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INTEGRATED REMOTE SENSING AND GIS TECHNIQUES FOR ELK HABITAT MANAGEMENT

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ABSTRACT

This inter-disciplinary study of habitat use by Rocky Mountain elk (*Cervus elaphus nelsoni* Bailey 1935), and of conflicts with human land use and development zoning, uses remote sensing, image processing, and geographic information systems for data manipulation and analysis. The project included the application of home range algorithms, satellite image classification, and geographic information systems (GIS) to identify and map critical habitat zones where elk and humans interact and compete for limited space and other resources in an area of the southern Rocky Mountains of central Colorado. Results reveal an ever increasing invasion by humans into prime elk habitat areas and the need for better control of human development in the mountain environments of the American West.

As the use of natural resources increases and as stress on the environment becomes more acute, and more expensive, better methods of evaluating, allocating, and protecting resource use are needed. New technology can and should play a significant role in this effort. For example, useful computer hardware and software are becoming more widely available to scientists addressing resource allocation issues. This article examines how several proven and emerging technological tools were melded to study habitat use and allocation for an ungulate species in the western United States.

Little is known about the use of and competition for habitat in the Southern Rocky Mountains of Colorado by Rocky Mountain elk (*Cervus elaphus nelsoni*). Earlier this century elk in Colorado were near extinction [1]. Elk were reintroduced, and herds throughout the state have increased since that time. A herd consisting of some 1,200 animals located west of Pikes Peak in central Colorado began in the 1920's with seventeen elk that were reintroduced into the area from

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Wyoming. This herd and its relationship to its habitat and the growing human influences are the subject of this study.

Considerable research has been conducted on elk and habitat relationships in many mountain regions of the United States. The Pacific Northwest is especially well studied as represented in works by Pedersen, Adams, and Skovlin [2], Thomas et al. [3], and Skovlin, Bryant, and Edgerton [4]. While this research is extremely valuable for the Northwest, it is less useful for the unique environments of the Southern Rocky Mountains.

The study area for this project includes a large and expanding exurban human population which is beginning to affect the elk of the region (Figure 1). Lack of knowledge about the elk, their habitat, or their relationship to humans in this area, prompted the present project. It is the continuation of a preliminary study [5] and was sponsored by a research group including the University of Colorado at

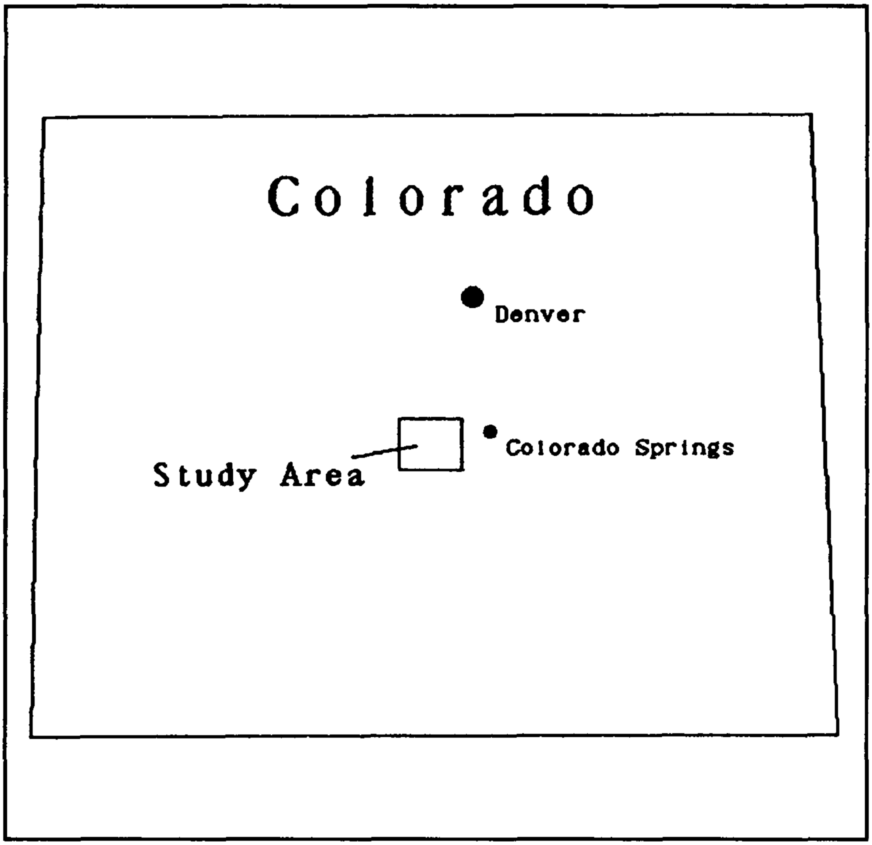

Figure 1. The study area is located in Central Colorado.

Colorado Springs, the Colorado Division of Wildlife (CDOW), the National Park Service, and the U.S. Forest Service. Because virtually no research has been done on this elk population from the time of its reintroduction, two general, overriding questions need to be addressed. First, what is the extent of elk movement and use of habitat in the area? Second, what are the current and future conflict areas between elk habitat use and human land use development?

STUDY AREA

The elk involved in the study are not one homogeneous herd but several small, intermingling herds that overlap in habitat use. For the purpose of this study, the name "Eleven Mile elk herd" will be used for the entire collection of elk in the study area. The study area includes approximately 2,456 square kilometers of mostly montane, upper montane, and subalpine vegetation regimes [6]; there is a significant alpine region on the far eastern edge of the area (Figure 2). Elevations for the study area range from 1,980m to over 4,300m at Pikes Peak. Eighty percent of the area lies between 2,560m and 3,000m on an undulating, ancient erosional surface.

The land ownership of the study region is significant. Over 3,516 hectares are in the Florissant Fossil Beds National Monument, almost 7,000 hectares are in Mueller State Park, 24,000 hectares of the study area is U.S. Forest Service (USFS) land in a protected water shed for the City of Colorado Springs (only recently opened to the public), almost 7,300 hectares are in a privately held, non-hunting reserve, and a total of about 150,000 hectares are in the Pike National Forest. The remaining 78,000 hectares are all privately owned, and much of this is being slowly but steadily developed into five to thirty-five acre residential lots.

RESEARCH METHODS

The study consists of three integrated segments: elk habitat mapping and analysis using satellite imagery; radio collaring and tracking of ten cow elk; and a determination of areas where human land use and elk habitat use conflict by means of geographic information system (GIS). These project segments were designed to produce two specific outcomes: 1) to determine the extent of suitable habitat and to the study of the use of that habitat by the elk, and 2) to delineate areas of current and potential conflict between critical elk habitat and human land development.

Elk Habitat Mapping and Analysis

According to Skovlin, elk habitat has four basic components—food, cover, water, and space [7]. The most basic and main contributor to habitat, because it directly affects three of the four components, is vegetation. Food, cover, and space

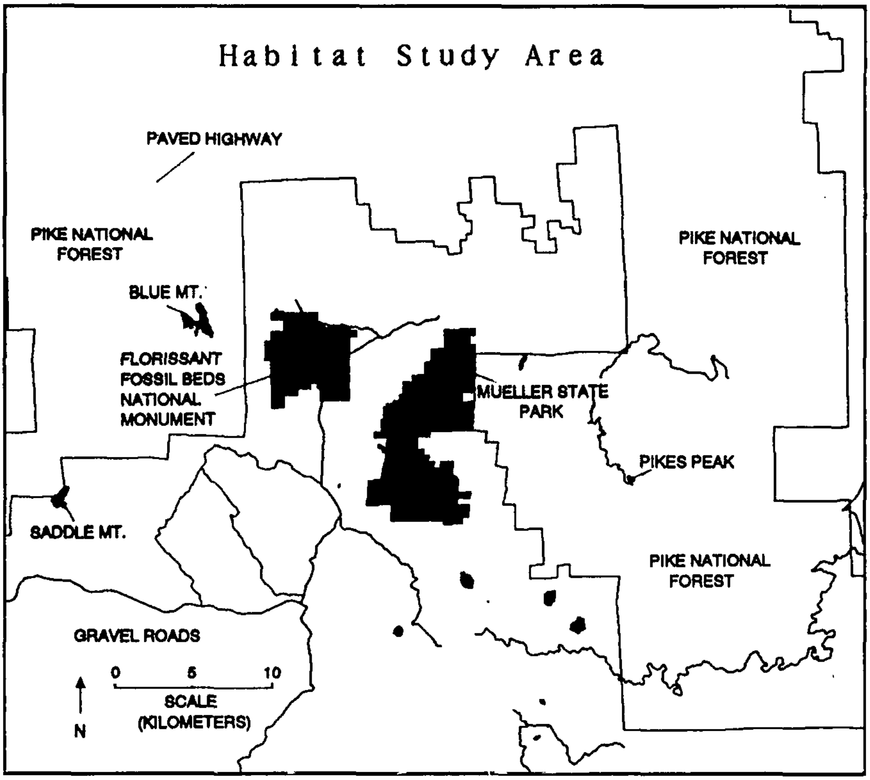

Figure 2. The study area includes large segments of Pike National Forest, Florissant Fossil Beds National Monument, and Mueller State Park.

are influenced by vegetation species distribution and vegetation structure. Water directly affects vegetation and is indirectly dependent on the vegetation characteristics of the area.

Because the study area was so large and complex, it was decided to use remotely sensed, satellite images to map the vegetation for the study. A Landsat Thematic Mapper (TM) image (scene ID# Y5120117021X0) procured on June 30, 1987 was chosen for its cloud-free view and its timing for seasonal vegetation growth. It has been shown repeatedly that TM imagery is useful for forest vegetation mapping at this scale [8, 9]. The 30m x 30m pixel size of the image was resampled to 28.5m x 28.5m spatial resolution with geometric correction, which produced a scale that was manageable for the large study area. Vegetation classification was done using six of the seven TM bands: band 1 (blue), band 2 (green), band 3 (red), band 4 (near infrared), and bands 5 and 7 (mid-infrared).

The vegetation classification scheme used was an existing CDOW system which was modified for use with TM data. This CDOW vegetation classification scheme is a multi-level system that may be used for several different resolutions of vegetation identification. Table 1 is an example of the system for forests. The resulting thirteen classes of vegetation extracted from the TM data are given in Table 2. This scheme was based on both vegetation structure and dominant vegetation species types. It is roughly equivalent to the Anderson et al. system levels III and IV which were initially designed specifically for use with remotely sensed data [10].

Experiments with various computer algorithms for the vegetation classification analysis were made. All operations were done on a PC-based 386 microcomputer using the Map and Image Processing (MIPS) software available from Micro-Images, Inc. The complex nature of the mountain environment in the study area made it difficult to choose the best classification algorithm. Different forest types, sun and sensor angles, spectral variations among vegetation species, topographic

Table 1. Example of CDOW Vegetation Scheme

Level I — Forests	
Level II —	Upland Forests
Level III —	Upland Confierous Forests
Level IV —	Douglas Fir Forests
Level V —	Mesic Douglas Fir Forests

Table 2. Vegetation Classes Derived from Landsat TM Data

Ponderosa Pine (*Pinus Ponderosa*)
Douglas Fir (*Pseudotsuga menziesii*)
Spruce/Fir (*Picea Engelmannii/Abies lasiocarpa*)
Mixed Conifer
Limber/Bristlecone Pine (*Pinus flexilis/P. aristata*)
Aspen (*Populus tremuloides*)
Water
Wet Meadow
Riparian Shrub
Mesic Grassland
Dry Meadow
Alpine
Non-Vegetated

variations, and atmospheric characteristics all contribute to this complexity for remote sensing purposes [11-13]. The most acceptable classification algorithm found for classifying the TM data into vegetation types in the study area was the Wagner and Suits supervised classification technique [14]. This algorithm is a combination and modification of the more common parallelopiped technique and the more complex maximum-likelihood classifier; both use Gaussian parameters for decision boundaries. Although a complete discussion of the theory behind the Wagner and Suits method is beyond the scope of this article, in essence, it transforms the parallelopiped, three dimensional space into a reoriented and truncated prism decision boundary classification scheme.

Other significant habitat influences that are not specifically included in Skovlin's four basic habitat components are slope and topographic aspect [7]. Zahn [15], Marcum [16], and many others discuss at length the use by elk of land at different slope angles and aspects. In this study we used U.S. Geological Survey (USGS) digital elevation model (DEM), 7.5 minute, 30m x 30m pixel size elevation data to calculate slopes and aspects for the entire study area. The slope and aspect of the terrain for each elk sighting was recorded to indicate the general pattern of slope and aspect use by the elk.

Elk Collaring and Tracking

Ten cow elk were radio-collared for the study. The Telonics radio collar was used in conjunction with the Telonics receiver/directional antenna for radio triangulation of the elk position. According to White and Garrott, at least three bearings should be taken for each triangulation [17]. Under terrain and project resource constraints, it is often necessary to use only two bearings as discussed in Mech [18]. Three bearings were used in this study where possible, but two bearings were used in many of the sightings.

These triangulation bearings were then transferred to the appropriate USGS 1:24,000 topographic map and the UTM coordinates for the elk position were recorded. More than 1,500 sightings of individual elk were collected. Along with the UTM position, other information including date, time of day, season (e.g., hunting or winter), habitat (if possible), and whether or not the cow was with a calf (if possible) were recorded. All of these data were entered into a DBase III+ database. Each elk sighting became a data point in the MIPS geographic information system (GIS) which could be displayed and/or analyzed over a map or image of the study area.

The elk positions were also analyzed using home range algorithms. Two separate home range algorithms were tested in the study: a harmonic mean measure [19] and a Fourier measure [20]. The harmonic mean home range gave the best overall results so all final home range locations for the final outcome of the study are harmonic mean home ranges. Home ranges for the entire study group of 1,500 sightings as well as for each elk for each of three seasons were calculated.

The seasons used were the calving (May 15-June 30), winter (January 1-March 31), and hunting (October 1-November 30) seasons. These home ranges were employed to determine the extent of habitat use by the elk. Although the home ranges are only statistical approximations, they were very useful in delineating elk movement loci and therefore presumed habitat use especially for each of the critical seasons (Figures 3, 4, and 5).

Elk/Human Conflict Determination

The data inputs for determining conflict areas between elk habitat use and human development were the habitat/vegetation classification map, land use/zoning maps obtained from the counties within the study area, and the home range locations. The zoning maps were digitized on an X-Y digitizer and stored in vector format for use with the GIS system. All three data sets (vegetation distribution, elk

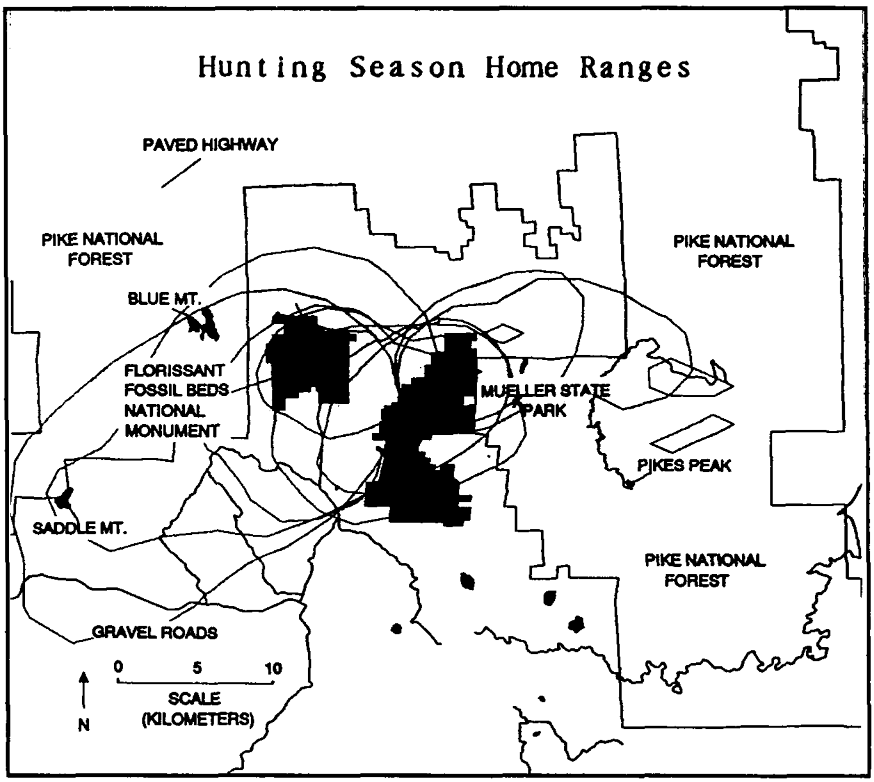

Figure 3. The hunting season home range polygons for all ten collared cow elk.

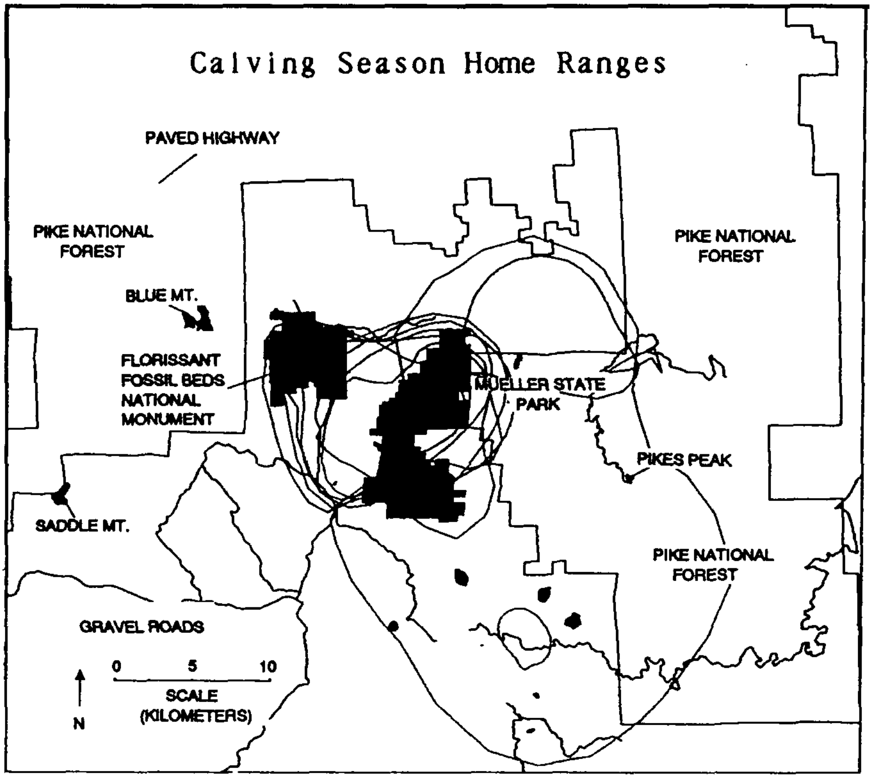

Figure 4. The calving seaon home range polygons for all ten elk. Notice the large anomalous polygon for elk #200 toward the southeast.

sightings/home range, and zoning maps) were calibrated to UTM coordinates and produced in compatible digital format. They could be easily digitally combined or overlain to indicate coincident human development and the areas of heaviest or most critical (e.g., calving) elk use.

RESULTS AND DISCUSSION

The thirteen vegetation classes obtained from the TM data proved to be quite accurate. The overall accuracy of the classification was 87.44 percent (Table 3). The most significant errors occurred where the Wagner/Suits algorithm confused the dry meadow with the mesic grassland classes and the wet meadow with the riparian deciduous shrub classes. The dry meadow and mesic grassland classes are very closely related, and even a ground survey produces mixed results with these two vegetation types. The wet meadow and riparian deciduous shrub classes are

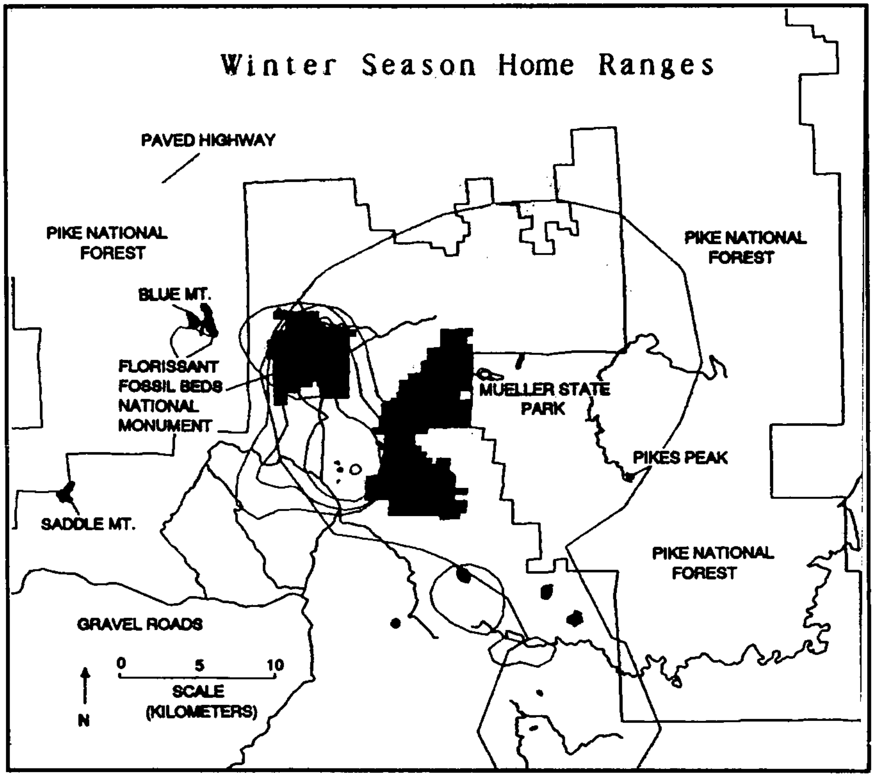

Figure 5. The winter seaon home range polygons for all ten elk. Notice the large anomalous polygon for elk #200 toward the east and southeast.

obviously different when seen on the ground, but their spectral signatures are extremely similar. It is very difficult for any classification algorithm to distinguish these vegetation types from each other. If the errors for these classes are disregarded, the percentage accuracy for the classification exceeds 92 percent.

Another characteristic arises while assessing the final vegetation map: this area possesses a very complex pattern of vegetation distribution. The mountain environment, with its rapidly varying topography (i.e., aspect, slope, elevation), significantly affects the development of vegetation. This makes the classification of the vegetation using moderate resolution satellite imagery more difficult, but the vegetation complexity also adds to the usable elk habitat. The intricate nature of the vegetation pattern itself enhances overall elk habitat availability in the region because of the tremendous increase in edge effect and mixed vegetation mosaic.

Table 3. Contingency Table for Ground Checked Sample of Pixels

		Classified As:												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Actual Observations	1	54												
	2		64	17										
	3	4		22										
	4	1	5	2	36									
	5					60	15				6			
	6					4	41							
	7							113	19		3			
	8							9	36					
	9									37				
	10										18			
	11											29		
	12										4	4	19	
	13													63

Note: Total number of pixels = 677. (87.44%) total correct.

Vegetation use by the elk can be best illustrated by the use of home range data. The home ranges were calculated for each individually collared elk's sightings for each season and for all elk sightings for the total study period. The use of specific vegetation types by the elk for each season and for the overall study are seen in Table 4. The calving season for all elk indicates a lower use of dry meadow vegetation, a slightly lower use of the grassland, and a generally higher use of forested areas. The winter figures show a dramatic increase in dry meadow use and corresponding decrease in use of forested sites. Hunting season habitat use is very similar to that for the winter.

Overall differences in home range areas for the seasons are also suggestive (Figures 3-5). Table 5 shows the total area for all home ranges for all elk for each season. The inclusive home ranges for the hunting season have an area of 531km^2. The inclusive home ranges for the calving and winter seasons are 556km^2 and 576km^2 respectively. Cow elk collar #200 could be considered an outlier during the study. This elk used large areas beyond the extent of the study area, and travelled great distances even during calving season. If we eliminate the calving and winter home ranges for elk collar #200 because of this anomaly, the calving and winter home ranges for the other nine elk decrease to 198km^2 and 123km^2 respectively. No significant change occurs for the hunting season with the elimination of elk #200. Calving season displays a small inclusive home range where prime habitat, especially cover, is available. Winter inclusive home range is

Table 4. Vegetation Classes by Home Range Type (in Percent of Total)

	Calving	Winter	Hunting	All-Harmonic	All-Fourier
Ponderosa Pine	2	2	2	1	1
Douglas Fir	6	3	2	3	3
Spruce-Fir	8	1	2	4	5
Mixed Confier	5	2	2	4	5
Limber/Bristlecone	4	1	4	3	4
Aspen	6	3	4	6	7
Water	4	3	4	4	5
Wet Meadow	6	5	6	7	7
Riparian Shrub	9	9	9	8	9
Mesic Grassland	15	17	17	14	14
Dry Meadow	20	41	35	28	25
Alpine	4	5	5	7	4
Non-Vegetation	4	5	5	7	4

Table 5. Inclusive Home Range Areas by Season

Hunting Season	Calving Season	Winter Season
Area = 531 km^2	Area = 566 km^2 Area w/o elk collar #200 = 198 km^2	Area = 576 km^2 Area w/o elk collar #200 = 123 km^2

the smallest area and is again in a region of very high quality habitat, especially for forage and grazing. Hunting season home range area is very large in comparison, implying very large and rapid movements under the stress of hunting pressure.

General elk migration did not occur during the study period. Each collared elk did move to a given locale for each season, and often repeatedly went to the same vicinity year after year, but no general migration was seen to higher regions in the summer or lower areas in the winter. In fact as one elk moved away from a seasonal home range, for example her calving area, to go to her summer range, another cow elk would often replace her in the vacated location. In essence, the elk "traded places."

Almost no use was made of the higher elevation areas. Nearly 98 percent of all telemetry observations were between 2,500m and 3,150m. There is no evidence that the alpine areas on Pikes Peak were used by the collared elk during the study. However, only cow elk were collared. The usually more transient bull elk were not tracked during the study. These males may or may not have used the higher elevations. In addition to the lack of bull elk sightings, all of the winters during the study period were relatively mild and snow-free. Forage was readily available throughout the winter, and the elk had little reason to relocate.

Aspect had almost no effect on the use of habitat by the elk. There was no significant pattern to the use of different aspects by the collared elk. Slope did have some influence on habitat use; higher slope angles were avoided consistently. Almost 97 percent of the sightings were on slopes of less than 30 degrees, and 81 percent of the sightings were on slopes of less than 15 degrees.

Finally, the study revealed that human presence had a dramatic influence on habitat use. Of the 2,456 square kilometers of the entire study area, the overall home range calculations indicated that all ten collared elk used only 436.8 square kilometers (17.8%) of the total study area. Of these 436.8km^2, 63 percent was in private ownership, but 82 percent of all sightings occurred on the 37 percent public land or on large, private land holdings where there are severe restrictions on hunting.

Much of the private land is currently being developed or is platted for development. Figure 6 shows the relationship between the elk sightings and the development areas. Even within the calculated home range areas, elk are avoiding the private land, and these platted areas are avoided by the elk even if little construction is currently occurring.

CONCLUSIONS

The most critical result from this work was that the elk avoided the private, platted property even before much development had proceeded. Even the sparse road network that was being constructed for future residential development seemed to affect elk movement and habitat use.

The significance of this finding is important. It suggests that elk are being forced into areas only on public or non-developing private land. Although total habitat availability is large in the entire region, elk have confined themselves to a very small segment of prime habitat. This segment is being systematically and rapidly over-populated by elk. Unless meaningful steps are taken to ameliorate this situation, the elk herds of this area are at risk. Results of this work are useful in resource allocation by appropriate agencies, planning departments, and policy makers to alter future residential zoning decisions so that large displacement in elk population can be avoided.

Finally, the combined use of several technologies allowed this study to be conducted. Lack of resources would have precluded any such work in the past. Only the availability of these technologies and the willingness of agencies to work

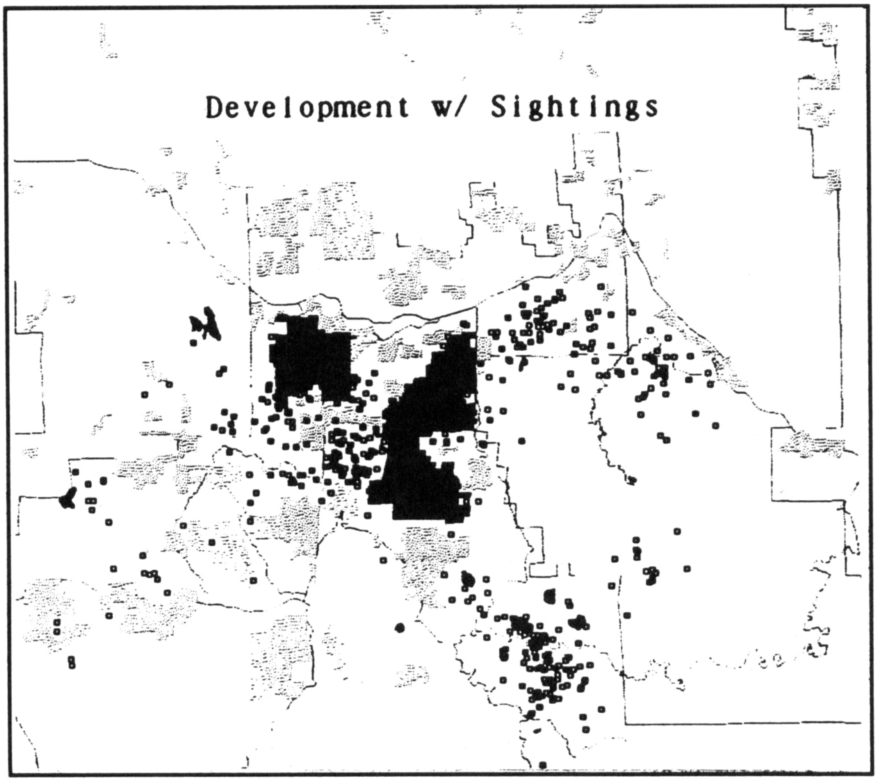

Figure 6. The light grey polygons are platted development areas. The elk sightings concentrate in areas outside of the plats.

together enabled the work to be completed successfully. More combined efforts between agencies, universities, and other research organizations are needed in this day of stringent governmental budgets and increased stress upon natural resources.

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