<$ 32 kmph (20 mph). The optimal condition for a winter aerial survey is the sun-rise of a day with calm wind following a significant snowstorm.

Aerial surveys were ineffective for the NGPC in the early 1990s because of limited information on seasonal and annual distribution. The increased understanding of seasonal herd home ranges and verified ground observations will increase the efficacy and cost-effectiveness of aerial surveys. Aerial surveying high-use areas when elk are using open habitat will provide a thorough search within a 3 to 4 day period, decrease the time spent surveying and likelihood of double-counting animals. Late summer and winter aerial surveys flown at low speeds should produce an accurate and relatively complete estimation of the sex and age structure of the Bordeaux Creek and Hat Creek herds.

Potential limitations are the inability to conduct aerial surveys when elk are using open habitat. Elk were observed from the ground feeding on agricultural fields during low-light conditions during the early-morning and late-evening hours of late-summer. Elk began moving toward forested cover before sunrise. The lack of adequate light to fly may reduce the effectiveness of helicopter surveys due to poor visibility when elk are under relatively closed canopies. The limited amount of optimal surveying conditions before sun-rise may also limit the number of areas flown in a morning and increase the time and cost of the survey.

Option 3 - Ground and Aerial Surveys -- Pine Ridge Area

The goal of Option 3 is to estimate the number of elk in the entire Pine Ridge area. The previous 2 study options only generate data for the Bordeaux Creek and Hat Creek study areas.

Implement Option 2 -- Ground and Aerial Surveys -- Bordeaux Creek and Hat Creek areas, and then aerial survey areas of high-use habitat types that are currently thought to be non- or low-use areas. Survey alfalfa and grain fields after the 24th July - September in the following areas: Ash Creek, White River, Ponderosa, Peterson, and

Metcalf Wildlife Management Areas (WMA). Aerial survey these areas during periods of complete snow cover after the Bordeaux Creek and Hat Creek study areas are surveyed.

A survey of the entire Pine Ridge may increase understanding of elk abundance and distribution in areas outside of the Bordeaux Creek and Hat Creek study areas, but we believe the cost of the additional flight-time is likely greater than potential output gained from such a survey. At this time, we suggest implementing a survey that accounts for random landowner observations in areas thought to be low- or non-use areas.

Landowner Observations

NGPC should establish a procedure that landowners can use to report elk sightings outside of the Bordeaux Creek and Hat Creek areas. We recommend the NGPC mail a memo to those residing in areas of the Pine Ridge that are not currently used by elk that requests the date, location, number, and composition of elk observations. These additional observations will allow NGPC field biologists to verify sightings and direct field surveys. Benefits of a landowner survey include: improved public relations, better understanding of elk abundance and distribution, and potential prevention of elk damage problems.

MANAGEMENT RECOMMENDATIONS

We recommend that the NGPC implement the ground and aerial survey specified in Option 2 to collect accurate and complete population demographic estimations of the Bordeaux Creek and Hat Creek study areas. In addition, the

STELLA population model should be used to incorporate demographic data, and to estimate future populations and set seasons according to management objectives. The population model should not be a replacement for field surveys. Models are only as good as the input data. Continued surveys will provide further validation and improved demographic rate estimates that can be incorporated into the model.

The use of a landowner reporting procedure should be implemented to increase agency awareness of elk observations across the Pine Ridge. Unexpected population increases and depredation complaints would be minimized, while improving landowner relations in the Pine Ridge.

We recommend that both herds be maintained above the minimum viable population of 75 and within levels tolerable to landowners. We suggest maintaining 75-100 elk in the Bordeaux Creek and Hat Creek herd, including 50% adult females and at least 3 mature males. The Bordeaux Creek herd will require an increase of approximately 15 elk and less than 5 in the Hat Creek herd to meet these population objectives. A 1-year reduction in harvest will allow the Bordeaux Creek herd to approach 75. Consideration should be given to having an antlered only season in the Bordeaux Creek Unit. An antlered only season would allow females to increase while maintaining adequate sex ratios, and still provide hunters recreational opportunities. The Hat Creek herd is likely above 75 since estimates are from known-alive-elk surveys. A medium harvest with annual removal of 6 females and 6-9 males should maintain this population $\geq$ 75 animals. Management of elk in northwestern Nebraska should be adaptive to meet population objectives and adjust to unforeseen stochastic events.

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Table 1. Visual estimate of the number of elk occupying the Bordeaux Creek and Hat Creek areas of northwestern Nebraska, 1996-1999.

Year	Females	Males	Calves	Total
Bordeaux Creek				
1996[a]	33	10	16	59
1997[a]	35	10	20	65
1998[b]	45	18	14	77
1999[b]	33	14	14	61
Hat Creek				
1996[a]	32	14	15	61
1997[a]	35	18	18	71
1998[b]	37	18	16	71
1999[b]	37	19	16	72

[a] Estimated from visual observations by University of Nebraska graduate students and technicians.

[b] Estimated from visual observations by Nebraska Game and Parks Commission biologists.

Table 2. Ratios of calves and males per female elk in the Bordeaux Creek and Hat Creek herds of northwestern Nebraska, 1996-1999.

Year	Calves:Female	Males:Female
Bordeaux Creek herd		
1996[a]	0.48	0.33
1997[a]	0.57	0.29
1998[b]	0.31	0.40
1999[b]	0.42	0.42
Hat Creek herd		
1996[a]	0.47	0.44
1997[a]	0.51	0.51
1998[b]	0.43	0.49
1999[b]	0.43	0.51

[a] Estimated from visual observations by University of Nebraska graduate students and technicians.

[b] Estimated from visual observations by Nebraska Game and Parks Commission biologists.

Table 3. Population estimates of elk in Northwestern Nebraska, based on visual observations (O) and STELLA computer model simulations (S), 1996-1999.

	Females		Calves		Males		Total	
Year	O	S	O	S	O	S	O	S
Bordeaux Creek herd								
1996	33		16		10		59	
1997	40	39	20	14	12	19	72	70
1998	53	43	14	16	21	24	88	83
1999	51	50	17	20	24	23	92	93
2000		39		15		18		72
Hat Creek herd								
1996	32		15		14		61	
1997	36	38	18	16	21	19	75	73
1998	43	42	18	18	27	24	88	84
1999	42	42	16	18	25	24	83	83
2000		43		18		23		84

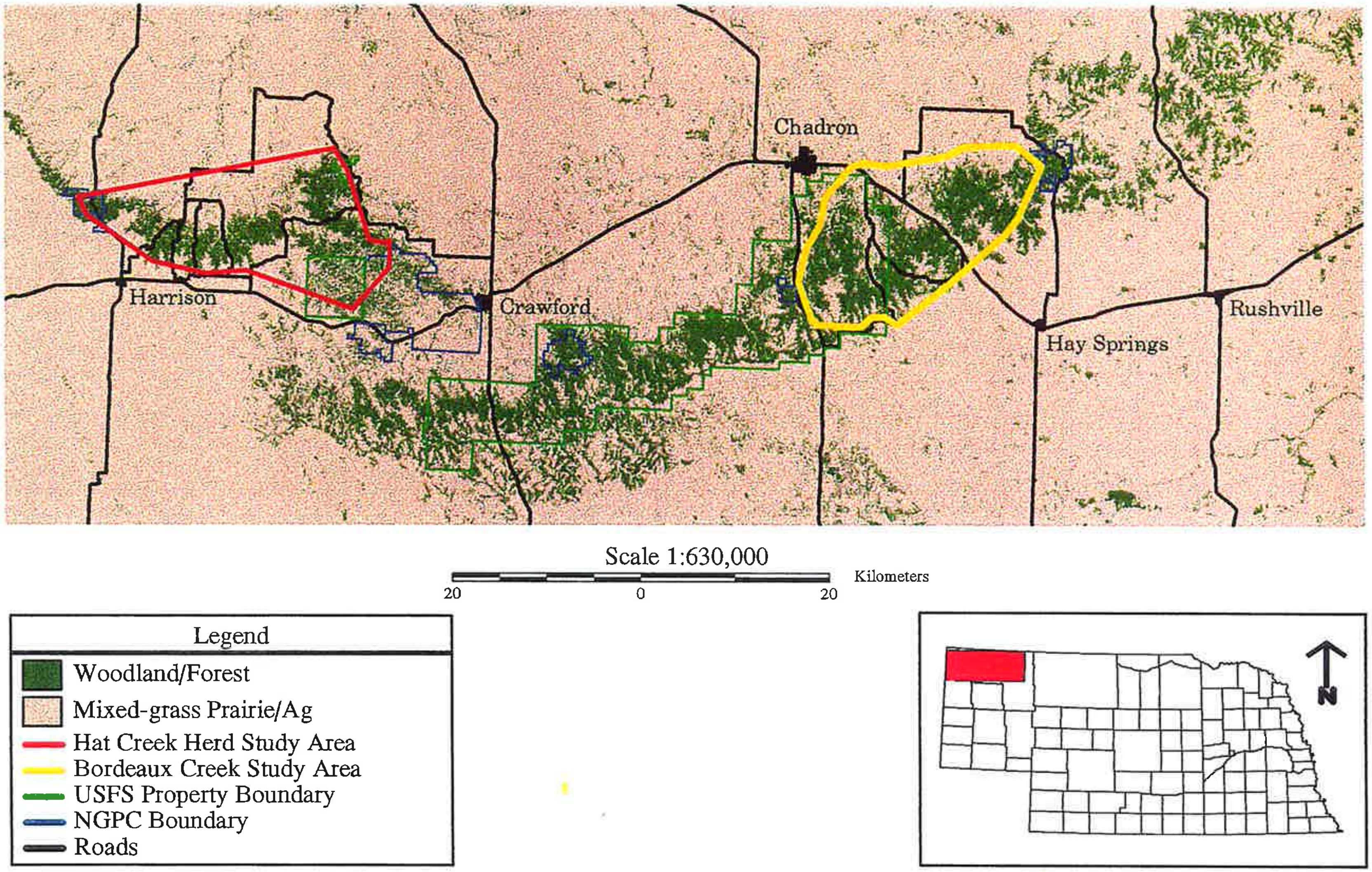

Figure 1. Pine Ridge region of northwestern Nebraska.

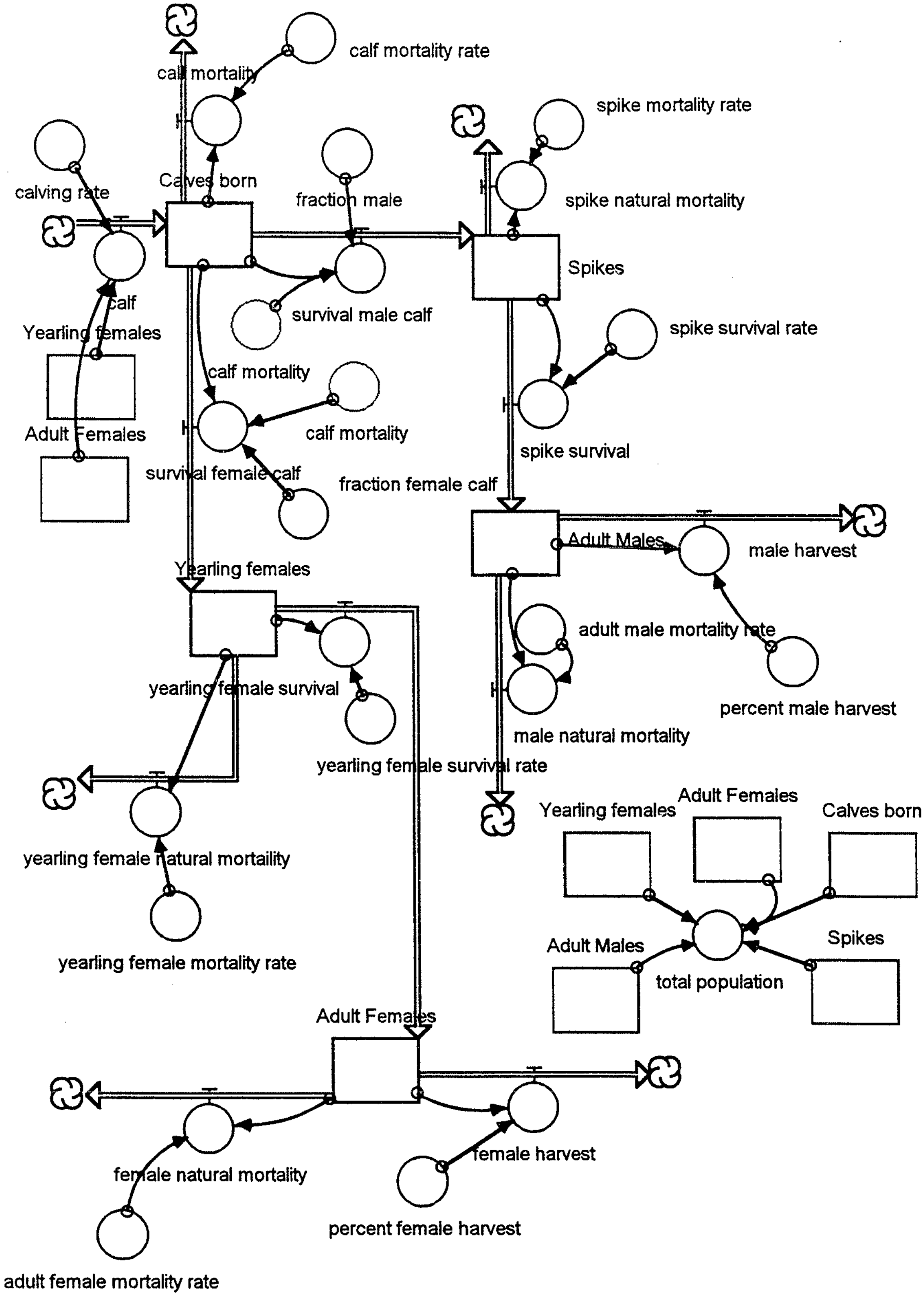

Figure 2. Population model of elk in the Pine Ridge region of northwestern Nebraska.

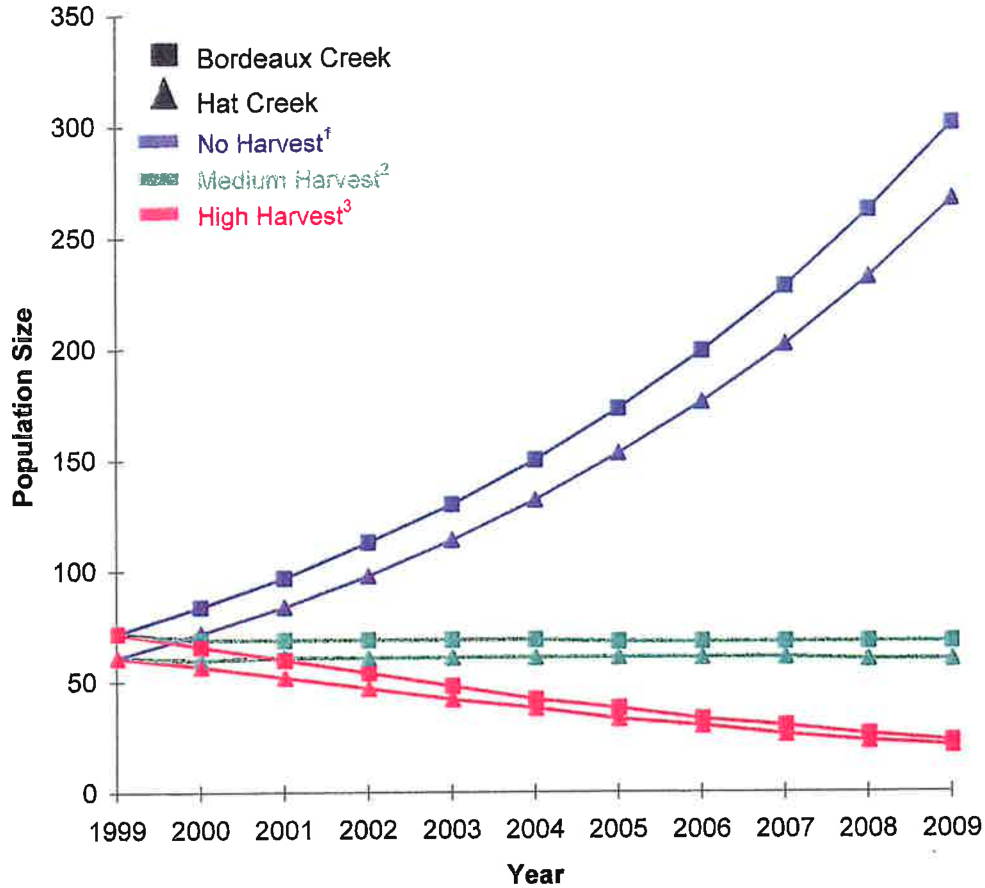

Figure 3. Population model simulations of elk in northwestern Nebraska under 3 harvest regimes, 1999-2009. ([1] no harvest, [2] annual harvest of 22% of adult females and 75% of adult males, [3] annual harvest of 35% of adult females, 42% of adult males, and 18% of calves).

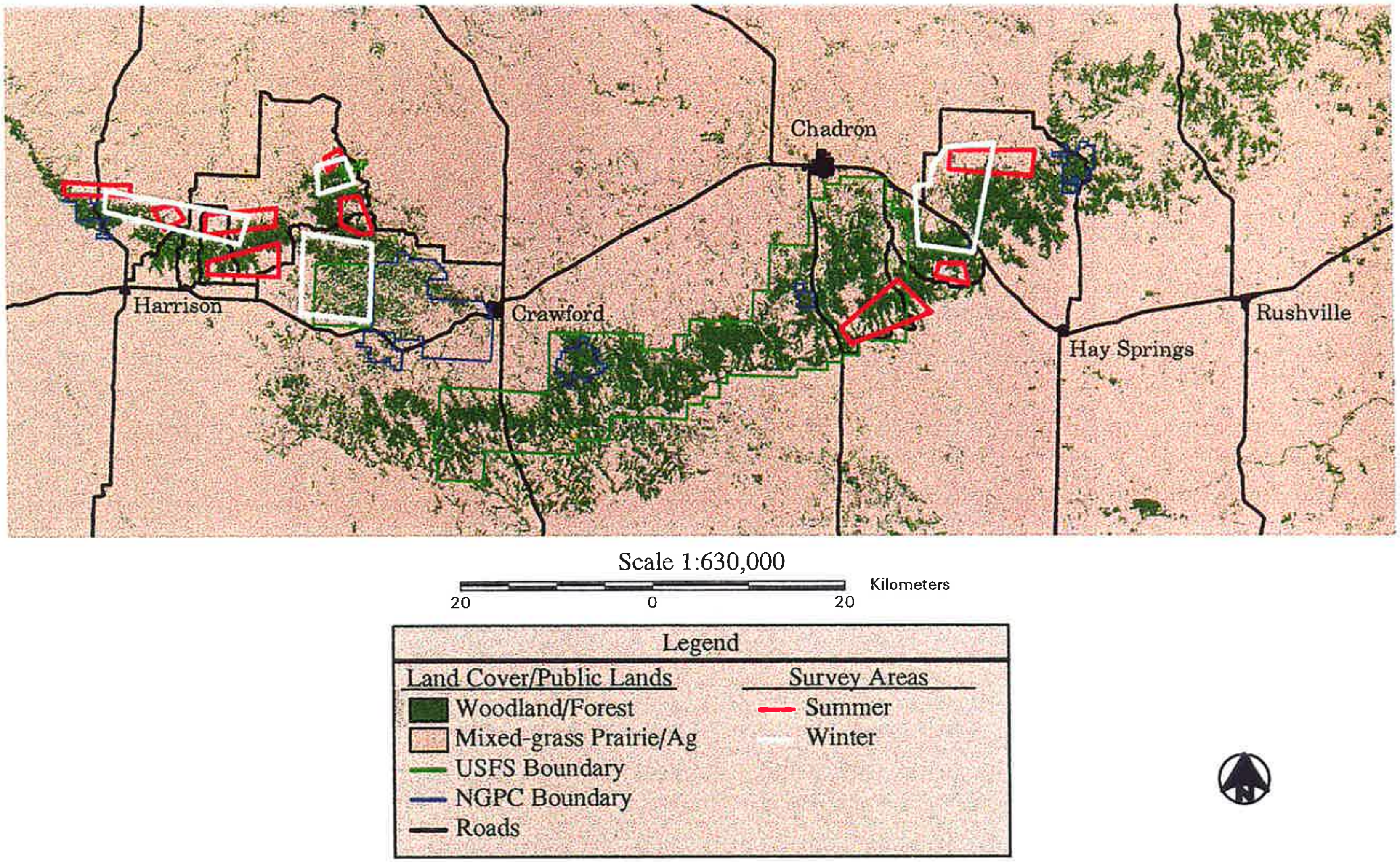

Figure 4. Summer and winter survey areas in the Hat Creek and Bordeaux Creek study areas.

Appendix A. Number of elk harvested in the Bordeaux Creek (BC) and Hat Creek (HC) Units in northwestern Nebraska, 1995-1998.

Year	Unit	Females	Calves	Males
1995	BC	4	1	3
	HC	3	1	2
1996	BC	5	0	2
	HC	1	0	3
1997	BC	8	0	3
	HC	6	2	9
1998	BC	18	3	10
	HC	5	0	6

CHAPTER 3:

EFFECTS OF HUMAN DISTURBANCE ON FEMALE ELK IN THE PINE RIDGE REGION OF NORTHWESTERN NEBRASKA.

Abstract:

Twenty-one female Rocky Mountain elk (Cervus elaphus nelsoni) were radiotracked for 5789 elk days in the Pine Ridge region of northwestern Nebraska from April 1995 to August 1997 to determine the effects of active timber harvest, agricultural crops, cattle, roads and houses on elk distribution. Radio-collars were placed on female elk in two distinct herds; the Bordeaux Creek herd located east of Chadron and the Hat Creek herd, which is located west of Crawford. Active timber harvest was found to temporarily displace elk. The distance between home range centers of elk exposed to logging ($\bar{x}$ = 5554 m, CI = 1048, n = 37) was larger than the distance moved of elk not exposed to logging ($\bar{x}$ =3337 m, CI=743, n = 44; t_{79} = 1.99, P = 0.0006). Elk responded to summer agricultural crops by reducing and shifting home ranges approximately 2.5 km toward crops after the second cutting of alfalfa, and maturation of oats and millet during the late dough-stage. Winter elk distribution in the Bordeaux area was driven by the onset of the feedground. Mean distance from home range centers to the feedground was significantly reduced after supplemental feeding began ($\bar{x}$ = 2323 m, CI = 1432, n = 9; t_8 = 8.4, P < 0.0001). Initial stocking of cattle occurred at the same time as the calving season. Elk responded to cattle by moving out of recently stocked pastures and reducing the size of their home ranges. Road density and amount of travel were the two most important variables

quantifying differences between elk use and non-use areas. Areas with greater than 0.51 km road/km^2 and a road use index larger than 1650 are predicted to be avoided by elk.

Keywords: agricultural crops, *Cervus elaphus*, elk, home range, housing density, human disturbance, radio-telemetry, roads, timber harvest.

Elk responses to human disturbance have been a major concern for land managers, especially in western states. Elk have been displaced from areas disturbed by active timber harvest (Lyon et al. 1985, Edge and Marcum 1985), road construction (Lyon 1979a, Rost and Bailey 1979, Lyon 1983, Czech 1991, Edge and Marcum 1991), and cattle grazing (Mackie 1970, Ward 1973, Lyon et al. 1985, Brown 1987, Christensen et al. 1993).

Elk herds are being reintroduced to a variety of habitats throughout the United States. Current guidelines for elk habitat and responses to land practices are based on research conducted primarily in the coniferous forests throughout the Intermountain West. Responses of elk to timber harvest, agricultural crops, land development, and cattle grazing are likely variable across less traditional habitats. Elk in Custer State Park, South Dakota remained > 600 m from recreation trails during the day, but moved closer during the night. Elk also abandoned areas with a continued and predictable disturbance, such as walk-in fishing trails, cook out area, and horse-back riding trails (Millspaugh 1995). A unique opportunity existed in northwestern Nebraska to quantify the effects of a variety of human disturbances on elk distribution in a ponderosa pine (Pinus ponderosa) habitat on private land. The response of elk in areas that have agricultural crops available throughout the year will add new insight to the potential problems that may be encountered in Nebraska and other states with similar habitats and land ownership. Thus, our objective was to determine the distribution of elk relative to timber harvest, agricultural crops, livestock, roads and houses.

STUDY AREA

The Pine Ridge, which lies in the northwest corner of Nebraska, is approximately 160 km long and 1-8 km wide covering approximately 120,000 ha. Four small towns are located near the 2 study areas. Chadron is the largest with a human population of 5933. Rural land surrounding these small urban areas is sparsely populated by ranchers and farmers (0-0.28 houses/km^2).

Two distinct study areas, defined by annual herd home ranges, were used for this project: the Hat Creek area (44,035 ha) is located between Crawford and Harrison, and the Bordeaux Creek area (48,398 ha) is located east of Chadron (Figure 1). Elevations range from 939 m to 1594 m above sea level. Road densities, consisting of two major state highways and unpaved county roads are low (0.09-0.46 roads/km^2) within the 2 study areas. Public land managed by the Nebraska Game and Parks Commission (NGPC) and United States Forest Service (USFS) occurs in both areas. The 2 study areas combined consist of 94% privately owned land and 6% public. Seventy-100 elk occurred in each of the study areas from 1996-1999.

The Pine Ridge is dominated by ponderosa pine forest, interspersed with grassland pastures and agricultural fields. The Hat Creek area consists of 47% ponderosa pine forest, of which 14% was burned in 1989, 50% grassland, and 3% agricultural crops. The Bordeaux Creek area consists of 51% ponderosa pine forest, 46% grassland, and 3% agricultural crops. Predominant hardwood species associated with riparian areas include green ash (Fraxinus pennsylvanica), and cottonwood (Populus deltoides). Predominant grass species include big bluestem (Andropogon gerardii), little bluestem (Schizachyrium scorparium, and Kentucky bluegrass (Poa pratensis). The two major agricultural crops include alfalfa and winter wheat. Land uses in the region include cattle grazing, crop production, and commercial timber harvest.

Cattle on private land are stocked into forested pastures in mid-May to mid-June. Typically, 100-150 cows and calves are stocked into a pasture resulting in an average of 0.33 animals/ha (Hulls, D., University of Nebraska, pers comm.). Cattle use these pastures during the summer months and are removed in September or October before the first snowfall. Cattle are then moved to grassland pastures close to the ranch house where they are fed alfalfa bales during the non-growing season. Cattle are excluded from forested habitats during the calving season (February-April) to prevent abortions caused by consuming pine needles. Agricultural fields are typically < 16 ha in size. Nine timber harvest operations occurred in the 2 areas during the study. Timber harvest occurred during the spring, summer, and fall months within the Hat Creek area, while occurring only in the fall within the Bordeaux Creek area during 1996. During 1997, timber harvest occurred during summer in the Hat Creek area, while no timber harvest occurred within the Bordeaux area.

The NGPC has implemented management strategies to reduce elk depredation to privately-owned agricultural crops. The NGPC provided second cutting alfalfa for deer (Odocoileus spp.) and elk during late November through March in the Bordeaux Creek area since 1993, while elk in the Hat Creek area are not artificially fed. Hunting has occurred in both units since 1995. Annual harvests have ranged from 7 to 31, and 5 to 17 in the Bordeaux Creek and Hat Creek areas, respectively.

METHODS

Capture and Radio-telemetry

Twenty-one female elk were captured using a helicopter net-gun team (Helicopter Wildlife Management, Salt Lake City, Utah) in March 1995, August 1995 and March 1996. One female calf was captured using an alfalfa-baited Clover trap in December 1996. Eleven and 10 female elk were radio-equipped in the Bordeaux Creek and Hat Creek areas, respectively. All were ear-tagged and equipped with mortality-sensing 150-151 MHZ radio-collars (Advanced Telemetry Systems, Insanti, Minnesota, USA).

Elk were located by radio-telemetry, primarily using a vehicle-mounted, 9-element Yagi antenna. Two to 3 azimuths were taken at fixed receiver locations (i.e., road intersections) to locate the elk. We used receiver locations as close to each elk as possible and attempted to approach 90° on bearing intersection angles. The accuracy of the tracking system was determined by 2 independent observers following the same procedures and using the same equipment as in the study. Three transmitters were suspended 1.5 m above the ground at 10 locations located throughout the Bordeaux Creek area. Receiver to transmitter distances averaged 601 m (range = 297 to 1245 m). The average angular error between 60 true and estimated bearings was ±3.1°.

Visual observations were recorded when individual elk were identified, particularly during early morning or late evening hours. Ground-tracking was done using a 3-element Yagi antenna or a 2-element H-antenna to obtain visual observations during daytime (bedding) hours. Telemetry locations were obtained at different time periods (0300-0900 = 35%, 0901-1500 =31%, 1501-2100 = 21%, 2101-0259 =13%) to ensure a true representation of movements and home ranges. Elk were typically located daily and at least once a week during each time period from April 1995 to August 1997. Weather, road conditions, other work duties, and landowner concerns of nocturnal radio-tracking reduced the number of locations during some time periods and weeks. This project was approved by the University of Nebraska Institutional Animal Care and Use Committee (IACUC # 94-09-075).

Location Data Analysis

For each bearing, the animal identification number, date, time, receiver locations, and bearings were entered into an Excel spreadsheet (Microsoft, Seattle, Washington, USA). We processed data with CALHOME (Kie et al. 1996) to determine elk locations. Location data were imported into a Geographic Information System (GIS; Map and Image Processing System (MIPS); MicroImages, Lincoln, Nebraska, USA) and laid over covertype maps. Woodland, grassland, and agricultural crops were determined from a LANDSAT thematic mapper (TM) image of the 2 study areas. We ground-truthed the 2 study areas to verify the habitat classification of the LANDSAT image.

Home Ranges

We used a harmonic mean method of home range analysis (Dixon and Chapman 1980) to analyze elk locations. At least 20 locations ($\bar{x}$ = 24, range = 20-28) were used for each seasonal home range analysis. We used the 95% isopleth to delineate the boundary of each home range (White and Garrot 1990) and the 50% isopleth to define core area. The 50% isopleth was used to calculate the center point of the home range. In cases where more than 1 50% isopleth existed per home range (i.e., bimodal home ranges) the 95% isopleth was used.

Elk location data were divided into 2 categories: before a disturbance or stimulus and during a disturbance or stimulus. Home range periods were 45 or 60 days long, depending on the disturbance or stimulus being examined (Appendix A). In cases where the date of disturbance was discrete (i.e. beginning of timber harvest), the same dates defined the associated home range periods for all elk. In cases where the date of the stimulus varied among elk (i.e. movement to crops and cattle stocking), associated dates of home ranges depended on when the particular stimulus affected the individual elk. We compared home range size before a disturbance or stimulus to home range size during time of disturbance or stimulus. Home range periods were kept at a minimum to minimize the influence of other factors. Distance between home range centers before and during a disturbance also was calculated.

We used a single-factor ANOVA (SAS Institute 1990) to determine whether home range sizes could be pooled across seasons, years, or herds. The data were independent and normally distributed and the variances were homogenous. We used paired sample t -tests to analyze differences in home range sizes, distances moved between home range centers, and distances to an agricultural field before and during a disturbance or stimulus (Zar 1984). We used 95% confidence intervals (CI) to report home ranges and distances moved (Zar 1984).

Timber Harvest

To determine the effects of timber harvest on elk home ranges we compared the size of home ranges before and during active timber harvest. The dates of the timber harvest operations in the 2 study areas were obtained from the commercial logging companies and by visual observation when radio-tracking elk. Home range periods were limited to 45 days to evaluate the short-term effects of timber harvest and to reduce the effects of other factors impacting elk distribution. To further determine the effects of timber harvest on female elk, home range size and distance moved between home range centers of female elk exposed to logging were compared to cows not exposed. Elk with home ranges containing the logged pasture during the 45 days before timber harvest were considered as exposed to the disturbance. The location of home ranges was also examined during the 45-day period after timber harvest had completely stopped.

Agricultural Crops

We evaluated the impact of summer crops (alfalfa, oats, and millet) and winter crops (winter wheat and supplemental feeding) on female elk home range size and location using the procedure similar to that used on white-tailed deer (VerCauteren and Hygnstrom 1998). Home range periods were 45 days long. To examine the location of home ranges to crops, we compared the distance to an agricultural field 45 days before and after female elk began feeding on summer or winter crops. To further determine effects of the feedground, we compared Bordeaux Creek elk, that have access to a feedground to the Hat Creek elk, that do not.

Cattle

We evaluated the effects of cattle on female elk home range size and location after being stocked into a pasture that contained radio-collared elk. Dates of cattle stocking were obtained from area ranchers and by visual observation. We compared elk home range size 45 days before and after cattle were stocked into the pasture containing the female elk. Initial distance moved within 3 days of stocking and distance between home range centers also were calculated.

Roads and Houses

Road density, road use, and housing densities were determined within 16 elk annual home ranges in 1996, 6 within the Bordeaux Creek herd and 10 within the Hat Creek herd. Road and housing data were compared between elk home ranges and 20 randomly located, hypothetical home ranges of 127 km^2 in elk non-use areas of similar habitat. The size of hypothetical home ranges was determined by averaging the size of annual elk home ranges. Non-use was defined as areas with similar habitat that were not occupied by collared elk in the 29 months of radio-tracking. To the best of our knowledge no or few elk occupied these non-use areas. Road and housing densities were determined using MIPS. Only roads with gravel or paved surfaces and significant year-round travel and occupied houses were included in the analysis.

We used MANOVA (SAS Institute 1990) to test for differences between elk use and non-use areas, considering road and housing densities as well as the amount of vehicle traffic on roads (Ford, C., Nebraska Department of Roads, pers comm.). To estimate amount of use on roads, we calculated a road use index for each home range. Roads were divided into 5 categories (unmapped, low use, medium use, high use, and very high use) depending on average daily vehicle use (Appendix B). The distance (km) of each road type within a home range was determined using MIPS and multiplied by the degree of use it received and summed to represent a unitless road use index. The amount of daily vehicle traffic on unmapped 2-track and logging roads was minimal and limited to seasonal use, thus we used a vehicle traffic multiplier of 0 to generate a 0 for the road use index. Correlation analysis was conducted between road density, road use index, and housing densities to determine which variables should be included in the analysis. We used logistic regression (PROC LOGISTIC; SAS Institute 1990) to determine if roads and houses were significant in affecting elk habitat use and to develop a threshold value of road and housing density that can predict whether an area will be an elk use or non-use area.

RESULTS

Timber Harvest

Pre-logging elk home range sizes ($\bar{x}$ = 1375 ha, CI = 306, n = 37) did not differ among seasons ($\underline{F}_3$ = 0.19, $\underline{P}$ = 0.91) or between years ($\underline{F}_1$ = 0.01, $\underline{P}$ = 0.92), thus we pooled the data for further analysis. Elk exposed to timber harvest had similar sized home ranges (Table 1) before logging ($\bar{x}$ = 1375 ha, CI = 306, n = 37) and during logging ($\bar{x}$ = 1916 ha, CI = 674, n = 37; t_{36} = 1.69, P = 0.13). Further, the home range size of elk exposed to logging ($\bar{x}$ = 1916 ha, CI = 674, n = 37) was not different than that of elk not exposed to active logging ($\bar{x}$ = 1971 ha, CI = 609, n = 44; t_{79} = 1.99, P = 0.90). The mean distance between home range centers (Table 2) of elk exposed to logging ($\bar{x}$= 5554 m, CI = 1048, n = 37) was larger than distance moved of elk not exposed to logging ($\bar{x}$ = 3337 m, CI = 743, n = 44; t_{79} = 1.99, P = 0.0006).

Summer Agricultural Crops

During the summers of 1995-1997, all of the radio-collared elk (n = 15) in the Bordeaux Creek herd began feeding in areas with agricultural crops; alfalfa and millet were selected in late July ($\bar{x}$= 25 July, CI = 4.7, n = 14). During the summers of 1996 and 1997, all of the radio-collared elk (n = 18) in the Hat Creek herd also began feeding in areas with alfalfa and oats in late July ($\bar{x}$ = 23 July, CI = 2.8, n = 18).

Size of home ranges 45 days before elk shifted into agricultural areas were different for the Bordeaux Creek elk ($\bar{x}$ = 3963 ha, CI = 1325, n = 14) and the Hat Creek elk ($\bar{x}$ = 1490 ha, CI = 554, n = 18) among areas and years (F_4 = 7.99, P = 0.0002), thus we analyzed the 2 herds separately. The Bordeaux Creek elk home ranges before shifting toward agricultural crops were similar in size and pooled among years (F_2 = 2.75, P = 0.11). The Hat Creek elk home ranges before shifting toward agricultural crops were also similar in size between years (F_1 = 3.33, P = 0.09), which allowed the data to be pooled for analysis.

Bordeaux Creek Elk

Elk home ranges were larger before they started using agricultural crops in July ($\bar{x}$ = 3963 ha, CI = 1325, n = 14) than during the period when they used agricultural crops ($\bar{x}$ = 1910 ha, CI = 884, n = 14; t_{13} = 3.71, P = 0.002). Bordeaux Creek elk moved an average of 2486 m toward agricultural crops during the 3 summers. The mean distance of the home range center to an agricultural field (Table 3) before the elk started using the agricultural fields ($\bar{x}$= 2275 m, CI = 781, n = 14) was nearly twice as far as during the use ($\bar{x}$ = 1205 m, CI = 439, n = 14; t_{13} = 3.27, P = 0.005). Females (n = 14) were located in alfalfa or millet fields 5 times greater than the availability of agricultural crops in the study area after the second cutting of alfalfa occurred in 1995-1997.

Hat Creek Elk

Elk home ranges before they started using agricultural fields ($\bar{x}$ = 1490 ha, CI = 554, n = 18) were twice the size of home ranges during the use of agricultural crops ($\bar{x}$ = 772 ha, CI = 209, n = 18; t_{17} = 2.87, P = 0.01). Hat Creek elk moved an average of 2453 m toward agricultural crops during the 2 summers. The mean distance of the home range center to an alfalfa or oat field before elk began using agricultural crops ($\bar{x}$ = 2276 m, CI = 546, n = 18) was nearly twice as far as during the use period ($\bar{x}$ = 1254 m, CI = 215, n = 18; t_{17} = 3.78, P = 0.001). Females (n = 18) were located in alfalfa or oats > 5 times the availability of agricultural crops within the study area after the second cutting alfalfa period during 1996 and 1997.

Winter Agricultural Crops

Bordeaux Creek Elk

The size of home ranges before a shift toward winter wheat and the feedground were not different between years (F_1 = 0.58, P = 0.47), thus we pooled them for further analysis. Elk shifted home ranges an average of 4952 m toward winter wheat fields and the NGPC feedground in late November ($\bar{x}$ = 23 November, CI = 3.6, n = 9) during the 1995/96 and 1996/97 winters. The mean size of home ranges 60 days before the shift ($\bar{x}$ = 5711 ha, CI = 855, n = 9) did not significantly differ from home ranges 60 days after the shift ($\bar{x}$ = 3712 ha, CI = 1790, n = 9; t_8 = 1.99, P = 0.08). The mean distance to a winter wheat field before elk shifted home ranges ($\bar{x}$ = 3704 m, CI = 1985), n = 9) did not differ from after the shift ($\bar{x}$ = 2353 m, CI = 1423, n = 9; t_8 = 1.32, P = 0.22). The mean distance to the feedground before the shift ($\bar{x}$ = 6657 m, CI = 927.0, n = 9) was nearly 3 times greater than the distance after the shift ($\bar{x}$ = 2323 m, CI = 1432, n = 9; t_8 = 8.4, P < 0.0001). Winter home ranges of Bordeaux Creek elk ($\bar{x}$ = 3712 ha, CI = 1789, n = 9) were smaller than those of elk in the Hat Creek herd ($\bar{x}$ = 4233 ha, CI = 538, n = 16; t_{23} = -0.78, P = 0.44), that did not have access to a feedground. Bordeaux Creek elk (n = 9) were located in winter wheat or at the feedground 6 times greater than the availability of agricultural crops in the study area during the 1995 and 1996 winters. Hat Creek elk (n = 16) were located in agricultural crops (private hay yards) slightly less (2%) than the availability of agricultural crops in the study area (3%) during the winters of 1995 and 1996. Locations were collected during diurnal, crepuscular, and nocturnal periods.

Cattle

The home ranges of the Bordeaux Creek elk before cattle were stocked into pastures ($\bar{x}$ = 4158 ha, CI = 1271, n = 11) were larger than those of Hat Creek elk ($\bar{x}$ = 1944 ha, CI = 582, n = 20; F_3 = 8.65, P = 0.003) among areas and years, thus the herds were analyzed separately. The sizes of home ranges of Bordeaux Creek elk before cattle were stocked into summer pastures (F_1 = 3.82, P = 0.08, n = 11) were similar in size between years, allowing the data to be pooled for further analysis. Similarly, home ranges of Hat Creek elk before cattle were stocked into summer pastures (F_1 = 1.47, P = 0.24, n = 20) were similar in size between years, thus home ranges were pooled in the analysis.

Bordeaux Elk

The average date of stocking cattle into pastures occupied by radio-collared female elk was 15 May during 1996 and 1997. Elk home ranges ($\bar{x}$ = 4158 ha, CI = 1271, n = 11) were larger 30 days before cattle stocking than after cattle stocking ($\bar{x}$ = 1134 ha, CI = 524, n = 11; t_{10} = 2.29, P = 0.0003). Home range centers of radio-collared elk shifted an average of 6574 m after cattle were stocked into the pastures they occupied. The average initial distance moved within 3 days of stocking was 1935 m.

Hat Creek Elk

Pastures were stocked with cattle during late May and early June ($\bar{x}$ = 4 June, CI = 4.5, n = 20) during the summers of 1996 and 1997. Elk home ranges were larger 30 days before cattle stocking ($\bar{x}$ = 1944 ha, CI = 582, n = 20) than after stocking ($\bar{x}$ = 681 ha, CI = 249, n = 20; t_{19} = 2.09, P = 0.001). Home range centers of radio-collared female elk shifted an average of 3021 m after cattle were stocked into the pastures they occupied. The average initial distance moved within 3 days of stocking was 1646 m.

Roads and Houses

The density of roads (P = 0.0015), road use index (P = 0.0002), and density of houses (P = 0.05) were significantly lower in elk use areas than non-use. The correlation coefficients between road density and road use index, and road density and housing density were 0.21 and 0.70, respectively. Thus all 3 variables were included in the logistic regression model. Road density (P = 0.0013) and road use index (P = 0.0084) were considered significant at α = 0.05 within the logistic regression model. The model including road density and use index is $y = 7.90 + (-22.0*X_1) + (0.002*X_2)$, y being the dependent variable (use or non-use area), 7.90 the intercept, -22.0 and 0.002 are the slopes of the line, while X_1 (road density) and X_2 (road use index) are the independent variables. The model was tested by using the known road densities and road use index of use and non-use areas. The model correctly predicted elk use or non-use 69% of the time. The threshold value predicting an area to be not used corresponded to a road density of 0.51 km road/km^2 and a road use index of 1650. Road densities and use indices larger than these values were predicted as non-use areas.

DISCUSSION

Timber Harvest

Elk avoidance of activities associated with timber harvesting is variable. We found that elk in the Pine Ridge shifted their home range centers an average of 5554 m away from active timber harvest. This was significantly different than elk not exposed to active timber harvest, which shifted their home range centers an average of 3337 m during the same time periods. The degree of avoidance is likely dependent on the size of timber operation, previous experience to disturbance, time of year, terrain, available habitat, and the importance of area being logged. Elk avoided areas within 500-1000 m of an active timber harvest in Idaho (Edge and Marcum 1985). Lyon (1979b) reported that elk reduced use of habitat within 8000 m of active logging.

The area occupied by active timber harvest was < 5% of the annual elk herd home ranges, which allowed elk to move away from active logging sites to areas undisturbed with adequate cover. Elk did not abandon use of annual home ranges, but rather vacated disturbed areas until timber harvest activities were finished. Female elk in Idaho did not abandon traditional home ranges when adequate cover existed (Edge and Olson 1985). Effects of logging on elk distribution in the Pine Ridge appear to be short-term, resulting in a shift away from the disturbance until activities cease.

Schultz and Bailey (1978) reported that elk habituate rapidly to repeated disturbance. Elk in western Montana reoccupied logged areas within 2 days to a few weeks after the operation was completely shut down (Beall 1974, Lyon 1979b, Lyon 1985). Elk may develop an avoidance behavior to areas that are repeatedly disturbed (Lyon 1979b). Duration of logging in the Pine Ridge was short (1 to 3 months). We found that elk in the Pine Ridge did not habituate to the logging disturbance, but did return to areas that were logged when activities ceased. The best example of this occurred in the summer of 1996 when a female elk moved into a logged pasture the day after logging terminated. She spent the next 2 weeks on a logged ridge where she calved. The pasture was rested from cattle grazing during the summer of 1996 and contained the home range centers of 20% (n = 2) of the radio-collared elk in the Hat Creek area during July and August. Eight (22%) of the 37 female elk exposed to timber harvest established home ranges that included the logged pasture 45 days after activities ceased, while 100% (n =37) established home ranges that included the pasture within 6 months.

Timber harvest of the ponderosa pine forest in the Pine Ridge occurs on a 20-30 year rotation. Selective harvests are implemented to remove the tallest and largest diameter trees at the site. Timber harvested in a pasture during 1996 will not produce marketable lumber to be logged until the year 2020-2030. This long interval between disturbances allows elk to simply avoid the area and greatly reduces the risk of elk permanently avoiding specific sites.

Summer Agricultural Crops

Elk distribution in the Pine Ridge was affected by the presence of alfalfa, oat, and millet fields during the summers of 1995-1997. Elk shifted their home ranges and began feeding on these crops in late July of each year. The average date of this movement occurred about 24 July in both study areas. Elk appear to be attracted to the crop fields at a time that corresponds to the ripening of oats, maturing of millet, and second cutting of alfalfa. Elk may also shift away from grasses to reduce interspecific competition with cattle in forested pastures as forage quality and quantity decline through the late summer. Mule deer in Utah shifted their diets to include more alfalfa when other preferred forages became limited (Austin et al. 1984).

Elk activity and movements in Montana were related to forage availability and preference (Mackie 1970), and "preferred spots" (Lieb 1981). Reduction of home range size and movement of home range centers toward alfalfa, oat, and millet fields indicates that Pine Ridge elk are selecting these areas as preferred spots. The size of elk home ranges decreased by half in the Hat Creek and Bordeaux Creek herds, while use of agricultural crops was on average 5 times greater than its availability. Reduction of home range size and increased time spent in agricultural fields by elk is consistent with the theory of optimal foraging, which predicts that when resources are not limiting, species should concentrate their feeding on the best types of food or the best types of habitat (Caughley and Sinclair 1994, Begon et al. 1990). Further, this theory predicts that animals should select foraging areas to increase fitness by maximizing energy intake, while minimizing energetic costs of obtaining that energy. Elk are able to do this by concentrating feeding activity on agricultural crops during crepuscular and nocturnal periods when there is a less chance of human disturbance. The lack of a major predator also makes it advantageous to feed in these open agricultural fields.

Elk did not necessarily shift to the closest agricultural fields, but to fields that were surrounded by, or in proximity to hiding cover. Areas with alfalfa and/or oat fields that were located adjacent to or within 1100 m of forested cover were selected by elk in the Hat Creek area, while Bordeaux Creek elk selected areas with alfalfa and/or millet fields within 500 m of forested cover. Elk in the Hat Creek and Bordeaux Creek herds appear to prefer areas that include both alfalfa and a grain crop. Elk shifted home ranges (n =32) toward areas with alfalfa adjacent to or within 400 m of a grain field 60% (n = 19) of the time, while areas with only oats were selected 25% (n = 8), and areas with only alfalfa were selected 15% (n = 5) of the time during the 3 summers.

During the evening hours of late July and August, elk moved from hiding cover to feed in alfalfa, oat, or millet fields during the darkness before returning to cover at daybreak. The fields selected by elk were planted between ponderosa pine canyons, adjacent to forested cover, or on secluded ridges close to cover. Both lactating females and pre-rut males are in search of the highest nutritional forage available during late summer. Isolated alfalfa and grain fields are ideal feeding locations for both sexes to fulfill their nutritional requirements when grasses are becoming less nutritional.

Winter Agricultural Crops

Bordeaux Creek Elk

The average date that elk shifted movements toward winter wheat fields and the feedground was 23 November during the winters of 1995 and 1996. This date coincided with the time NGPC initiated the feedground by providing baled alfalfa for deer and elk. A significant reduction in home range size was not as apparent around winter wheat fields and the feedground as it was with summer crops. The average home range size before and after the shift decreased from 5711 ha to 3712 ha. The lack of difference was probably related to weather and hazing of elk from winter wheat fields. During periods of warmer weather and no snow cover, elk would expand movements away from the feedground and winter wheat fields. Shell crackers and propane cannons were used to haze elk away from private winter wheat fields.

The average distance from the home range center to a winter wheat field was 3704 m 60 days before 23 November and 2353 m 60 days after 23 November. The movement of elk toward winter wheat may have been a result of movements shifting toward the feedground. The average distance of the home range center to the feedground 60 days before 23 November was 6657 m and 2323 m 60 days after 23 November. The average distance between home range centers before and after the shift was 4952 m. This was approximately three quarters of a km farther than the average distance of a winter wheat field before the shift occurred. Elk would not have had to move as far if they were stimulated to move solely on the basis of feeding on winter wheat. Winter distribution of elk seemed to be driven more by the onset of the feedground rather than winter wheat fields. Elk were drawn to the feedground and then venture onto private winter wheat fields that are in the vicinity. Three winter wheat fields are located within 1600 m of the feedground. Elk in the Bordeaux Creek herd selected wintering areas with a variety of foraging opportunities. The area provided alfalfa bales at the feedground, privately stored alfalfa hay, winter wheat fields, and rested grassland pastures. We located Bordeaux Creek elk (n = 9) in winter wheat or at the feedground 18% (range = 6-33%) of the time, while grassland habitat within elk home ranges was used 39% (range = 20-53%) of the time during the 1995 and 1996 winters. We located elk (n = 9) within forested cover 43% (range = 0.24-0.72). Elk in Montana were redistributed from private to public land by incorporating a rest-rotation cattle grazing system on a wildlife management area (Alt et al. 1992). The productivity of pastures was improved by removing residual growth and stimulating succulent regrowth.

Feedgrounds have been used in western states as early as 1912 to alter elk distribution, increase winter survival, reduce depredation on private land, and to compensate for loss of winter habitat. Reliance on feedgrounds by elk has also created an unnatural system that prolongs the life of old and weak animals, increases potential for disease transmission, and has lead to complex management issues dealing with the control of increasing populations (Smith and Robbins 1994). The feedground in Nebraska was a good way to improve public relations with area ranchers and reduce damage to stored hay, but it may have increased the use of winter wheat fields in the area and the potential for disease transmission.

Hat Creek Elk

Elk in the Hat Creek area were not artificially supplemented with alfalfa during the winter. Home range sizes were larger than the Bordeaux Creek elk, possibly due to increased effort searching for forage. Hat Creek elk selected areas with pastures ungrazed by cattle during the summer or areas where cattle were removed by early August allowing a period of rest and time for grass to regrow before the first freeze. Privately stored alfalfa hay was also available to Hat Creek elk. Female elk (n = 16) were located in private hay yards an average of 2% (range = 0-11%) of the time, while grassland habitat was used an average of 34% (range = 18-70%) of the time during the winters of 1995 and 1996. We located elk (n = 16) within forested habitat an average of 64% of the time (range = 27-82%). Elk in the Hat Creek area selected wintering areas much differently than the Bordeaux Creek elk by using foraging resources within grassland and forested habitats, rather than concentrating movements around the feedground and winter wheat fields.

Cattle

Lyon et al. (1985), Christensen et al. (1993) reported that elk avoid cattle, especially during the summer months . Elk in the Pine Ridge were displaced when cattle were stocked into a pasture. The average movement between home range centers were large, 3021 m in the Hat Creek herd, and 6774 m in the Bordeaux Creek herd. The large distance moved indicates that elk were vacating areas to avoid cattle and associated human presence. Initial movements within 3 days of cattle stocking support that elk were displaced from cattle occupied pastures.

In the Pine Ridge, cattle were typically stocked into private and public forested pastures after calving in mid-May to mid-June. Cattle were stocked on pastures occupied by radio-collared elk in mid-May (range = 10 May-20 May) within the Bordeaux study area and early June (26 May-15 July) within the Hat Creek study area. Elk calving season was defined as 15 May to 30 June. This includes the time when female elk begin isolating themselves from the herd in mid- late May, calve, and when movements were reduced because of the calf. The average date of calving was 17 June (range = 10 June-23 June). The overlap of cattle being stocked into forested pastures and the elk calving season may have negative impacts on female elk site selection.

Mackie (1970) reported that elk are socially subordinate to cattle and therefore are displaced when they come into contact. Rice (1988) found that elk in the Black Hills vacated pastures stocked with cattle or selected habitats with little cattle use. Bordeaux Creek elk initially moved an average of 1935 m, while Hat Creek elk moved 1646 m away from pastures stocked with cattle. Brown (1987) reported that elk prefer spatial separation from cattle. In the 30-day period after cattle were stocked, 86% (n = 31) of elk home range centers were located within pastures without cattle.

Water is a limiting factor for cattle in most forested pastures in the Pine Ridge. Ranchers checked cattle daily to ensure that water and minerals were available. The repeated human presence likely compounds the effect that cattle have on elk distribution.

After elk moved away from pastures occupied by cattle, home range sizes decreased. The average home range size of Bordeaux Creek females decreased from 4158 ha to 1134 ha after cattle were stocked. Hat Creek elk responded similarly by reducing home ranges on average from 1944 ha to 681 ha after cattle stocking. The separation from cattle and reduction of area used is likely a response of avoiding cattle and selecting an area to calve.

For example, on May 8th, 1997 an adult female elk in the Bordeaux Creek area returned to the timbered pasture where she calved in 1996. This pasture was rested from cattle grazing in 1996. On May 15th, cattle were stocked into the pasture, and the elk was located 2307 m away from the cattle 1 day later. She moved out of the ponderosa pine forested habitat into a deciduous creek bottom located 1245 m away from the Pine Ridge. She remained in the creek bottom to calve. Her home range decreased from 9004 ha before cattle were stocked to 1987 ha after cattle were stocked. The reduction of area used and large distances between home range centers of elk during May and June seemed to be associated with parturition and avoidance of cattle. Pregnant white-tailed deer also reduce the size of their home range prior to parturition (Nixon et al. 1991). The consequences of pregnant elk avoiding livestock and making large movements during late stages of gestation are not understood in terms of calving success and calf survival.

Post-parturition movements were less affected by the presence of cattle. Once elk calves were sufficiently mobile, female elk movements were less affected by the presence of cattle, and more by forage quality. Brown (1987) reported that there is little evidence of elk intolerance to livestock under conditions of limited resources. This is probably the case in the Pine Ridge, as the availability of grasses is reduced by cattle grazing, elk became more tolerant of cattle. Elk use steeper slopes, range farther from water and use closed canopy stands more than cattle (Mackie 1970). Within a pasture stocked with cattle, elk utilized steep slopes and terrain unavailable to cattle. Although elk were using pastures occupied by cattle, they were able to increase foraging opportunities by using rough terrain to maintain spatial separation. This response is similar to results of Yeo et al. (1993) who found that elk and deer avoided habitats frequented by cattle by selecting sites with higher elevations and steeper slopes.

Two and 3 of the 22 calving events in 1996 and 1997 were on public land, respectively. The amount of public land within the Bordeaux Creek and Hat Creek area is approximately 6%. Cattle grazing on public land incorporated more deferred, rest-rotation practices than grazing on private land (Abegglen, J., USFS, pers comm.). Both NGPC and USFS land were used by elk for calving sites during the 2 summers. The Gilbert-Baker Wildlife Management Area (WMA), Fort Robinson State Park, and Soldier Creek Wilderness Area were used as calving sites by female elk in the Hat Creek study area, while USFS land was used in the Bordeaux Creek area. Female elk in both areas selected areas rested from cattle grazing during the calving season.

Roads and Houses

Loss of available wildlife habitat due to high road densities and expanding urban developments is a concern in many areas of North America. Avoidance of roaded areas, vulnerability of animals during hunting seasons, and less available habitat are a few of the problems associated with roads and urban expansion.

Road densities were significantly different between elk use and non-use areas in the Pine Ridge. The average road density within the Bordeaux Creek and Hat Creek use areas was 0.35 km road/km^2 (range = 0.09-0.46), compared to an average road density of 0.47 km road/km^2 (range = 0.3-0.66) within the randomly located non-use areas. Based on 8 years of research in Montana, (Lyon 1979a, 1985 et al.) found that elk use of habitat declined dramatically in areas with road densities greater than 0.61 km road/km^2. According to Lyon's (1979a), road densities within the Pine Ridge are low and should not limit the amount of elk use.

Surprisingly, the average road use index (distance of road × road use multiplication factor) was lower in non-use areas ($\bar{x}$ = 290, range = 37-1377), than in elk home ranges ($\bar{x}$ = 591, range = 25-1650). The density of roads may have more of an effect on the distribution of elk in the Pine Ridge than the actual amount of travel on roads. Elk in the Pine Ridge selected areas with the lowest road densities, but not the areas associated with the lowest road use. Home ranges of elk in the Hat Creek study area had the lowest road densities and road use indices, while the Bordeaux Creek elk ranges had the second lowest road densities, but the highest road use indices. Road use indices were dramatically increased by the presence of State Highway 20 in all collared elk home ranges in the Bordeaux Creek area. Bordeaux Creek elk were not affected by 1 of the busiest highways ($\bar{x}$ = 2177 vehicles/day) in northwestern Nebraska. They crossed back and forth throughout the year and occasionally bedded within 200 m of the highway in the winter. Elk response to roads is likely dependent on past experience, acclimation, season, and associated habitat. Elk in a remote area of Yellowstone National Park moved large distances when they encountered cross-country skiers, while elk in a less remote areas were continually exposed to this disturbance and moved very little (Cassirer et al. 1992). Similarly, elk in the Bordeaux Creek study area were attracted to the winter feedground, which was located about 500 m from Highway 20. They received positive reinforcement from the foraging opportunity at the feedground and acclimated to the traffic along the highway.

Road density and vehicle traffic does not appear to affect the habitat suitability of non-use areas. The regression model predicted that areas with road densities greater than 0.51 km road/km^2 and road use indices larger than 1650 would not be used by elk. The average road density and use index of all non-use areas were below threshold levels predicted by the logistic regression model. Hypothetical home ranges southwest of Fort Robinson, including the Peterson WMA are most similar to road characteristics associated with elk home ranges. The model predicted 4 hypothetical home ranges located within this area as use sites.

Land mangers in the western United States are concerned about the impacts of logging and improved road access for recreationists on undisturbed areas. Increased road densities on USFS land in Idaho was directly correlated to increases in adult male mortality (Leptich and Zager 1991). Road closures have alleviated much of the problems associated with low bull to cow ratios, displacement from preferred areas, and loss of security cover. Irwin and Peek (1979) reported that road closures have been effective in allowing elk to occupy preferred habitats longer during the hunting season, while Lyon and Canfield (1991) found that loss of habitat providing security cover due to roads was partially mitigated by extensive road closures.

The situation concerning logging and associated road building is much different in the Pine Ridge compared to the public land in the western states. The establishment of roads on public land increases the vulnerability of elk during the hunting season, and critical periods of the year, such as the winter and calving seasons (Lyon and Ward 1982). Elk in the Pine Ridge are less vulnerable from increased access into timbered habitat because the majority of land is privately-owned, with restrictions to access and travel. Logging operations have occurred exclusively on private land in the Pine Ridge since 1994. Logging companies attempt to reseed roads that were built on fragile slopes, but many of the roads were washed out by spring rains and became impassable. Ranchers typically maintain roads that provide access to windmills and minimize the amount of hunter traffic on these roads by allowing land access to only a select few. Other ranchers do not allow hunters to use motorized vehicles on roads accessing forested cover because of the potential to degrade roads needed during the summer.

Road construction associated with timber harvest on USFS land was kept at a minimal by using existing private and public 2-track roads to access the harvested sites. Current road densities within the forested habitat of the Pine Ridge do not appear to severely limit the suitability or pose major problems with elk vulnerability.

Urban expansion into the foothills and mountains is a concern for biologists in Colorado, Wyoming, Idaho, and other Rocky Mountain states. Housing densities in the Pine Ridge were significantly different between use and non-use areas. Use areas averaged 0.16 houses/km^2 (range = 0.03-0.33), while non-use areas averaged 0.22 houses/km^2 (range = 0.08-0.47). Regional and local losses of habitat may be the cause for elk in many locations to currently occur at densities that exceed historic averages due to the reduced habitat available to expanding elk populations (Skovlin 1882). According to state figures, Colorado is losing about 36,000 ha of rural land each year to urban expansion (Long 1996). Loss of winter range has been the greatest detriment from these expansions, forcing state agencies to provide artificial feedgrounds to sustain many elk herds.

Vogel (1989) reported that deer in the Gallatin Valley of Montana avoided areas with > 0.21 houses/km^2. Housing densities ($\bar{x}$ = 0.22) in the non-use areas of the Pine Ridge are similar to this level. Half of the 20 hypothetical home ranges in the non-use areas had housing densities > 0.21 houses/km^2, while 31% (n = 5) of the elk home ranges (n = 16) were greater than this level. Elk have selected areas of the Pine Ridge with the lowest housing densities, while non-use areas appear to be suitable for elk habitat based on human occupancy. The houses within the Pine Ridge are located near maintained roads and away from or on the edge of forested cover. The relatively low density and positioning of houses within the Pine Ridge minimize the negative impacts of human disturbance on elk distribution.

There are approximately 150 elk in the Bordeaux Creek and Hat Creek study areas, which is likely below densities that stimulate emigration into these unused areas. The objective of the NGPC is to have a minimum of 100 elk in the Pine Ridge (NGPC 1995). Suppressing the population at low densities will not stimulate elk to seek unused habitats. If populations are allowed to increase, the non-use areas of the Pine Ridge appear to be well suited for elk, based on the low impacts of roads and houses to the habitat.

MANAGEMENT IMPLICATIONS

Management of the 2 Pine Ridge elk herds can be improved by increasing our understanding of elk response to a variety of human disturbances. Managers may be able to minimize disturbance by altering management actions during specific times of the year. For example, timber harvests and livestock grazing should be scheduled to avoid disturbing elk during critical times of the year, such as during the winter and calving season.

Current timber harvests are short in duration and infrequent. Elk avoidance of active sites is a short-term response that is minimized by the availability of undisturbed areas with adequate cover within annual home ranges. Timber management plans should include consideration of elk distribution and evaluation of the potential impacts to core use areas. Coordination between logging companies, private landowners, and the NGPC will be essential for the development of such management plans. Further, the long-term effects of logging on elk habitat selection in Pine Ridge should be evaluated to fully understand the impacts of this disturbance.

Elk distribution was significantly affected by summer crops. Elk moved large distances to feed in alfalfa, oat, and millet fields. Tolerance of elk feeding in agricultural fields is variable among ranchers (Crank, 1998). The NGPC has responded to depredation complaints by implementing hunting seasons, the first being held in 1986 and 1987 within the Bordeaux Creek area. Seasons have been held annually in both the Bordeaux Creek and Hat Creek areas since 1995. Propane cannons and shell crackers are distributed to ranchers that are experiencing damage to crops caused by elk. These frightening devices are employed after elk have fed on these fields for consecutive nights. Our research indicates that the average date of shift toward summer crops occurred about 24 July in both study areas. Control methods should be implemented before elk establish feeding patterns in individual fields. Landowners should consider implementing a variety of control methods, including electric fencing, repellents, and harassment with a variety of frightening devices.

Establishing food plots and/or implementing habitat improvement projects on public land may attract elk away from private agricultural crops. Long (1989) reported that spraying herbicides, fertilizing, and salting were effective methods to redistribute elk from private to public rangeland during the spring, while Brown and Mandery (1962) reported that damage to private agricultural fields in Washington was virtually eliminated by applying fertilizer to adjacent public land. Habitat improvement projects implemented on public land may attract elk and help alleviate damage to private agricultural fields during the summer. Both the USFS and NGPC manage land in the Bordeaux Creek and Hat Creek study areas. Damage control methods implemented on private land and agricultural crops planted on public land may shift elk away from sensitive areas during July and August. Landowner perceptions may improve if damage is reduced, which may improve the feasibility of herd expansions.

Elk distribution in the Bordeaux Creek herd was influenced by the establishment of a feedground. The feedground was maintained to prevent damage caused by deer and elk to privately stored hay and winter wheat fields. Concern for the potential of disease transmission resulted in the termination of the feedground in 1998. Based on NGPC observations, elk were still using the area in 1999 even though supplemental feeding ceased. Investigators found that elk have a high fidelity to seasonal and annual home range areas (Knight 1970, Craighead et al. 1972, Craighead et al. 1973, Edge and Marcum 1985). If depredation problems persist, redistribution of elk away from the feedground area may be desirable. Habitat improvement projects implemented on public land may alter distribution of elk. Elk in Montana and Wyoming responded to the increased cultivation of alfalfa by shifting their home ranges to include this agricultural crop (Van Dyke et al. 1998). Elk in Wyoming have been redistributed away from private land by enhancing transitional habitat between fall and winter range.

Prescribed burns are conducted on public land to improve forage and hold elk in the fall and winter months (Smith, S., Wyoming Game and Fish Department, pers comm.). Public land in the Bordeaux Creek area is used by elk during the fall, and is located approximately 3 km away from the old feedground area. The public land could be enhanced with prescribed burns, fertilization, or food plots, which may shift elk away from the privately-owned traditional wintering area and reduce depredation complaints. Land acquisition or conservation easements within the wintering area would also give managers the opportunity to manage the land to attract elk.

Elk clearly avoided cattle when cattle were initially stocked into pastures. This response occurred in conjunction with a period when female elk were seeking undisturbed areas to calve. Public land appears to play an important role for female elk that are selecting areas to calve. Management plans for grazing public land should include consideration of the elk calving season and ensure that some pastures are rested annually and others do not begin grazing until after 1 -15 July. The suitability of forested pastures on private land may be enhanced by purchasing conservation easements, which would incorporate rest-rotation and deferred grazing practices during the elk calving season.

Urban expansion to western states has severely limited the amount and availability of big-game winter range (Long 1996). Colorado's rural land is being converted into housing subdivisions, shopping malls, and ski resorts at an alarming rate (Buchanan 1998). The rural land of northwestern Nebraska is relatively unpopulated compared to areas of the western United States experiencing urban expansion.

Although, the current road and housing densities are low within the Pine Ridge and do not severely limit the potential of elk habitat, land in the Pine Ridge is being purchased by hunting clubs, elk ranchers, and non-residents with interest in developing the area. The opportunity exists to manage this unique ecosystem in Nebraska to prevent increased rural development and avoid the problems encountered by western states. Conservation easements purchased on important elk range that restricts land development should be considered in order to protect this unique area of Nebraska.

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Table 1. Home range size (ha) of female elk in the Bordeaux (BC) and Hat Creek (HC) areas relative to 4 environmental periods, 1995-1997.

Unit	Period	n	$\bar{x}$	C.I.	Range
BC/HC	Pre-logging	37	1375	305	338-3177
	Logging	37	1916	674	322-10781
BC/HC	Logging	37	1916	674	322-10781
	No-logging	44	1971	609	261-8079
BC	Pre-second cutting alfalfa	14	3963	1324	1043-6859
	Post-second cutting alfalfa	14	1910	884	420-5232
HC	Pre-second cutting alfalfa	18	1490	553	250-3796
	Post second cutting alfalfa	18	772	209	213-1923
BC	Pre-Feedground	9	5711	855	3975-6810
	Feedground	9	3712	1789	901-8576
BC	Feedground	9	3712	1789	901-8576
HC	No Feedground	16	4233	537	2578-6936
BC	Pre-cattle	11	4158	1271	1770-9004
	Cattle	11	1134	524	346-2819
HC	Pre-cattle	20	1944	582	331-3911
	Cattle	20	681	249	146-2297

Table 2. Mean distance (m) between home range centers of female elk before and during 4 environmental periods in the Bordeaux (BC) and Hat Creek (HC) areas, 1995-1997.

Unit	Period	n	$\bar{x}$	C.I.	Range
BC/HC	Logging	37	5555	1048	322-6683
	No logging	44	3337	743	49-8633
BC	Summer crops	14	2179	947	638-6969
HC	Summer crops	18	2453	1042	769-6791
BC	Winter crops	9	4952	1248	2862-6381
BC	Cattle Stocking	11	6574	1420	4114-10788
HC	Cattle Stocking	20	3021	877	265-7519

Table 3. Mean distance (m) between home range centers and the closest agricultural crop field before and after 3 environmental periods, Bordeaux Creek (BC) and Hat Creek (HC) areas, 1995-1997.

Unit	Period	n	$\bar{x}$	C.I.	Range
BC	Pre-second alfalfa cutting	14	2275	781	839-5608
	Post-second cutting alfalfa	14	1205	438	535-2735
HC	Pre-second alfalfa cutting	18	2276	545	995-4513
	Post-second cutting alfalfa	18	1254	215	491-1759
BC	Pre-feedground	9	6657	927	4929-8981
	Post-feedground	9	2323	1432	537-5893
BC	Pre-feedground (winter wheat)	9	3704	1984	1834-5622
	Post-feedground (winter wheat)	9	2353	1422	552-6502

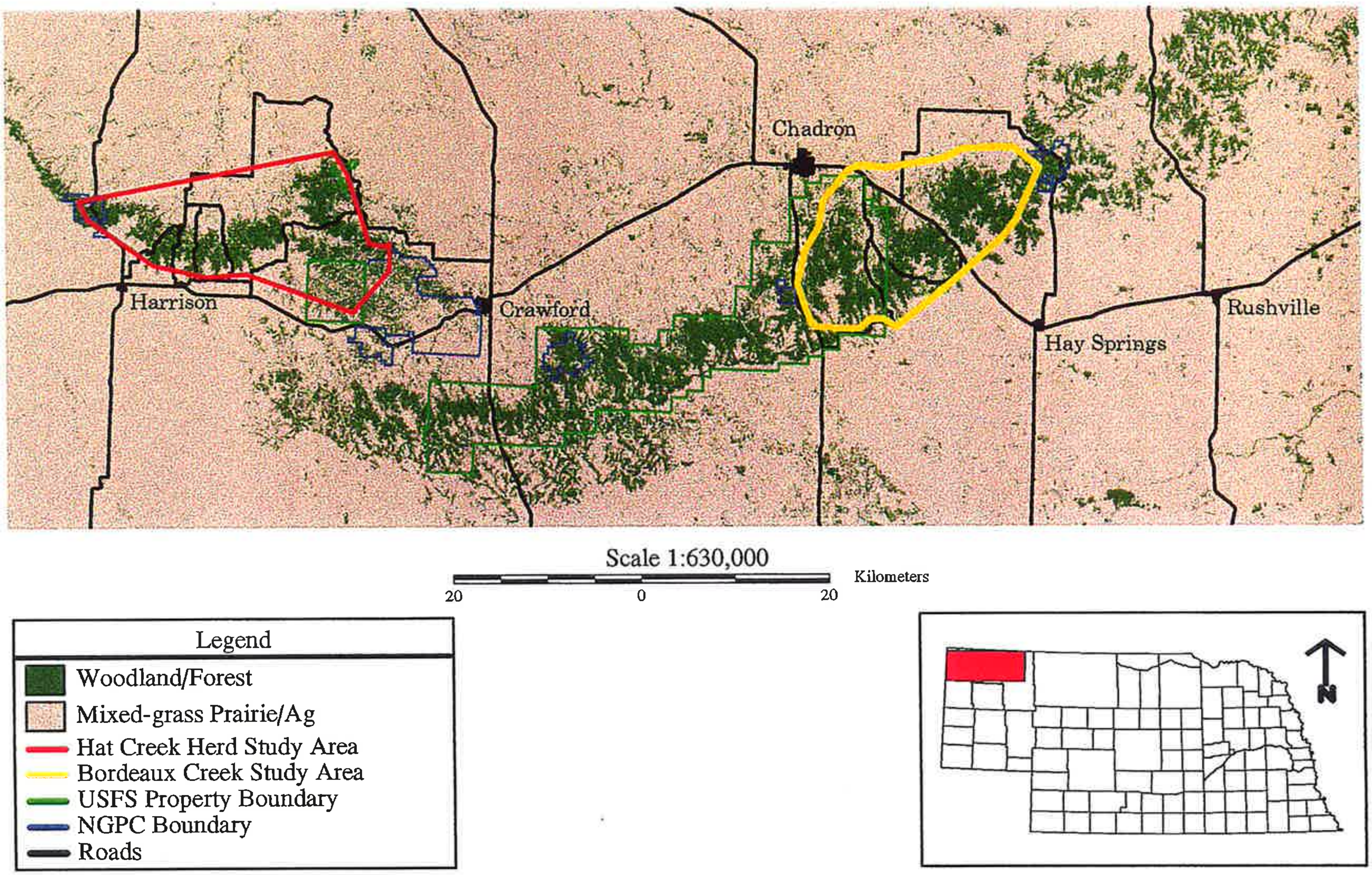

Figure 1. Pine Ridge region of northwestern Nebraska.

Appendix A. Home range (HR) periods and their average associated dates for females in the Bordeaux Creek, and Hat Creek herds, 1995-1997.

HR Period	Associated Dates	No. Cows Tracked	Mean No. Locations/Cow
Pre-logging	01/15/96 - 02/28/96	5	22
	03/14/96 - 04/28/96	7	24
	05/15/96 - 06/29/96	8	21
	06/15/96 - 07/31/96	11	25
	07/15/96 - 09/01/96	13	21
	08/08/96 - 09/22/96	5	24
	12/20/96 - 02/05/97	6	23
	02/25/97 - 03/09/97	13	26
	05/17/97 - 06/30/97	8	22
During logging	02/29/96 - 04/16/96	5	21
	04/29/96 - 06/15/96	7	23
	06/30/96 - 08/15/96	8	24
	08/01/96 - 09/15/96	11	22
	09/02/96 - 10/17/96	13	22
	09/23/96 - 11/05/96	5	25
	02/06/97 - 03/21/97	6	21
	03/10/97 - 04/25/97	13	23
	07/01/97 - 08/16/97	8	24
Pre-second alfalfa cutting	06/10/95 - 07/23/95	4	26
	06/10/96 - 07/23/96	16	25
	06/10/97 - 07/23/97	15	26

(Appendix A. Cont.)

HR Period	Associated Dates	No. Cows Tracked	Mean No. Locations/Cow
Post-second alfalfa cutting	07/24/95 - 09/07/95	4	24
	07/24/96 - 09/07/96	16	25
	07/24/97 - 08/31/97	15	23
Pre-feedground	09/22/95 - 11/22/95	4	28
	09/22/96 - 11/22/96	6	27
Post-feedground	11/23/95 - 01/23/96	4	26
	11/23/96 - 01/23/97	6	28
Pre-cattle	04/14/96 - 05/14/96	6	21
	04/14/97 - 05/14/97	5	20
	05/04/96 - 06/02/96	10	22
	05/04/97 - 06/02/97	10	21
Post-cattle	05/15/96 - 06/15/96	6	20
	05/15/97 - 06/15/97	5	22
	06/03/96 - 07/03/96	10	24
	06/03/96 - 07/03/97	10	23

Appendix B. Road type, mean daily vehicular traffic[1], and associated multiplication factor for the Pine Ridge region of Nebraska, 1995-1997.

Type	$\bar{x}$	Multiplication Factor
Unmapped (2-tracks)	0	0
Low Use (County Roads)	20	1
Medium Use (HW 20)	990	50
High Use (HW 20)	1780	89
Very High Use (HW 385)	2177	109

[1] Ford, C., Nebraska Department of Roads, pers comm.

CHAPTER 4:

DISTRIBUTION AND HABITAT CHARACTERISTICS OF ELK CALVING AREAS IN THE PINE RIDGE REGION OF NORTHWESTERN NEBRASKA.

***Abstract*:**

We located 22 elk (Cervus elaphus) calving sites and 42 random locations and measured 10 micro- and 9 macro-habitat variables between mid-June and July 1996 and 1997 to determine factors that affect habitat selection during the calving season. Seventy-three percent (n = 16) of elk calving areas were located in ponderosa pine (Ponderosa pinus) forest, and 82% (n = 9) were on private land in 1996 and 73% (n = 8) in 1997. The logistic regression model that best described elk use and fit the independent variables using a manual selection procedure, included: cattle, slope, ponderosa pine forest and riparian habitat, and distance from a road (AIC = 49.57, $R^2 = 0.65$). The second best fitting model included cattle, slope, distance from a road, ponderosa pine forest and riparian habitat, and hiding cover (AIC = 50.35, $R^2 = 0.67$). Elk selection of calving areas appears to be related to cattle avoidance. Elk were 250 and 333 times more likely to select areas to calve that were free of cattle. Variables that were insignificant in calving site selection included: aspect, distance to water and edge, edge type, road type, stand type, tree basal area, overstory canopy coverage, and ground cover. Application of the developed model using a Geographic Information System (GIS) may aid managers in predicting potential elk calving areas and modifying habitat management plans.

Keywords: Calving, cattle, Cervus elaphus, elk, habitat selection, hiding cover, logistic regression, Nebraska.

Considerable research has been conducted on elk habitat use patterns in the western United States (Knight 1970, Mackie 1970, Skovlin 1982, Irwin and Peek 1983, McCorquodale et al. 1986, Edge et al. 1987, 1988, Unsworth et al. 1998). Elk habitat selection depends on the interaction of various factors, such as behavior, topography, weather, food, water, and cover (Skovlin 1982).

Pregnant elk leave the herd a few days before giving birth (Craighead et al. 1972). The new-born calf is relatively stationary and hidden for the first 10 days to 3 weeks of life (Knight 1970). Habitat selected for calving is variable, depending on the availability of vegetational types during 15 May-15 June (Skovlin 1982). Elk calves in the Intermountain West are vulnerable to predation by bear (Ursus spp.), mountain lion (Felis concolor), and coyote (Canis latrans) (Gese and Grothe 1995, Myers et al. 1996, Singer et al. 1997, Smith and Anderson 1998). Elk calving habitat that reduces the vulnerability of calves is critical to the growth of a population, therefore these areas should be identified and protected (Roberts 1974, Bian and West 1997). Habitat selected by elk for calving appears to be associated with forage quality for the female and escape cover for the calf (Skovlin 1982).

Selection of habitat for calving in a ponderosa pine (Ponderosa pinus) region with the majority of the land privately-owned, and used for cattle ranching and agricultural production is likely different from the Intermountain West and prairie environments. Distribution and habitat characteristics of calving areas will assist managers protect sensitive habitat, and identify potential use-areas. Thus, our objectives were to 1) determine the distribution of calving areas, 2) evaluate the habitat characteristics, and

3) develop a predictive model that incorporates the most important variables associated with calving sites.

STUDY AREA

The Pine Ridge, lies in the northwest corner of Nebraska and is approximately 160 km long and 1-8 km wide, covering approximately 1,200 km^2. Elevations range from 939 m to 1594 m above sea level. The Pine Ridge is dominated by ponderosa pine forest, interspersed with grassland pastures, riparian areas, and agricultural fields. Predominant hardwood species associated with riparian areas include green ash (Fraxinus pennsylvanica), and cottonwood (Populus deltoides). Predominant grass species include big bluestem (Andropogon gerardii), little bluestem (Schizachyrium scorparium, and Kentucky bluegrass (Poa pratensis). The two major agricultural crops include alfalfa and winter wheat.

Two distinct study areas, defined by annual herd home ranges, were used for this project: the Hat Creek area, which is 440 km^2 in size and located between Crawford and Harrison, and the Bordeaux Creek area, which is 484 km^2 in size and located east of Chadron (Figure 1). The Hat Creek area consists of 47% ponderosa pine forest (of which 14% was burned in 1989), 50% grassland, and 3% agricultural crops. The Bordeaux Creek area consists of 51% ponderosa pine forest, 46% grassland, and 3% agricultural crops. Four small towns are located near the 2 study areas, the largest being Chadron, which has a population of 5933. Rural land surrounding these small urban areas is sparsely populated by ranchers and farmers. Housing densities are very low, ranging from 0-0.28 houses/km^2. Road densities, consisting of 2 major state highways and unpaved county roads are also low (0.09-0.46 roads/km^2). Public land managed by the Nebraska Game and Parks Commission (NGPC) and United States Forest Service (USFS) occurs in both areas. The 2 study areas combined consist of 94% privately owned land and 6% public.

The land uses in the region include livestock grazing, crop production, and commercial timber harvest. Cattle on private land are stocked during mid-May to mid-June into forested pastures. Typically, 100-150 cows and calves are stocked into a pasture resulting in an average of 0.33 animals/ha (Hulls, D., University of Nebraska, pers comm.). Cattle occupy these pastures during the summer months and are removed in September or October before the first snowfall. Cattle are moved to grassland pastures close to the ranch house during the fall and winter and are fed alfalfa bales during the non-growing season. Agricultural fields are typically < 16 ha in size. Nine timber harvest operations occurred in the 2 areas during the study. Timber harvest occurred during the spring, summer, and fall months within the Hat Creek area, while occurring only in the fall within the Bordeaux Creek area during 1996. During 1997, timber harvest occurred during the spring and summer months in the Hat Creek area, while no timber harvest occurred within the Bordeaux area.

METHODS

Capture and Radio-telemetry

Twenty-one female elk were captured using a helicopter and net-gun (Helicopter Wildlife Management, Salt Lake City, Utah, USA), ear-tagged and fitted with 150-152 MHZ radio-collars (Advanced Telemetry Systems, Insanti, Minnesota, USA). Elk were located by radio-telemetry, primarily using a vehicle-mounted, 9-element Yagi antenna. Two to 3 azimuths were taken daily at fixed receiver locations to locate the elk.

Distribution of Calving Areas

We used a harmonic mean method of home range analysis (Dixon and Chapman 1980) to determine the distribution of the radio-marked elk during the calving season. At least 20 locations ($\bar{x}$ = 23, range = 20-33) were used for the home range analysis. We combined the 50% isopleth of individual elk to delineate the boundary of each herd home range (White and Garrot 1990). The calving season was defined as 15 May-30 June.

Calving Sites

When the location of a female radio-marked elk became relatively stationary in June, we used a hand-held 3-element Yagi antenna or a 2-element H-antenna to radio-track and locate the female elk. We observed the adult female to confirm the presence and determine the location of a new-born calf. We used the location of the new-born calf as the center point of the calving site. The relative location was recorded using a global positioning system (GPS) and the route into the area was marked by tying blue survey flagging around trees. We did not return to the site and sample vegetation until the radio-location of the female elk indicated that the pair had abandoned the area.

Available Sites

Randomly-located sites were sampled to determine availability and compared to calving sites to determine the significance of selected variables for elk calving areas. Two randomly-selected available sites were sampled for each calving site to increase the sample size. We determined the boundaries of the sampling area by recording the outermost radio-locations (Universal Transverse Mercator coordinate, UTM) of the radio-marked elk in each cardinal direction. We used an Excel spreadsheet (Microsoft, Seattle, Washington, USA) to randomly select UTM coordinates within the defined areas. We used the random UTM coordinate as the center location and located the sites by using a GPS.

Habitat Measurements

Center

We recorded the center location (UTM), and relative aspect of each site. We recorded slope position as bottom, middle, or top. The distance to a road, water, and edge were measured from the center of the sample site in the field or using 1:24,000 US Geological Survey (USGS) topographic maps. The type of road was classified as either low-use (2-track and log-trail) or high-use (gravel and paved). We determined the adjacent edge type as woodland (ponderosa pine or deciduous trees) or non-woodland (grassland pasture, cropland or Conservation Reserve Program [CRP] field). Trees in the sample sites were ocularly classified as pole (10-20 cm diameter at breast height [dbh]), mature (>20 cm dbh), or a mixture of pole and mature class trees. The habitat of the area was classified as ponderosa pine forest, riparian area, grassland, agricultural crop, or burned ponderosa pine forest. These categories were condensed into woodland (ponderosa pine forest and riparian habitat) and non-woodland (grassland, agricultural crops, and burned ponderosa pine).

Transects

Selection of calving sites is also likely influenced by the area surrounding the center. Therefore, we randomly sampled a 31,416 m^2 area around the center. We laid out eight 100-m transects that radiated out from the center location. Two transects within each quadrant were determined using a random numbers table. We sampled slope, ground cover, tree basal area, overstory canopy coverage, and hiding cover every 20 m on each transect, resulting in 40 samples at each site. Slope was determined using a clinometer. Ground cover was measured using a 20 x 50 cm plot (Daubenmire 1959). The percent ground cover < 1-m in height of grass, forb, shrub, litter, and bareground was ocularly estimated. A 20-power prism was used to determine tree basal area (Higgins et al. 1994). Overstory canopy coverage was recorded using a spherical densiometer (Lemon 1956). Hiding cover or horizontal obstruction (% of cover cloth covered) was measured by using a 2.25-m^2 checkered density board. The cover board was held at the center of the study plot, while percent of the cloth covered was determined by an observer standing at each 20-m sample site.

For each of the sample areas, we generated a mean value for slope, ground cover (grass, forb, shrub, bareground, litter), overstory canopy coverage, and hiding cover. In addition, the 5 ground cover measurements made at each sample point were used to create 2 new variables. Ground covered with grass, forb, and shrub was summed and averaged to produce a new variable of living vegetation and ground covered with bareground and litter was summed and averaged to produce a variable of non-living vegetation. For center hiding cover, we generated a mean value from only the 8 measurements made at

20 meters because we were interested in determining the amount horizontal obstruction provided by vegetation rather than topographic terrain features. Topographic terrain features functioning as hiding cover were assessed by the slope of the area.

Correlation Analysis

We constructed a correlation matrix (SAS Institute 1990) to determine levels of association among the variables. When 2 variables were highly correlated (> 0.70), we decided to retain 1 of the variables for further analysis based on biological importance. For example, overstory canopy coverage was highly correlated (0.91) with tree basal area. Therefore, we decided to keep the overstory canopy coverage variable because tree basal area, which gives an index of stem density and an indirect measure of horizontal obstruction was better represented by the hiding cover measurement. No pair of variables exceeding a correlation of ± 0.35 was entered into model.

Logistic Regression

We used logistic regression (SAS Institute 1990) to compare elk-use areas and random (available) sites, and to model the significant variables associated with elk calving sites. The variables with ≥ 2 classes (cattle, habitat type, slope position, road, edge, and stand type) were coded with indicator values to ensure proper interpretation of the odds ratios.

We generated 54 models using "the best subsets algorithm program" which is built into proc logistic (SAS Institute 1990) to assist in the initial model selection. SAS was programmed to output a "resource selection function" to generate the "relative" probability of used sites vs. random sites since an absolute probability is unknown (Manly et al. 1993). The models were scrutinized using a manual selection procedure to reduce the number of models with variables that were highly correlated and ensured that the indicator values of variables with multiple classes were either all included or excluded. The Akaike's Information Criterion (AIC) intercept and covariates value (Burnham and Anderson 1992), Hosmer and Lemeshow (H&L) Goodness-of-Fit p-value (SAS Institute 1990), and the max-rescaled R^2 (Nagelkerke 1991) were the criteria used to assess the models. Models with the lowest AIC intercept and covariates value, and H&L and R^2 values approaching 1 were the best fitting models that explained the variation of the data set. We used the mean ratio of the resource selection function (RSF, mean value of calving sites/mean value of random sites) and odds ratio to determine the biological significance of the model and individual variables. For example, a RSF ratio of 20 indicates that given the characteristics at all the areas, elk calving sites were 20 times more likely of being used than random sites. Further, if road distance had an odds ratio of 1, that would indicate that elk calving sites moved 100-km closer or farther away from a road would not change the likelihood of being used by elk. In this example, distance to a road has no biological meaning. Odds ratios further from 1 indicate a significant relationship between the dependent and independent variable. Distance from a road with an odds ratio of 1.45 would indicate that for each kilometer away from a road, elk were 45% more likely to use the site.

Variables with multiple classes and indicator values are reliant upon interpreting the odds ratio by using 1 of the categories as a reference. For example, if the variable stand type was considered in a model then the first category (pole-class timber) would be the reference. If the odds ratio for a mature stand was 0.011 and 1.474 for a mixed-age stand, then the interpretation would be that if the site was a mature stand, the site is 9 (1/0.11) times less likely to be used by elk than a site classified as a pole-stand. Similarly, if the area was classified as mixed-age stand, then the area is 47% more likely to be used by elk than a site classified as a pole-class stand.

RESULTS

Distribution of Calving Areas

Elk herd home ranges during the calving season were located throughout the 2 study areas (Figure 2). All of the radio-marked females isolated themselves from the herd and calved separately during June ($\bar{x}$ = 17 June, range = 10-23June). They did not congregate to a specific area to calve. Four of the 22 calving events in the Pine Ridge were < 400 m of the previous year's location and used by the same elk during 1996 and 1997. Certain female elk in Montana exhibited fidelity to calving areas (Zahn 1974). Six-teen (73%) of the calving sites were located in ponderosa pine forest, 4 (18%) in riparian areas, and 2 (9%) in areas with burned ponderosa pine trees and deadfall. Eighty-two percent (n = 9) of the calving areas were on privately-owned land in 1996 and 73% (n = 8) in 1997.

Macro-habitat Characteristics

Calving Areas

Ninety-five percent (n = 21) of the elk calving areas were located in pastures that were absent of cattle. The closest road was low-use for 95 % of the use-areas. The calving areas were located in stands with a mixture of mature and pole-class ponderosa pine trees (63%), riparian areas (18%), mature ponderosa pine trees (10%), and burned ponderosa pine (9%). Fifty-five percent of the calving centers were adjacent non-woodland and 45% woodland.

Random Sites (Available)

Thirty-six percent (n = 15) of the random areas were located in pastures absent of cattle and the closest road was low-use for 98% of the sites. Fifty-five percent of the randomly-located centers were adjacent woodland and 45% non-woodland. The centers of randomly-located areas were found in stands with a mixture of mature and pole-class trees (49%), grassland (26%), mature trees (14%), pole-class timber (9%), and burned timber (2%).

Micro-habitat Characteristics

The calving and random areas were remarkable similar with the exception of the distance to a road, slope, and hiding cover (Table 1). The calving areas were located further from roads ($\bar{x}$ = 1.1 km, range = 0.08-3.6 km) than randomly available ($\bar{x}$ = 0.62

km, range = 0.002-4.7 km). The slope of calving areas ($\bar{x}$ = 19^0, range = 12-29^0) was steeper than randomly available ($\bar{x}$ = 15^0, range = 2-28^0). The average slope of the centers of calving areas was 11^0. Elk also selected calving areas with hiding cover ($\bar{x}$ = 44%, range = 7-92%) greater than available ($\bar{x}$ = 30%, range = 0-68%).

The average aspect of elk calving centers was southwesterly at 229^0. Calving areas contained 43% grass, 7% forb, 7% shrub, 11% bareground, and 32% litter, while random areas contained 47% grass, 7% forb, 5% shrub, 11% bareground, and 30% litter. Elk selected areas with slightly denser stands ($\bar{x}$ = 28 m^2/ha) than randomly available ($\bar{x}$ = 24 m^2/ha), although areas selected by elk were not in the densest areas available in the Pine Ridge (62 m^2/ha). Elk calving areas also contained areas with slightly more overstory canopy closure ($\bar{x}$ = 70%, range = 52-90%) than randomly-located sites ($\bar{x}$ = 66%, range = 0-89%). The average distance from calving centers to water was 676 m, which was similar to randomly-located sites ($\bar{x}$ = 706 m).

Models of Calving Habitat

The variables that appeared to best explain differences between elk calving and randomly-located sites were presence of cattle, slope, distance from a road, woodland habitat (ponderosa pine forest and riparian area), and hiding cover. The simplest model (1) that described relationships among the calving data was:

G (x)= -7.399 – 5.495 (Cattle) + 0.332 (Average Slope) + 0.179 (Road Distance) +2.650 (Ponderosa Pine Forest) + 1.399 (Riparian Area) where $G(x) = \ln[\pi/(1-\pi)]$ and π is the probability that elk-use = 1 (i.e., the probability that a site is used). It had an AIC value = 49.57, max-rescaled R^2 of 0.65, H&L p-value of 0.97, and SF ratio of 52 (Table 2).

Another model (2) that effectively described the relationships among the calving data was:

G (x)= -8.376 – 5.730 (Cattle) + 0.356 (Average Slope) + 0.210 (Road Distance) + 0.021 (Hiding Cover) +2.499 (Ponderosa Pine Forest) + 1.139 (Riparian Area).

It had an AIC value of 50.35, max-rescaled R^2 of 0.67, H&L p-value of 0.86, and SF ratio of 92.58.

DISCUSSION

Distribution of Calving Areas

Woodland habitat (ponderosa pine forest and riparian areas) was used by radio-marked female elk to calve. Seventy-three percent (n = 16) of elk calving areas were located in ponderosa pine forest, and 16% (n = 4) in riparian areas. Elk were 12-14 times more likely to calve in a ponderosa pine forest and 3-4 times more likely to use a riparian area than non-woodland habitat. Elk in the Black Hills of South Dakota bedded during the summer in ponderosa pine forest with closed canopies and gentle northerly slopes (Millspaugh 1995). Elk in Kansas selected riparian areas to calve (Robinson 1992), whereas elk in Idaho used areas with slash, or downed logs (Phillips 1966). Calving areas in Nebraska had similarities with those used by elk in South Dakota, Kansas and Idaho. Elk use of forest, riparian, and disturbed habitats may indicate there is no single covertype required for calving, rather selection may depend on the land-use patterns and availability of habitat in a particular region.

Eighty-two percent (n = 11) of calving areas were located on privately-owned land in 1996 and 73% (n = 8) in 1997. Although the majority of areas were on private land, public land appears to play an important role for elk calving. Elk made greater use (18% and 27%) of public land in both years than was available (6%). The grazing regimes on public land may be enhancing habitat for elk seeking areas to calve. Cattle grazing on USFS land incorporated more deferred, rest-rotation practices than grazing on private land (Abegglen, J., USFS, pers comm.). Cattle were not grazed on the Gilbert-Baker Wildlife Management Area (WMA) during 1996 and 1997. The northwest pasture of Fort Robinson State Park was lightly stocked with 120 yearling bison (Bison bison), which resulted in a stocking rate of 0.06 bison/ha. Both NGPC and USFS land was used by elk for calving during the 2 summers. The Gilbert-Baker WMA, Fort Robinson State Park, and Soldier Creek Wilderness Area were used by elk to calve in the Hat Creek area, whereas USFS land was used in the Bordeaux Creek area.

Macro-habitat of Calving Areas

Distance to a Road and *Road Type*

Female elk in the Pine Ridge selected calving areas away from roads likely to decrease the chance of being displaced by humans and improve probability of rearing a calf. Elk were 20-23% more likely to use a site as the distance from a road increased by 1 km. Elk prefer to use habitat without human disturbance and away from traveled roads (Lyon 1979, 1983, 1985 et al., Rost and Bailey 1979, Hershey and Leege 1982, Grover and Thompson 1986, Edge and Marcum 1991).

Roads were classified as either low-use (2-track or log-trail) or high-use (gravel or paved). All roads considered in the analysis were traveled since it is the disturbance associated with the road that elk avoid. It seems logical to expect that the likelihood of elk use would greatly increase if the closest road to the site was a low-use road. Models including the type of road indicated similar probabilities of use regardless if the closest road to the site was low- or high-use. The distance to a road, regardless of the amount of use was a significant variable characterizing elk calving areas. Similarly, elk selected annual home ranges with the lowest road densities, but not the lowest road-use indices (Stillings, ch. 3. 1999). Elk habitat selection appears to be more a function of the distance to a road and density rather than the amount of daily travel. An unpredicted disturbance caused from vehicular travel on a 2-track or log-trail likely causes more of a flight response than a predictable event, such as the traffic on Highway 20. Elk may also perceive a vehicle encounter on a low-use road more threatening, especially if prior events were associated with hunting, poaching, or other harassment. Therefore, it may be advantageous for elk to seek areas to avoid a disturbance altogether and minimize the chance of being displaced near the time of parturition or being separated from its calf. The lack of significance associated with road type in the Pine Ridge differs from a model produced for calving areas in Kansas that determined the distance from high-use roads (gravel road or paved highway) was significant in determining elk-use (Bian and West 1997).

Distance to Water

Typically, female elk in the Intermountain West calve < 400 m of water (Skovlin 1982). Elk calving areas in the Pine Ridge were slightly > 400 m from water. The average distance from water was 676 m, which was similar to randomly-located sites ($\bar{x}$ = 706 m). The location of calving areas in the Pine Ridge may indicate that female elk are willing to calve further from water and travel longer distances to fulfill this physiological requirement. The extent in which elk are dependent upon water is unclear (Skovlin 1982). Research in Oregon and Idaho indicate that lactating female elk are dependent on water (Marcum 1975, Thomas et al. 1976). We measured the distance to water in the field when the closest source was easily determined (e.g. windmill or creek). When the distance to water was not easily determined in the field, we used 1:24,000 USGS topographic maps to record the closest known water source. It is possible that elk were using a closer unrecognized water source, such as a depression that collected rainfall.

Distance to Edge

Elk in the Pine Ridge calved < 300 m on average from the edge of 2 habitat types. Typically, calving areas were located in ponderosa pine forest adjacent to an open grassland park. Elk calving areas in Idaho are characteristic of being located in the ecotone between a sagebrush community and a forest (Phillips 1966, 1974, Roberts 1974). The ecotone may provide the optimal habitat in terms of cover for the calf and forage for the dam (Skovlin 1982).

Cattle

The absence of cattle within a pasture was the most significant variable determining calving sites. Site selection appears to be an annual event that is related to grazing management. Areas free of cattle were 250 and 333 times more likely to be used as calving sites. Ranchers moved cattle into summer pastures during the period (15 May-9 June) when elk were selecting areas to calve. Radio-marked elk responded by moving > 1600 m within 3 days of cattle being stocked into the pasture (Stillings, ch. 3, 1999). For example, on May 8th, 1997 an adult female elk in the Bordeaux Creek area returned to the timbered pasture where she calved in 1996. This pasture was rested from cattle grazing in 1996. On May 15th, cattle were stocked into the pasture, and the elk was located 2307 m away from the cattle 1 day later. She moved out of the ponderosa pine forested habitat and into a deciduous creek bottom 1245 m away from the Pine Ridge, where she remained to calve. Mackie (1970) reported that elk are socially subordinate to cattle and therefore are displaced when they come into contact. Elk cow and calf groups in Grand Teton National Park immediately vacated traditional calving grounds after the stocking of cattle (Sauer 1980). Elk avoidance of cattle in the Pine Ridge is confounded by the disturbance created by ranchers checking windmills and minerals.

The consequences of pregnant elk avoiding livestock and making large movements during late stages of gestation are not understood in terms of calving success and calf survival. Elk may avoid areas with cattle as a response of increased ungulate densities (Sauer 1980). High densities of ungulates could attract coyotes and other calf predators to the area. The potential for calf mortality may be highest if cattle are stocked into a pasture shortly after an elk birth. Female elk moving long distances away from cattle would leave calves unprotected and increase potential of predation and desertion.

Micro-habitat of Calving Areas

Aspect

The average aspect of elk calving centers was southwesterly at 229^0, but varied in the 4 cardinal directions. Aspect does not appear to be an important variable for elk during the calving season. Altmann (1952) found that elk in Wyoming used southerly exposures most frequently, while elk in Idaho preferred northwesterly exposures (Phillips 1974, Roberts 1974). Selection for aspect is likely more a function of the availability of the slopes at the time when the pregnant female is near parturition, rather than specifically searching for the ideal exposure.

Slope

The average slope of the area was an important variable of elk calving sites in the Pine Ridge. Elk were nearly 400% more likely to use a site as the average slope of the area increased by 10 degrees. Typically, calving sites consisted of a gradual sloping center ($\bar{x} = 11^0$) surrounded by steeper slopes ($\bar{x} = 19^0$, range = 12^0 - 29^0). Elk in Idaho preferred slopes < 20% and avoided slopes > 60% (Hershey and Leege 1982). The use of areas with steeper slopes is likely to decrease the accessibility of humans and minimize the impacts of disturbance. Female elk in Montana selected calving sites away from high-traffic roads and with topographic barriers between the use area and road (Edge and Marcum 1991). Similarly, elk in the Pine Ridge isolated themselves from human disturbance by using areas of rugged topography with steep slopes.

Ground Cover

Elk calving areas and randomly-located areas had very similar ground cover. Calving areas contained 43% grass, 7% forb, 7% shrub, 11% bareground, and 32% litter, while random areas contained 47% grass, 7% forb, 5% shrub, 11% bareground, and 30% litter. Selection for calving areas does not appear to related to understory characteristics. Similarly, herbage production under the timber types appeared to have little or no influence on elk in Idaho selecting calving areas (Phillips 1974).

Tree Basal Area and Overstory Canopy Coverage

Elk used areas with slightly denser stands ($\bar{x}$ = 28 m^2/ha) than randomly available ($\bar{x}$ = 24 m^2/ha), although areas selected by elk were not in the densest areas available in the Pine Ridge (62 m^2/ha). Stands selected by elk were considered at the desired levels of stocking and indicative of timber harvest (Overstreet, J., state forester, University of Nebraska, pers comm.). Timber harvest does not appear to negatively impact the habitat for calving elk. Elk calved in areas that were unlogged, logged 2-30 years ago, and even areas with logging ceased the day before the female arrival. One radio-marked female calved during 1996 and 1997 in an area dominated by burned snags, downed timber, and few living pine trees due to the 1989 wildfire.

Elk calving areas also contained areas with slightly more overstory canopy closure ($\bar{x}$ = 70%, range = 52-90%) than randomly-located sites ($\bar{x}$ = 66%, range = 0-89%). Elk in the Pine Ridge selected calving areas with greater canopy closure than reported for elk in Idaho ($\bar{x}$ = 37%, range = 20-60%, Phillips 1974). Big game biologists have speculated from radio-telemetry studies that there are energetic benefits for elk using relatively closed canopies. Areas under closed canopies provide cooler temperatures in the summer and less fluctuating conditions in the winter (Skovlin 1982). Recent evidence indicates that thermal cover, consisting of an environment with a relatively closed canopy does not increase the condition of elk (Cook et al. 1998). Yearling elk consumed more water in areas with < 70% canopy coverage, while growth and condition did not differ among the amount of forest canopy. Although canopy closure may not provide energetic benefits to elk, all females in the Pine Ridge calved in areas with some overstory coverage. Elk calving in areas with canopy coverage may be simply related to selection for hiding cover. Coniferous, riparian, and burned areas contained some degree of canopy closure, but all had significant amounts of hiding cover. Visually observing elk was as or more difficult in areas with burned snags and deadfall, with few living pine trees as it was in dense stands of ponderosa pine forest. The variability of tree basal area and overstory canopy closure among elk calving areas may indicate that an ideal micro-habitat or micro-climate is not required for elk in a ponderosa pine/grassland landscape. Elk calving areas in the Intermountain West are also variable and dependent on the regional availability of habitat (Skovlin 1982).

Hiding Cover

The importance of hiding cover for calving areas is variable among elk (Skovlin 1982). Female elk in Wyoming appeared to select calving areas based on hiding cover (Altmann 1952), while no such selection was detected in Montana (Marcum 1975). Hiding cover for elk in the Pine Ridge appears to be an important component for calving areas. Elk calving areas contained more hiding cover ($\bar{x}$ = 44%, range = 7-92) than randomly-located sites ($\bar{x}$ = 30%, range = 0-68%). The likelihood of elk use increased approximately 22% with an increase of 10% in hiding cover. Thus, we included hiding cover in model 2. Hiding cover consists of vegetative or topographic terrain features, or a combination of these features, that allow elk to avoid detection by predators and other disturbances, or to escape when detected (Brown 1987). Elk in the Pine Ridge satisfy hiding cover requirements and avoid detection by using terrain with steep slopes ($\bar{x}$ = 19%) and areas with horizontal obstruction that are located away from roads and cattle. Security cover appears to be required by elk in the presence of human disturbance (Peek et al. 1982). Elk in the Pine Ridge are affected by human disturbances. Female elk responded to active timber harvest and cattle by vacating the areas with the disturbance, and selected areas with low road densities (Stillings, ch. 3. 1999).

Model Selection

Final model selection was based on detailed examination of over 50 individual models. In each case, highly correlated variables were excluded, and indicators for each categorical variable were entered or excluded together. Among the models ultimately selected, no pair of variables had correlation exceeding ±0.35. We measured 19 variables that might serve to explain whether a site in the study was selected by elk or not. The goal was to identify those habitat characteristics that are most important for elk. A simple approach was to conduct univariate tests to separately examine each variable. There were 2 groups of sites, used and randomly-located available sites, establishing the basis for tests of means (e.g., t tests) for continuous variables or tests of proportions (e.g., χ^2 tests) for categorical variables. The problem may really be a multivariate one; it seems likely that elk do not assess each habitat characteristic separately, but rather evaluate many characteristics simultaneously. In statistical terms, the effect of 1 variable may depend on the presence of other variables in a model. Furthermore, given that the response variable is binary (used or not used) and that there were categorical and continuous explanatory variables, we chose logistic regression as the most appropriate tool for analysis. In some cases, multivariate discriminant analysis might be a viable alternative, but this method has more restrictive assumptions than logistic regression. In particular, discriminant analysis cannot accommodate categorical variables, and requires multivariate normality (Johnson and Wichern 1998).

While significance of individual parameters in the candidate models were examined, the decision to retain or discard a particular variable was not based on strict significance levels. Thus, it was possible to obtain a model with low AIC, but have certain estimated slope coefficients with p-values greater than 0.05 or even 0.10. Philosophies of model selection differ among statisticians, and some of those who advocate use of AIC argue that the entire suite of variables in a model should be considered together. Thus, greater importance was placed on the multivariate significance as contrasted with significance of individual variables. Any model under consideration had to be biologically reasonable. Small differences in AIC were not considered important. Thus, given several candidate models with identical, or very similar AIC values, the "best" model (or models) should then be chosen on the basis of simplicity and reasonableness (Burnham and Anderson, 1992).

Models and Calving Habitat

Elk selection of calving areas appear to be related to an interaction of macro- and micro-habitat characteristics. Typically, female elk in the Pine Ridge calved in woodland habitat without cattle that contained steep slopes and were located away from roads. The presence of cattle, distance to a road, and woodland habitat were the macro-habitat variables that were most influential in determining calving sites, while slope and hiding cover were important micro-habitat variables. The 5 variable model with cattle, slope, ponderosa pine forest, riparian habitat, and distance to a road best explained differences between elk calving areas and randomly-located sites. The 6 variable model, with the addition of hiding cover was also good and may be more comprehensive. The odds ratios for cattle in the 2 models were 0.004 and 0.003, thus elk were 250 (1/0.004 = 250) and 333 (1/0.003 = 333) times more likely to use sites free of cattle. Furthermore, as the average slope of the area increases by 10 degrees, elk were nearly 400% more likely to use the site. Finally, as the distance from a road increases by 1 kilometer, elk were 20-23% more likely to use a site. The likelihood of elk use increases by approximately 22% with an increase of 10% in hiding cover. Elk also were 12-14 times more likely to select ponderosa pine forest than non-woodland habitat. For model number 1, the SF Ratio is 52, indicating that given the characteristics at all the areas, elk calving sites were 52 times more likely of being used than random areas. In model 2, elk calving sites were nearly 93 times more likely of being used than random sites. The AIC and Hosmer and Lemeshow (H&L) Goodness-of-Fit p-values indicate that both models fit the data well.

The Pine Ridge supports approximately 1,200 km^2 of woodland habitat. The majority is ponderosa pine forest with rugged terrain interspersed with riparian areas. Elk fulfilled hiding and security cover requirements by selecting ponderosa pine forest and riparian areas away from roads to calve. Hiding cover in terms of woodland habitat with rugged terrain does not appear to be a limiting factor for elk calving in the Pine Ridge. Road densities in the Pine Ridge also are low (0.09-0.46 km^2) allowing elk to select calving areas away from vehicular disturbance.

Elk selection of calving areas coincides with the period that cattle were moved into woodland pastures. The interaction between elk and cattle, and increased human activity in woodland habitat appears to be the factors determining calving site selection. Cattle stocked into summer pastures after 1 July may improve the suitability of the Pine Ridge habitat for calving elk.

Application of Calving Habitat Models

We used the resource selection function to determine the relative probability of use when considering all the sites (Manly et al., 1993). The developed models with macro- and micro-habitat variables may be applied to the entire Pine Ridge using a GIS to determine the suitability of calving habitat. For example, given the measured characteristics at 2 potential sites, Ash Creek and the White River area, one may determine that the Ash Creek area is, say, 10 times more likely to be selected than the White River area. Similarly, from samples of non-use areas west of Crawford and areas east of Chadron, one might find that on average the region west of Crawford is 6.5 times more likely to be used by elk than the region east of Chadron.

Suppose there are 3 explanatory variables, cattle (X_1), slope (X_2), and distance from a road (X_3), in a particular model for elk. The values of these variables at site j might be designated x_{1j}, x_{2j}, and x_{3j}, respectively. If the estimated slope coefficients for these 3 variables are β_1, β_2, β_3, then the estimated resource selection function for the elk-use area is:

$$w(x_j) = \exp\{\beta_1 x_{1j} + \beta_2 x_{2j} + \beta_3 x_{3j}\}$$

The selection function may similarly be estimated for site k, which may be an unused area adjacent to the Bordeaux Creek study area, yielding $w(\mathbf{x}_k)$. The ratio $w(\mathbf{x}_j)/w(\mathbf{x}_k)$ gives the probability of selecting a use-site relative to an unused area. As indicated above, the selection function might be evaluated for many sites; then different groups of sites might be compared to each other.

MANAGEMENT IMPLICATIONS

Avoidance of cattle appears to be the most influential factor in determining elk calving sites and the variable most easily manipulated by managers. The suitability of forested pastures on private land may be enhanced by purchasing conservation easements, which would incorporate rest-rotation and deferred grazing practices during the elk calving season. Public land also appears to play an important role for female elk that are selecting areas to calve. Management plans for grazing public land should include consideration of the elk calving season and ensure that some pastures are rested annually and others do not begin grazing until after 15 July. Elk preferred calving areas away from roads. Road closures on USFS land during 15 May-15 July should be considered to improve the suitability of habitat for calving.

The absence of cattle, average slope of the area, habitat type, and distance from a road were identified as important variables in the model for calving areas in the Pine Ridge. This model may assist future evaluation of elk calving habitat in the Pine Ridge. We suggest using the model with a GIS to evaluate the suitability of habitat for calving in the entire Pine Ridge. Results from a landscape evaluation may assist managers in identifying potential calving areas and enhancing habitat on public and private land.

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Table 1. Habitat values for elk calving areas (n = 22) and randomly-located available areas (n = 42), Pine Ridge region, Nebraska, 1996-1997.

Habitat Characteristic	Calving Areas (Use)		Random Areas (Available)	
	$\bar{x}$	range	$\bar{x}$	range
Center				
Aspect (degrees)	229	30-338	193	2-353
Slope position (bottom, mid, top)	mid	bottom-top	mid	bottom-top
Distance to road (km)	1.1	0.08-3.60	0.62	0.002-4.70
Distance to water (m)	676	25-1601	706	40-2000
Distance to edge (m)	258	5-2696	201	5-1800
Slope (%)	19	12-29	15	2-28
Transect				
Ground Cover				
Grass (%)	43	24-65	47	19-79
Forb (%)	7	2-14	7	1-23
Shrub (%)	7	0-20	5	0-30
Bareground (%)	11	0-29	11	0-35
Litter (%)	32	4-59	30	4-57
Horizontal Cover and Forest Overstory				
Tree basal area (m^2/ha)	28	2-55	24	0-62
Forest overstory (%)	70	52-90	66	0-89
Hiding Cover (%)	44	7-92	30	0-68

Table 2. Significant variables, AIC, H&L P-values, odds ratios, resource selection function (RSF) ratios, and individual P-values of the 2 selected models of elk calving areas in Northwestern Nebraska.

Model	Variable	R^2	AIC	H&L P-Value	Odds Ratio	RSF Ratio	P
1	Cattle	49.57	0.65	0.97	0.004	52.00	< 0.001
	Slope				1.394		0.018
	Distance to Road				1.196		0.080
	Ponderosa pine Forest				14.157		0.661
	Riparian Area				4.051		0.210
2	Cattle	50.35	0.67	0.86	0.003	92.58	0.001
	Slope				1.428		0.020
	Distance to Road				1.234		0.470
	Ponderosa pine Forest				12.165		0.623
	Riparian Area				3.125		0.174
	Hiding Cover				1.022		0.273

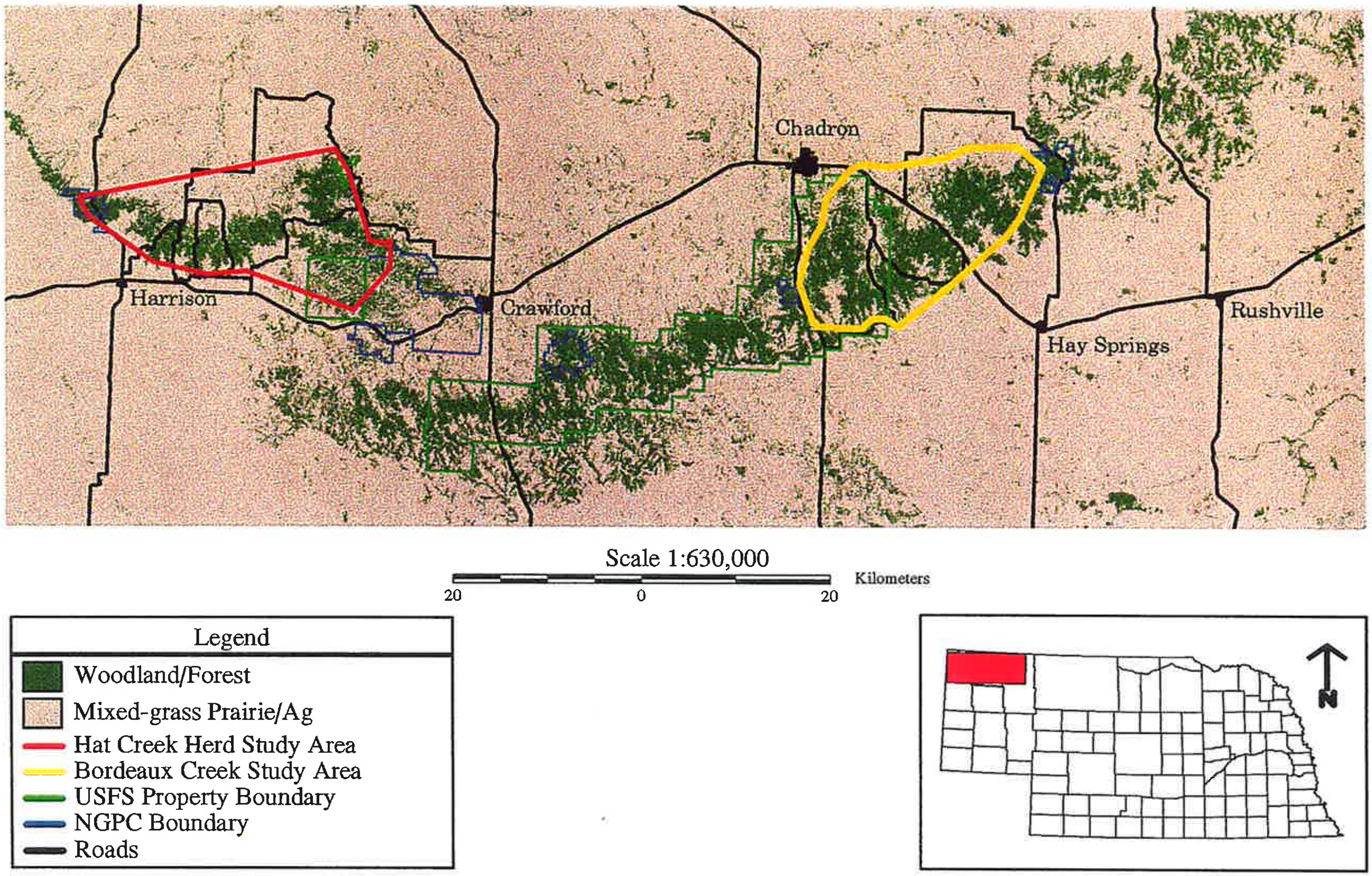

Figure 1. Pine Ridge region of northwestern Nebraska.

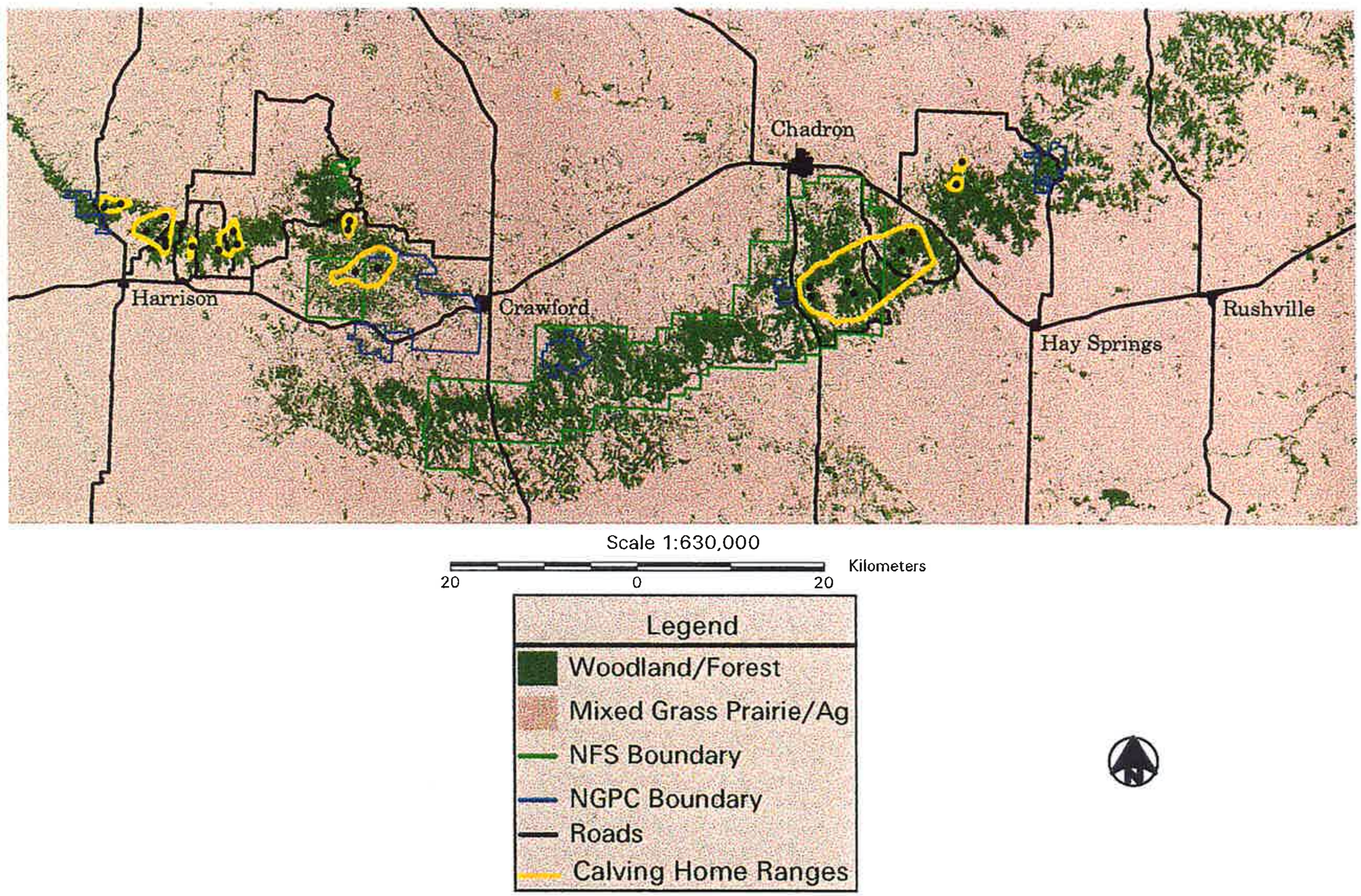

Figure 2. Herd home ranges and center locations (•) of elk calving areas in the Pine Ridge region of northwestern Nebraska, 1996-1997.