Effects of intensive salvage logging on Rocky Mountain elk at the Starkey Experimental Forest and Range

Jennifer Morgan Rinehart

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EFFECTS OF INTENSIVE SALVAGE LOGGING ON ROCKY MOUNTAIN ELK AT THE STARKEY EXPERIMENTAL FOREST AND RANGE

by

Jennifer Morgan Rinehart

B.Sc. Clemson University, 1995

Presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

May 2001

Approved by:

[Signature]

Chairperson

Dean, Graduate School

[Signature]

Date
ABSTRACT

Rinehart, Jennifer Morgan MS., December 2000 Forestry

Effects of Intensive Salvage Logging on Rocky Mountain Elk (*Cervus elaphus nelsonii*) at the Starkey Experimental Forest and Range

Director: Jack Ward Thomas

Effects of intensive silvicultural activities on Rocky Mountain elk (*Cervus elaphus nelsonii* V. Bailey) are examined using three separate study approaches. Ten elk were collared and monitored in each of six years before (1990, 1991), during (1993, 1994) and after (1995, 1996) timber harvesting at the Starkey Experimental Forest and Range in northeast Oregon. Elk ranging behavior in response to the silvicultural treatment was studied by measuring areas of core use contours (50%, 75%, and 90% core areas) and comparing them with a Kruskal-Wallis nonparametric analysis of variance. No significant difference in core area size was detected before, during or after the harvests (p = .09, .12 and .68 respectively). Habitat variables identified from previous studies were chosen to evaluate their influence over elk resource selection. Logistic regression of use or non-use of a pixel unit was used to create models based on habitat characteristics before and after harvesting. Models were compared for composition of variables. Distances to roads and water were found to be more important in selection before harvesting while distance to cover was most influential after the harvests. Finally, Akaike's information criterion methods were used to compare models of elk mean velocities before, during and after harvests. Simplistic models were selected to include variables of year of study, season of year and treatment block (before, during and after harvests). The model relating year of study to mean velocity was found to be more plausible based on the information available in the data. The Starkey project enabled research on the effects of silvicultural activities when avoidance by the elk was impossible.
ACKNOWLEDGEMENTS

I am indebted to the following for all their help and guidance in directing this research, especially from a distance: B. Johnson, M. Wisdom, J. Kie, P. Coe, R. Stussy, B. Dick, N. Cimon, S. Findholt and J. Noyes.

I am also grateful to Dr. Jack Ward Thomas, Dr. Mark Lindberg, and Dr. Kerry Foresman for their patience and insightful critique.

Finally, I owe everything to Ron and Janet Morgan. Without their ears and hearts, I would have never made this journey. And to Lee, whose faith, patience, and love make each trial a triumph.

To Maddie Lee, whose smiles make every moment of life worth living.
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INTRODUCTION

Understanding the interactions between species and their habitats is central to the ability to manage natural resources. Researchers study the interplay between animals and their environments to draw a picture of the natural world which, in turn, responds to changes in habitat. In most cases, clarity is limited by the architecture of studies, which alters the accuracy of predictions.

For example, manipulating a forest with an intensive timber harvest potentially changes both habitat and the numbers and distributions of wildlife species. Predicting the exact relationship between change in habitat composition and subsequent animal response is difficult. Improvement in the understanding of wildlife/habitat relationships is increasingly crucial as land managers examine the ecological, economic, and social aspects of their decisions. Forest management balances decisions between “commodity management” and “habitat requirements” for wildlife species of concern (Wisdom 1992). With a better understanding of the biological relationships involved in planning, the manager can make better-informed decisions and more effectively manage land as a multiple-use resource.

Land managers must strike just such a balance when planning timber sales within elk habitat. Biologists have intensively studied the effects of timber manipulations on elk populations since the 1960’s, examining the varied effects of harvesting on population dynamics (Lyon et al. 1985). Specifically, researchers have tried to establish relationships between elk numbers and activity patterns and such indicators of human activity as road building, road use, hunter access and timing and method of timber harvests (e.g. Collins, Urness, and Austin 1978, Morgantini and Hudson 1979, Lyon and

New methods and tools are allowing scientists to detail the behavior patterns of species at a much finer scale with greater accuracy than was previously possible. Some of these new technologies have been in place since 1989 at the Starkey Experimental Forest and Range near La Grande, Oregon. For instance, while it was known that elk avoided roads open to vehicular travel (Thomas et al. 1979) at varying levels of traffic (Lyon 1983) and during hunting season (Lehmkuhl 1981, Edge 1982). Researchers working on the Starkey Experimental Forest can examine the intensity of those avoidance patterns, directions elk might move, and under what circumstances (location of food, use intensity, time of day or weather patterns) elk will tolerate more or less human activity. Such information improves our understanding of elk behavior and manager's ability to balance commodities and habitats.

This study addressed selected responses of Rocky Mountain elk (*Cervus elaphus nelsonii* V. Bailey) at the Starkey Experimental Forest and Range to intensive timber harvest and regeneration methods. Testing the effects of manipulations of forests on wild ungulate home ranges is not novel. However, the setting of this study and methods of radio tracking used are unique. Starkey is a fully enclosed 10,125-hectare area. An automated animal tracking system (AATS) that can track locations of a collared elk as often as every 20 seconds is in place. Researchers cordoned off a 1,453-hectare section of the range and maintained a small herd of elk within its fences while implementing an
intensive timber harvest. By tracking these animals before, during and after timber harvest, a more accurate description of the effects of timber management practices on elk was possible. While research at Starkey is limited to local effects, the involved technologies and methods offer options for more accurate studies.
Figure 1: Starkey Experimental Forest and Range, Wallowa-Whitman Forest, Oregon
THE STARKEY EXPERIMENTAL FOREST AND RANGE

Starkey (Figure 1) was designated by the USDA Forest Service in 1940 for the purposes of research. It is located in the Blue Mountains of Oregon on the Wallowa-Whitman National Forest 35-km southwest of La Grande, Union County. In 1987, managers transformed the range to meet new research goals that would span at least the next 13 years. The study was designed and instituted as a collaborative effort between the Oregon Department of Fish and Wildlife (ODFW) and the U. S. Forest Service (USFS) in response to demands for information germane to more efficient multiple-use management of the national forests.

The use and development of two technologies set Starkey apart in the world of wildlife research. First, 44 km of New Zealand big game fence, 2.4 m tall, enclose the range, creating the largest closed system for wildlife research in the world (Bryant et al. 1991, Rowland et al. 1997). The fence encloses enough area to support the normal summer movements of wild populations of approximately 614 elk and 300 mule deer (Odocoileus hemionus hemionus Rafinesque) as well as permit grazing of 590 domestic cow/calf pairs (Bos taurus) (Leckenby 1984, Bryant et al. 1991, Rowland et al. 1997). The range is subdivided further into three primary areas: the Main Study Pasture (8384 ha), the Northeast Study Pasture (1453 ha) and the Winter Pasture (265 ha). The Winter Area includes winter feeding pastures and a handling corral for collaring and physiological assessments of the elk (Wisdom et al. 1993, Cook et al. 1996). Second, Starkey is home to an elaborate telemetry based tracking system. The system triangulates collar locations at a resolution of 0.81ha with signals from Long Range Navigation C
(LORAN-C) towers in four states (California, Nevada, Washington, Montana) and British Columbia (Bryant et al. 1991, Rowland et al. 1997).

Starkey is characterized by “broad rolling uplands separated by moderately deep canyon drainage” (Skovlin 1991). Elevation varies from 1122 m to 1500 m (Bryant et al. 1991, Rowland et al. 1997). Annually, Starkey receives around 51 cm of precipitation mostly in winter snows. Seventy-five percent of the enclosed acreage is forested. Most of this forest community is composed of ponderosa pine \((Pinus ponderosa)\) or mixed pine-Douglas fir \((Pseudotsuga menziesii\) var. \(glauca)\). Parts of the forests also contain lodgepole pines \((Pinus contorta)\) or grand fir \((Abies grandis)\). The remaining twenty-five percent of the range is grasslands typified by bearded bluebunch wheatgrass \((Agropyron spicatum)\), Sandberg bluegrass \((Poa secunda)\), Idaho fescue \((Festuca idahoensis)\), and onespike danthonia \((Danthonia unispicta)\). Additional description of the physical and vegetative properties of the range can be found in Strickler (1965), Skovlin (1991), Noyes et al. (1996), and Rowland et al. (1997).

Before fencing was complete, Starkey constituted normal spring, summer, and fall range by mule deer and elk but was not used extensively as winter range. In order to control the physiology of the elk used for the studies, researchers capture or entice the study animals into the Winter pasture to be fed for the winter months. In this way, all animals receive the same quality and quantity of winter forage while being exposed to the same environmental conditions, establishing a more controlled population resulted. The elk are released back into the Main Study area and Northeast pasture from the feed grounds in the spring. The study season, then, lasts from early spring through late fall.
The combination of the environmental as well as technical capabilities of Starkey produces a situation for detailed study of the physical responses of elk to different timber management activities. Other ongoing research programs at Starkey involve 1) ungulate response to roads and road traffic, 2) herd reproduction related to age of breeding bulls, and 3) forage allocation between deer, elk and domestic cattle. For additional information on this ongoing research, see Johnson et al. (1991, 2000), Noyes et al. (1996), or Rowland et al. (1997, 2000).
### Table 1: Timetable of Important Events at the Starkey Experimental Forest and Range (Rowland et al 1997)

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 1989</td>
<td>AATS operational, averages 25 locations for each of 10 elk in Northeast per day.</td>
</tr>
<tr>
<td>February 1990</td>
<td>Timber in Northeast marked for green sale.</td>
</tr>
<tr>
<td>Summer 1990</td>
<td>USFS accepts Boise Cascade Corp. bid; plans to harvest 6 mill. board feet by fall of 1992</td>
</tr>
<tr>
<td>September 1990</td>
<td>AATS fully operational across Starkey Range (14 collared elk in Northeast)</td>
</tr>
<tr>
<td>Summer 1991</td>
<td>Road construction begins in Northeast</td>
</tr>
<tr>
<td>October 1991</td>
<td>Harvesting begins in Northeast</td>
</tr>
<tr>
<td>Winter 1991-92</td>
<td>Mild winter conditions: low numbers of elk arrive at winter feeding areas.</td>
</tr>
<tr>
<td>July 1992</td>
<td>Improved AATS installed and tested</td>
</tr>
<tr>
<td>November 1992</td>
<td>Harvesting completed in Northeast (over 7 mill. board feet)</td>
</tr>
<tr>
<td>Spring 1994</td>
<td>Burning of logging residue and planting preparation in Northeast</td>
</tr>
<tr>
<td>June 1994</td>
<td>Lightning strikes Headquarters II (main computer for Starkey “paging” system). System efficiency reduced for remainder of 1994 but repaired before 1995 field season</td>
</tr>
<tr>
<td>Spring 1995</td>
<td>Planting of cuts in Northeast completed</td>
</tr>
</tbody>
</table>
Figure 2: Map of Northeast study area including detail for roads before building and renovation began for the harvesting operation. Syrup Creek is the main drainage of the Northeast pasture.
The Northeast Study Area (Northeast) was the site of intensive timber harvesting (Figures 1-3). Fifty elk were released in Northeast each spring (mid-March) and were recaptured in the late fall (mid-December). Between 6 and 13 elk cows were radio-collared each year in Northeast. Beginning in 1989, the automated animal tracking system (AATS) collected location data for the collared elk every year through 1998 including data for before, during and after the treatment.

In 1991, the project team worked with the Forest Service’s La Grande Ranger District to plan and complete a timber sale in Northeast. Originally, the team planned the timber activities to mimic resultant stand condition that would emerge from projected silvicultural practices for the next 25-50 years. However, summer droughts and severe infestations of spruce budworm (*Choristoneura fumiferana*) limited the saleable cut. New roads were built and existing roads renovated in late 1991 totaling 44.4 km (Thomas 1990, Bryant et al. 1991, Rowland et al. 1997). Study cooperator Boise Cascade Corporation removed 6 million board feet between the fall of 1991 and the winter of 1992 (Figure 3). Over 50% of the standing timber in Northeast was cut (Barrett 1999). Of the 489 ha treated silviculturally, most timber removal was completed using shelterwood and seed tree regeneration cuts with some commercial thinning and individual tree selections (Barrett 1999). Prescribed burns for slash reduction and replanting occurred respectively in the summers of 1993 and 1994 (Bryant et al. 1991, Rowland et al. 1997).
Figure 3: Map of timber harvest contours within Northeast Study Area. Over 6 million board feet of timber were removed through seed tree and shelterwood silviculture techniques. Map also details the Northeast road system after building and renovations.
The study team monitored collared elk in Northeast for three years (1989, 1990, and 1991) before the silviculture treatment to gather baseline data. Similarly, the animals were tracked during the 3 years of timber sales, including burns and replants, to collect “during-harvest” data (1992, 1993, and 1994). Finally, data was collected through the post-sale years (1995, 1996, and 1997). Due to incomplete coverage of the range by the AATS system in 1989, useable “before-harvest” data was limited to 1990 and 1991. “During-harvest” data availability was limited to 1993 and 1994 due to insufficient numbers of functioning collars Northeast in 1992 (data available for only 4 collars). Finally, analysis of “after-harvest” data was concentrated on the two years immediately following the sale (1995 and 1996) for statistical consistency. Also work began in 1997 on cross fencing within Northeast to support new research efforts at Starkey and these fences as well as the presence of workers within Northeast would interfere with conclusions from this work concerning variability due to harvesting activity. The data used in this analysis is stored at the USDA Forest Service’s La Grande Forest and Range Sciences Laboratory, La Grande, Oregon.

**Automated Animal Telemetry System**

One unique aspect of the Starkey research program is the AATS (Bryant et al. 1991, Thomas et al. 1990). The telemetry system uses traditional methods of triangulation in accord with Long-Range Navigation-C (LORAN-C) and radio pagers to locate collared animals. The system takes a reading every 20 seconds and calculates an animal’s location within 45 to 53 m (Findholt et al. 1996, Johnson et al. 1998). Computers at the base station on Starkey work through the list of active collars, paging
and locating each in turn (Figure 4). The delay between each successive location for each animal is no more than the paging cycle of the computers and receivers. A completed cycle lasts from 1 to 2 hours depending on the number of animals in the paging sequences.

Figure 4: Paging cycle of the Automated Animal Telemetry System at The Starkey Project. Animal collars are paged by the main computer, triggering loran receivers in the units. These receivers pick up loran signals from transmitters in neighboring states and relay the signals back to the main computers which triangulate collar location on the Starkey range. Fixed collars on the range are used to calibrate for error, having been ground truthed by geographic positioning system units. (Taken from Rowland et al 1997).
Data included in my analyses were limited to 10 collared elk in each year. The AATS performed slightly differently during each year due to the number of animals in the paging sequences and brief shutdowns for updates of the systems (Bryant et al. 1991, Rowland et al. 1997) (See Table 1). Therefore, the numbers of locations recorded for a given collared elk varied from year to year. Ten collars with the maximum numbers of observations per data set were chosen for use in this study. (Table 2).

For a more complete description of the design, construction, and performance of the AATS, see Dana, Fowler, and Hindman (1989), Bryant et al. (1991), Findholt et al. (1996), and Johnson et al. (1998).

Table 2: Number of locations recorded for each study collar (ID) by study season. Minimum sample size (n) for each year is listed below each column.

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**NORTHEAST ELK HERD**

Each spring, elk were released from the winter handling area into Northeast. All elk were released into pastures in like condition (Dick, 2001). Prior to release, between 6 and 14 of the cows were fitted with radio-telemetry collars and then tracked throughout.
the study year. Animals were not released to maintain any specific sex ratio. Estimates of population size and ratio are reported in Table 3.

Table 3: Northeast herd construction by study year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Females</th>
<th>Calves</th>
<th>Males</th>
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<tbody>
<tr>
<td>1990</td>
<td>41</td>
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<td>2</td>
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<td>1994</td>
<td>62</td>
<td>21</td>
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</tr>
<tr>
<td>1995</td>
<td>71</td>
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At the end of a field season (late Fall), animals were herded back into the winter handling area. Weight measurements and blood samples were taken to determine pregnancy rates in females (Wisdom et al. 1993). Typical of wild elk herds, the animals lost weight on the feed grounds during the winter months (Dick, 2001). Elk weight comparisons were made between animals released in either main study or northeast pastures in 1990, 1991, 1992, 1993, 1994, and 1995. Mean weights and standard deviations are reported in Tables 4 and 5. There does not appear to be a relationship between weights of elk exposed to timber harvesting activities (Northeast study elk) and those not exposed (Main study elk).
Table 4: Comparison of adult (2+ yrs) cow mean weights (kg) in after recapture from Main study pasture (no timber harvesting activity) and Northeast study pasture (Timber harvesting activities).

<table>
<thead>
<tr>
<th>Study Year</th>
<th>Main Study Elk</th>
<th>Northeast Study Elk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( x \pm S D )</td>
<td>( x \pm S D )</td>
</tr>
<tr>
<td>1990</td>
<td>No Data</td>
<td>204.8 ( \pm 16.2 )</td>
</tr>
<tr>
<td>1991</td>
<td>196.9 ( \pm 21.4 )</td>
<td>No Data</td>
</tr>
<tr>
<td>1992</td>
<td>213.8 ( \pm 17.1 )</td>
<td>202.5 ( \pm 18.9 )</td>
</tr>
<tr>
<td>1993</td>
<td>207.0 ( \pm 18.0 )</td>
<td>199.1 ( \pm 19.1 )</td>
</tr>
<tr>
<td>1994</td>
<td>205.2 ( \pm 18.0 )</td>
<td>216.0 ( \pm 18.0 )</td>
</tr>
<tr>
<td>1995</td>
<td>211.5 ( \pm 20.2 )</td>
<td>212.6 ( \pm 14.6 )</td>
</tr>
</tbody>
</table>

Table 5: Fall recapture elk weights (kg) for adult, yearling and calf females.

<table>
<thead>
<tr>
<th>Female Elk</th>
<th>Main Study Elk</th>
<th>Northeast Study Elk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( x \pm S D )</td>
<td>( x \pm S D ) \nMax \nMin</td>
</tr>
<tr>
<td>Adult (2+)</td>
<td>210.9 ( \pm 17.3 )</td>
<td>265.5 ( \pm 166.5 )</td>
</tr>
<tr>
<td>Yearling</td>
<td>160.2 ( \pm 15.8 )</td>
<td>201.6 ( \pm 107.6 )</td>
</tr>
<tr>
<td>Calf</td>
<td>105.5 ( \pm 13.3 )</td>
<td>134.6 ( \pm 57.2 )</td>
</tr>
</tbody>
</table>

Pregnancy rates for adult cows in Northeast study herds remained above 85% in all years excluding 1994 when the percentage of cows pregnant was 70% (Dick, 2001).

**OBJECTIVE AND JUSTIFICATION**

My objective was to measure the impacts of intensive silvicultural treatments on elk. Three separate approaches were employed to assess these impacts.

First, I tested the hypothesis that there was no difference in the size of elk home range core areas before, during and after the treatment. It could be inferred that increased
size of core area of use would translate to increased activity levels for a collared elk. Increases in activity could imply decreases in fitness. Given no option for avoidance of habitat alteration increased activity would indicate increased energy consumption. This might impair physical health when availability and amount of forage remains constant.

Security cover is defined as the least amount of cover providing protection or escape routes from perceived dangers (Lyon and Ward 1982). Thermal cover provides protection against high and low weather extremes (Skovlin 1982). Either of these types of cover could include vegetation. Habitat alteration would likely change the distribution and location of these types of cover, negatively impacting fitness due to stress or reduced ability to thermoregulate (Lyon and Ward 1982). By more accurately documenting the ranging movements of elk in response to timber management activities, a clearer picture of the possible effects of timber harvests on elk welfare could be provided.

Second, I tested the hypothesis that there was no difference in the influence of habitat variables on elk resource selection before and after the treatment. Statistical models of elk use of habitat were developed, relating use of the landscape to its physical characteristics. These models are called resource selection functions (RSF). RSF’s were created to examine how models of habitat use based on habitat variables would differ in composition as elk adjusted to timber management activities within Northeast. Changes in habitat composition might be expected to influence elk response to their environment. Decreases in cover availability and increases in forage supply have been considered key for determining habitat selection (Thomas et al. 1979). Many researchers have shown that elk use of habitat decreases with decreasing distance to roads (e.g. Perry and Overly 1976, Hershey and Leege 1976, Marcum 1975, 1976, Pederson 1979, Wisdom 1998,
Rowland et al. 2000). Distances of radio-collared elk to roads, used primarily in the study for logging and regeneration activities, would also be expected to influence behavior. Models were created of use or non-use of habitat dependent on physical habitat characteristic variables. The best-fit models for each treatment condition (before or after timber harvest) were then compared for differences in independent variable composition. Changes in composition of models of habitat use before and after harvesting were viewed as indicative of the strength of influence of habitat characteristics on elk behavior.

Finally, Akaike’s information criterion (AIC) (Akaike 1973) was used to select the best model of the relationship between the intensive silvicultural treatments and mean velocities of collared elk. Mean velocity was a measure of the average rate of movement of elk across the range. Measures of distances between locations were divided by time between subsequent locations to arrive at velocities for collared elk movements. A mean velocity was then calculated for each collared elk’s set of velocities. Changes in resource locations and activities related to timber management were expected to influence the movements of the elk.

Elk response to timber management activities has been extensively studied since the early 1970’s (Lyon and Ward 1982). In such studies (e.g. Beall 1974, Marcum 1975, Hershey and Leege 1976, and Ward 1976), researchers found that elk avoid timber management activities. However, animals were exposed to treatments with the option of total avoidance of the activity (i.e. the elk could simply depart from the area). Such avoidance led to the conclusion that broad-scale harvesting has a significant effect on elk, even if only temporarily (Beall 1974, Marcum 1975). The Starkey experimental
environment affords the opportunity to explore elk response when total avoidance of
similar broad-scale habitat manipulations is not possible.

EVALUATING IMPACTS BY MEASURING SIZE OF CORE AREAS OF USE

SUMMARY OF STUDY DEVELOPMENT

The original hypothesis proposed for study in the conceptual stages of the Starkey
project was that there would be no difference in home range size for the elk before,
during and after the silvicultural treatment. Early on in the project, it became clear from
accumulating data that Northeast itself constitutes the home range of the elk due to the
effect of the fence. Telemetry data indicated that animals ranged over the entire
enclosure. Therefore, to determine the effects of the timber harvest on the home range
pattern of the elk, core areas of use within the fenced area were substituted as the
response variable.

METHODS

I tested the hypothesis that there was no difference in the distribution of core area
size before, during or after the timber harvest. Northeast constituted the whole of a home
range for an elk. As a surrogate for studying the explicit home range patterns of each
radio-collared elk before, during, and after treatment, I calculated core area sizes based
on percentages of use. Fifty, 75, and 90 percent core area contours were drawn for each
of the 10 elk followed in each of the 6 years studied: 2 years before treatment (1990,
The area within each contour was measured and added to a database. Differences
between the distributions of these area measurements were examined using a Kruskal-Wallis (1952) nonparametric test.

**DEFINING CORE AREAS**

Biologists have long used the concept of “home range” to help describe ranging behavior of animals. Burt defined the home range as simply “that area in which an animal performs its daily activities” (1943). The challenge for researchers has been to quantitatively define that area. The literature on home-range estimation is extensive especially those studies that attempt to compare the many home-range estimators in accuracy and efficiency, for example reviews by Worton (1987) and Harris et al. (1990). Similarly, researchers have approached studies of ranging behavior by studying areas within home ranges where use is disproportionate to the normal utilization distribution. These areas are called “core areas” (e.g. Burt 1943, Mohr and Stumpf 1966, Samuel et al. 1985, Samuel and Green 1988). These core areas provide particular insight into food and cover resource use (Samuel and Green 1988).

In this study, the core area serves as a surrogate for studying the Northeast elk’s home range and habitat preference. The fenced boundaries of Northeast inhibited expression of completely natural ranging motion and decision making by to radio-collared animals. Therefore, the area within the 100% contour of a kernel estimate of the elk’s home range is the area within Northeast – i.e., radio-collared animals essentially used the entire area to some degree.
DATA SET PRODUCTION AND ANALYSIS

To produce estimates of areas within these contours, I used CALHOME software (Kie, Baldwin, and Evans 1994) to draw the contours with an adaptive kernel method. Program CALHOME only allowed samples of 500 or less locations. Therefore, 500 locations for each radio-collared elk were randomly sampled without replacement from data sets that had more than 500 observations (see Table 2 for initial n of each collar data set). Otherwise, I used the complete data set. Universal Transverse Mercator (UTM) coordinates of the location data were plotted and contours drawn based on adaptive kernel estimates of probability of use for each location. The area within each contour was measured in hectares squared. These areas were pooled into a data set and given a dummy variable descriptor of treatment (0 = before treatment, 1 = during treatment, and 2 = after treatment). The final data set consisted of area measurements for 20 animals for each treatment class and percent contour (Figure 5).
There has been considerable discussion about violation of the independence assumption in home range estimation statistics. With correlation between successive locations, any statistical estimate will likely underestimate the size of the true home range (Swihart and Slade 1985a). Most of the discussion concludes statistical independence of observations is vital (Swihart and Slade 1985b, Worton 1987, Harris et al. 1990, Reynolds and Laundre 1990, Worton 1995a, DeSolla, Bonduriansky, and Brooks 1999). However, statistical independence of observations of animals is difficult to achieve when they move between locations in a non-random manner. Tests for independence have been proposed as well as methods for determining optimum time intervals between successive observations (Swihart and Slade 1985b).

Yet, there is the argument that biologically relevant information is lost when statistical independence is achieved (Lair 1987, Reynolds and Laundre 1990, DeSolla, Bonduriansky, and Brooks 1999). Swihart and Slade later suggested that autocorrelation of data does not negatively impact all estimators (1997). DeSolla, Bonduriansky, and Brooks (1999 p.222) found that nonparametric kernel estimates of home range “do not
require serial independence of observations” and suggested that larger numbers of
observations with relatively constant time intervals improve the accuracy of these home
range estimates.

Adaptive kernel methods (Worton 1989) were chosen to delineate the core areas.
Kernel methods are used to calculate a “probability density estimate of a distribution
based on a sample of points” (Seaman, Griffith and Powell 1998, p. 95). Interest was
focused on core use of the animals’ home range and estimates of kernel estimators of
home range provide superior representation of the “internal structure” of a home range
(Harris et al. 1990). Kernel estimators are robust to changes in spatial resolution (Seaman
et al. 1999), which is of reduced concern in this case as the study area was fenced.

The nonparametric nature of kernel methods enables reliable estimates without
knowledge of underlying distributions of data points. Finally, work by Seaman et al.
(1999) found kernel estimators more accurate in comparison to other popular estimation
methods such as convex-hull estimators, especially at sample sizes greater than 50.
Worton (1995b) found no advantage of adaptive kernel over fixed kernel estimates.
However, since I was limited to consideration of inner contours of the home range,
adaptive methods were utilized given that inner contours are less biased than with fixed
methods (Seaman et al. 1999).

I entered data sets available for each collared elk in the CALHOME program and
used it to calculate the 50%, 75% and 90% contours. Least squares cross validation
(LSCV) was used to select the appropriate level of smoothing of the kernels (Silverman
1986, Seaman, Griffith, and Powell 1998). LSCV is a “jack-knifing” method where
different values are used for the smoothing and compared. That value that minimizes
error is chosen (Silverman 1986, Seaman, Griffith, and Powell 1998). Use of the software displayed the contours within an overlay of the fences around Northeast and calculated the area within each contour (See Appendix 1 for CALHOME output). A Kruskal-Wallis (1952) nonparametric analysis of variance was used to test for differences in the mean area size before, during and after the intensive timber harvest.

Table 6: Mean areas (ha²) within percent use contours (90%, 75%, and 50%) by study year. (n for each year and percent is 10).

<table>
<thead>
<tr>
<th></th>
<th>90% Contour</th>
<th></th>
<th>75% Contour</th>
<th></th>
<th>50% Contour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x ±SD</td>
<td>x ±SD</td>
<td>x ±SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>1129.8 86.7</td>
<td>765.1 98.6</td>
<td>409.7 75.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>1205.7 107.6</td>
<td>781.1 81.7</td>
<td>366.4 69.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>1134.0 131.6</td>
<td>789.7 97.5</td>
<td>397.0 68.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>1197.8 62.9</td>
<td>872.6 76.1</td>
<td>472.2 48.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>1168.8 72.4</td>
<td>841.0 53.4</td>
<td>451.5 50.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>1125.4 77.7</td>
<td>783.0 71.6</td>
<td>417.7 69.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Kruskal-Wallis Two-way Analysis of Variance test of differences in mean area for proportion core area contours.

<table>
<thead>
<tr>
<th>Proportion</th>
<th>Kruskal-Wallis Chi-Square</th>
<th>Degrees of Freedom</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>4.8923</td>
<td>2</td>
<td>0.09</td>
</tr>
<tr>
<td>75%</td>
<td>4.2534</td>
<td>2</td>
<td>0.12</td>
</tr>
<tr>
<td>90%</td>
<td>0.7856</td>
<td>2</td>
<td>0.68</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

Mean areas within percentage use contours are reported in Table 6. There does not appear to be a strong relationship between core area size and treatment condition. The
Kruskal-Wallis test supports this conclusion (50%: p = .09; 75%: p = .12; 90%: p = .68) (Table 7). This suggests there may have been little influence of the intensive harvest on ranging behavior of the radio-collared animals. It is interesting to note that slight differences in some of the individual elk ranges can be visually discerned (Appendix 1). Visual examination of elk use patterns indicated a preference for sections of Northeast farthest from management activities during harvesting and regeneration in 1993 (Figure 6). Elk released in Northeast in 1994, after harvests and associated activities were complete, showed no such avoidance (Figure 7). Several of the home ranges (Appendix 1) show avoidance of the northeast corner of Northeast. In November of 1999, the AATS was set to track only those collars within Northeast and recorded locations at 10-minute intervals for those collars. There was complete coverage of the range (Kie, 2001) suggesting that any apparent “corner effect” is due to sampling from an elk’s complete data set. With only a static picture of the sample of elk locations it is difficult to assess the accuracy of such conclusions other than as general descriptions of the activity of those individual elk.
Figure 6: Locations for Elk #134 in 1993 during harvesting and regeneration activities. This particular elk shows extreme avoidance of harvesting activities along Syrup Creek (see Figure 2 Map of Northeast for road and drainage detail).
Figure 7: Locations for elk #353 in 1994 after most harvesting activity had ceased. Indiscriminate use of the range within Northeast is obvious regardless of road or drainage location (See Figure 2 for map of Northeast).
Researchers involved in the Cooperative Elk-Logging study in Montana found similar temporary avoidance patterns and tolerance for logging activities (Lyon et al. 1985). They reported that elk use of the study site was similar before and after logging and that any avoidance of a logging site was related to roads that remained open and the burning of logging slash (Lyon et al. 1985). They also noted that in areas where activity on roads was restricted to logging equipment, disturbance rarely exceeded one mile. The Northeast timber operations were the only human activity allowed within the Northeast fence other than controlled hunts and some vegetation sampling. The location data recorded during the days of those hunts was removed from our data sets in order to focus attention on variation related to timber management activities. Data was also removed for dates at least 3 days after hunting activity.

Disturbance patterns of elk herds have been evaluated in relations to logging and roads in many different studies (Edge 1982, Lyon 1979, Lyon and Jensen 1980; Irwin and Peek 1983; Hershey and Leege 1982; Morgantini and Hudson 1979; Pederson, Adams, and Skovlin 1980; Rost and Bailey 1979; Ward 1973; Skovlin, Bryant, and Edgerton 1989). Elk tend quickly use recently logged areas due to increases in forage (Skovlin, Bryant, and Edgerton 1989). Most studies agree that elk tend to avoid areas during harvesting and regeneration activities and return to previous or increased use in cut areas due to increased forage. Smaller core areas of use might be expected, as the harvests would have allowed elk to satisfy foraging requirements in smaller areas.
EVALUATING IMPACTS THROUGH RESOURCE SELECTION

SUMMARY OF STUDY DEVELOPMENT

The original hypothesis proposed for study in the conceptual stages of the Starkey project was that there would be differences in the distribution of elk before, during, and after the silvicultural treatment. The intent was to explore the relationship between the distribution of elk and the location of forage and cover. The geographic information system and habitat databases available for Starkey would be used to subdivide the habitat into categories based on percentage cover or forage per pixel of a size to be determined by the accuracy of locations for radio-collared elk. Use categories would be defined and displayed as contours. The elk distributions before, during and after would be compared based on a Chi-square contingency.

These original methods were later deemed inappropriate for two reasons. First, lack of independence in the data caused by serial correlation of locations violated principle statistical assumptions of parametric statistics. Second, random events that took place during the study (lightening strikes, tower or hardware installation, battery failures, etc.) add random variation to the data, producing an inconsistent design (Table 1). Such simple statistical procedures as Chi-square would not offer appropriate interpretation of the treatment effects.

A resource selection function methodology was proposed to address the effects of changing availability of habitat due to timber removal. Methods would include analysis of habitat use by season and time of day to exclude variability due to phenology and rutting behavior as well as daily activity patterns of bedding and foraging.
METHODS

A statistical modeling procedure based on logistic regression of use of habitat was used to identify which habitat variables were significant in elk habitat selection before and after the silvicultural treatment. Habitat variables for physical characteristics of the range were excluded from the models in a backward stepwise regression (Johnson et al. 2000) process until all variables included in the models were significant (α = .05). Models were created for selection of resources by elk before and after the timber harvest. The data for habitat use by elk was then divided by season and crepuscular/non-crepuscular condition and models evaluated similarly. Seasons were defined as Spring (all locations recorded before June 15th), Summer (all locations recorded between June 15th and August 15th) and Fall (all locations recorded after August 30th). Dates between August 15th and 30th were excluded from the data to avoid including variation in elk behavior due to hunts that took place in Northeast. Crepuscular periods were defined as 2 hours before or after sunrise or sunset. Non-crepuscular periods included all other times of day.

Pseudoreplication arose in these procedures because models were based on locations and not individual animals. Jackknifing procedures were employed to eliminate this concern (Efron 1982, Johnson et al. 2000).

DATABASE PREPARATION

The habitat database at Starkey is based on a grid map of the range with pixels sized 30- x 30-meters. Habitat variables such as slope, distance to water or percent canopy coverage are stored for each pixel in the database (see Table 8 for a description of
variables included in models). Pixels used by elk were linked to habitat descriptors. For example, each location was assigned to the 30- x 30-m pixel in it occurred using TELVIS software (Ager and McGaughey, in press). Habitat variables were then pulled from the main database for each pixel used.
Table 8: Description of Habitat Variables and Abbreviations (Johnson et al. 2000).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Depth</td>
<td>Soil depth of the A and B horizon (m)</td>
<td>Soil Depth</td>
</tr>
<tr>
<td>Percent Slope</td>
<td>Physical variable of landscape</td>
<td>% Slope</td>
</tr>
<tr>
<td>Sine of Aspect</td>
<td>Physical variable of landscape</td>
<td>SIN Aspect</td>
</tr>
<tr>
<td>Cosine of Aspect</td>
<td>Physical variable of landscape</td>
<td>COS Aspect</td>
</tr>
<tr>
<td>Convexity of Landscape</td>
<td>Physical variable of landscape</td>
<td>Convexity</td>
</tr>
<tr>
<td>Percent Canopy Cover</td>
<td>Canopy closure of trees &gt; 12 cm dbh</td>
<td>% Canopy</td>
</tr>
<tr>
<td>Distance to Cover</td>
<td>Distance to nearest pixel with 40% cover (m)</td>
<td>Dist Cover</td>
</tr>
<tr>
<td>Distance to Water</td>
<td>Distance to perennial streams and developed water sources (m)</td>
<td>Dist Water</td>
</tr>
<tr>
<td>Distance to Roads</td>
<td>Distances to all open roads (m)</td>
<td>Dist Roads</td>
</tr>
</tbody>
</table>
**VARIABLE SELECTION**

Recent research of the Starkey Project centered on creating resource selection functions for elk and mule deer (Johnson et al. 2000). Their models evaluated the relationship between animal resource selection and habitat characteristics and then cross-validated these models to compare selection between species. Drawing from their work, I chose to work with habitat variables included in the models from their studies. These variables include percent slope, sine of the aspect (SIN aspect), cosine of the aspect (COS aspect), convexity of the landscape, and depth of the A and B soil horizons (Soil Depth).

The distance to roads variable included distances to roads of all levels of use. Other research at Starkey (Rowland et al. 2000) focused on the relationship between elk distributions and differing levels of traffic on roads. Significant relationships were found between elk distribution and the level of use of open roads in the Main study area. However, traffic in Northeast was limited during the study to that primarily related to harvesting and regeneration activity. Reliable data from traffic counters, to disseminate differing levels of use on sections of open roads, was not available before institution of silvicultural treatments. Therefore, the distance to roads variable was a simple measurement of distance to any road, regardless of level of use of that road.

Distance to water sources could be expected to have a significant impact on elk locations as water represents a fundamental resource for elk (Thomas et al. 1979). The distance to water variable was again an aggregate of all perennial stream classes and developed water sources.
Finally, distance to cover, distance to forage and canopy closure habitat descriptors would be altered with the timber harvests. Johnson et al. (2000) found a strong correlation between distances to cover and distance to forage when included in their models. Therefore, they chose the cover variable as its measurements were more accurately assessed. The variable was created by aerial photointerpretation of natural color aerial photographs from 1987 to 1988 (before harvesting) and 1993 (after harvesting) (Rowland et al. 1998). Landsat Thematic Mapper data was used to produce the final cover classification (Leckenby, Isaacson, and Thomas 1985, Rowland et al. 1998). Percent canopy closure (% Canopy) refers to that percentage of a pixel with closure of trees greater than 12 cm diameter breast height. The variable was derived using aerial photographs (1:12,000) and on-site surveys. For a more explicit description of the creation of all habitat variables used at Starkey see Rowland et al. (1998) and Johnson et al. (2000).

MODEL SELECTION

Models of elk habitat selection were created using logistic regression (PROC GENMOD SAS Inst. 1997) of use/non-use of a pixel dependent on 9 habitat variables which included: soil depth; % slope; sine of aspect; cosine of aspect; convexity; % canopy; distance to cover; distance to water; and distance to roads. Models were created in a backward stepwise manner.

Pseudoreplication was a problem because regressions were based on animal locations and not individual animals. Therefore, a jackknifing process was necessary to correct underestimation of variance (Efron 1982, Johnson et al. 2000). The process
consisted of running regressions repeatedly, dropping one animal's locations from the data for each run. Variance of the variable coefficients was then examined with chi-squared probabilities for significance (\(\alpha = .05\)). Insignificant variables were dropped from models in a backward stepwise selection until all remaining model variables were significant. Model structures were then compared between treatment conditions, seasons and crepuscular periods.

**ANALYSIS**

The analysis of relationships between habitat characteristics and range use was based on comparison of models created for before and after the timber harvest. Models were created for use before (pooling data from 1990 and 1991) and after (pooling data from 1995 and 1996) the treatment. Other models were created with data subdivided by season and by season x crepuscular or non-crepuscular activity cycles to account for variation that would occur due to phenology, rutting behavior and daily cycling.

Inferences were drawn from changes in significant indicators of resource selection in each model. Variables of particular concern were distances to cover, water and roads as these were viewed as particularly correlated with the treatment activities. Changes in signs of coefficients indicate changes in animal selection relative to variables. If a coefficient is positive, elk were selecting for high values of a variable. If a coefficient is negative, elk were selecting for low values of a variable. The larger a coefficient, the more important that independent variable was in resource selection.

<table>
<thead>
<tr>
<th>Model</th>
<th>Soil Depth</th>
<th>% Slope</th>
<th>SIN Aspect</th>
<th>COS Aspect</th>
<th>Convexity</th>
<th>% Canopy</th>
<th>Dist Cover</th>
<th>Dist Water</th>
<th>Dist Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>9091</td>
<td>-0.11</td>
<td>0.13</td>
<td></td>
<td>0.10</td>
<td></td>
<td>0.04</td>
<td></td>
<td>0.15</td>
<td>0.23</td>
</tr>
<tr>
<td>9596</td>
<td>0.09</td>
<td>0.06</td>
<td></td>
<td>0.05</td>
<td>0.12</td>
<td>0.07</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 10: Resource Selection Function Coefficients for Significant Variables ($\alpha = .05$). Comparison of models for crepuscular (Crep) and noncrepuscular (Ncrep) periods before (1990/1991) and after (1995/1996) treatment.

<table>
<thead>
<tr>
<th>Model</th>
<th>Soil Depth</th>
<th>% Slope</th>
<th>SIN Aspect</th>
<th>COS Aspect</th>
<th>Convexity</th>
<th>% Canopy</th>
<th>Dist Cover</th>
<th>Dist Water</th>
<th>Dist Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>9091Crep</td>
<td>-0.12</td>
<td>0.18</td>
<td>-0.04</td>
<td>0.12</td>
<td>0.04</td>
<td>0.08</td>
<td>-0.06</td>
<td>0.14</td>
<td>0.16</td>
</tr>
<tr>
<td>9091Ncrep</td>
<td>-0.10</td>
<td>0.10</td>
<td>0.04</td>
<td>0.12</td>
<td>0.04</td>
<td>0.08</td>
<td>-0.06</td>
<td>0.14</td>
<td>0.25</td>
</tr>
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<td>0.09</td>
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<td>-0.04</td>
<td>-0.07</td>
<td>-0.07</td>
<td>-0.07</td>
</tr>
<tr>
<td>9596Ncrep</td>
<td>0.09</td>
<td>0.05</td>
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<td>0.05</td>
<td>0.04</td>
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</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables:</th>
<th>Soil Depth</th>
<th>% Slope</th>
<th>SIN Aspect</th>
<th>COS Aspect</th>
<th>Convexity</th>
<th>% Canopy</th>
<th>Dist Cover</th>
<th>Dist Water</th>
<th>Dist Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>9091 Spring</td>
<td>0.15</td>
<td>0.14</td>
<td>0.15</td>
<td>0.10</td>
<td>-0.29</td>
<td>0.11</td>
<td>0.54</td>
<td>0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9091 Summer</td>
<td>-0.12</td>
<td>0.14</td>
<td>0.04</td>
<td>0.10</td>
<td>0.13</td>
<td>0.06</td>
<td>0.06</td>
<td>-0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9596 Spring</td>
<td>0.16</td>
<td>0.10</td>
<td>-0.04</td>
<td>0.06</td>
<td>0.12</td>
<td>0.05</td>
<td></td>
<td>-0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9596 Summer</td>
<td>0.11</td>
<td>0.13</td>
<td>0.09</td>
<td>0.11</td>
<td>0.09</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 12: Resource Selection Function Coefficients for Significant Variables (α = .05). Comparison of models for season (Spring, Summer and Fall) and Crepuscular period (Crep, Ncrep) before and after treatment.

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables</th>
<th>Soil Depth</th>
<th>% Slope</th>
<th>SIN Aspect</th>
<th>COS Aspect</th>
<th>Convexity</th>
<th>% Canopy</th>
<th>Dist Cover</th>
<th>Dist Water</th>
<th>Dist Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>9091 Spring Crep</td>
<td></td>
<td>-0.05</td>
<td>0.29</td>
<td>0.04</td>
<td>-0.09</td>
<td>0.10</td>
<td>-0.05</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9091 Spring Ncrep</td>
<td></td>
<td>0.07</td>
<td>-0.17</td>
<td>0.18</td>
<td>0.17</td>
<td>0.10</td>
<td>-0.05</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9091 Summer Crep</td>
<td></td>
<td>0.28</td>
<td>0.08</td>
<td>-0.27</td>
<td>0.13</td>
<td>0.11</td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9091 Summer Ncrep</td>
<td></td>
<td>0.10</td>
<td>0.18</td>
<td>-0.28</td>
<td>0.42</td>
<td>0.14</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9091 Fall Crep</td>
<td></td>
<td>-0.13</td>
<td>0.18</td>
<td></td>
<td>-0.05</td>
<td>0.14</td>
<td>0.14</td>
<td>0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9091 Fall Ncrep</td>
<td></td>
<td>-0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.03</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9596 Spring Crep</td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>-0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9596 Spring Ncrep</td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9596 Summer Crep</td>
<td></td>
<td>0.15</td>
<td>0.12</td>
<td>-0.06</td>
<td>0.37</td>
<td>-0.09</td>
<td></td>
<td>-0.06</td>
<td></td>
<td>-0.07</td>
</tr>
<tr>
<td>9596 Summer Ncrep</td>
<td></td>
<td>0.15</td>
<td>0.09</td>
<td>-0.14</td>
<td>0.20</td>
<td>0.14</td>
<td></td>
<td></td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>9596 Fall Crep</td>
<td></td>
<td>0.08</td>
<td>0.18</td>
<td>-0.04</td>
<td>0.16</td>
<td></td>
<td>-0.06</td>
<td>0.06</td>
<td>-0.07</td>
<td></td>
</tr>
<tr>
<td>9596 Fall Ncrep</td>
<td></td>
<td>0.11</td>
<td>0.09</td>
<td>0.07</td>
<td>0.15</td>
<td>0.14</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Insufficient data: in After harvest data, AATS collected sets too small for statistical analysis when divided by time of day and season.
RESULTS AND DISCUSSION

Relationships between elk selection and distance to water and distance to cover were found in almost all subdivisions of data (See Tables 9-12). When data were pooled across years, seasons and crepuscular periods, distance to water and roads were found significant before treatment. In contrast, distance to cover was found significant after treatment.

Table 13: Comparison of coefficients of distance variables by activity period.

<table>
<thead>
<tr>
<th>Activity Period</th>
<th>Distance to Water</th>
<th>Distance to Roads</th>
<th>Distance to Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Crepuscular</td>
<td>0.14</td>
<td>0.16</td>
<td>-0.07</td>
</tr>
<tr>
<td>Non-crepuscular</td>
<td>0.14</td>
<td>0.25</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Distance to roads was found significant in all crepuscular vs. non-crepuscular comparisons. In crepuscular periods before harvesting took place, elk selected habitat with were distance to roads was greater. After harvesting, elk selected habitat where distance to roads was lesser during crepuscular periods. This might be due to the increase in road distance rather than the existence of open roads.

Distance to water was significant in both crepuscular and non-crepuscular activity periods before treatment and in neither period after treatment. This would suggest a strong relationship between distance to water before harvesting and elk selection of habitat that did not occur after harvesting.

Distance to cover was only significant in crepuscular periods before treatment while it was significant in both crepuscular and non-crepuscular periods after treatment. Before and after harvesting, elk selected habitat closer to cover during crepuscular
periods. This may be indicative of the strong correlation between cover and forage and could be interpreted as elk selection of habitat close to forage during feeding periods.

Table 14: Comparison of coefficients of distance variables by season.

<table>
<thead>
<tr>
<th>Season</th>
<th>Distance to Water</th>
<th>Distance to Roads</th>
<th>Distance to Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Spring</td>
<td>-0.07</td>
<td>0.54</td>
<td>0.06</td>
</tr>
<tr>
<td>Summer</td>
<td>0.11</td>
<td>0.39</td>
<td>-0.08</td>
</tr>
<tr>
<td>Fall</td>
<td>0.15</td>
<td>0.05</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Selection of habitat in Spring was dependent on distance to roads before treatment and distance to cover and water after treatment. Elk habitat selection appears to be strongly influenced by distance to roads (coefficient = .54). After harvesting, however, elk appear to be selecting for habitat closer to water (negative coefficient).

Selection of habitat in Summer was dependent on all three variables before treatment but only on distance to roads after treatment. Distance to roads (coefficient = .39) was most important in the resource selection function before harvest. It appears elk were selecting habitat closer to cover and/or forage before harvesting.

Selection of habitat in Fall depended on distance to water and roads before treatment but only on distance to water after treatment. Distance to roads was more important in the fall resource selection function before harvesting than distance to water.
Table 15: Comparison of coefficients of distance variables by season and activity period.

<table>
<thead>
<tr>
<th>Season and Activity Period</th>
<th>Distance to Water Before</th>
<th>Distance to Water After</th>
<th>Distance to Roads Before</th>
<th>Distance to Roads After</th>
<th>Distance to Cover Before</th>
<th>Distance to Cover After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crepuscular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-crepuscular</td>
<td>Insufficient data to compare Spring seasons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crepuscular</td>
<td>0.13</td>
<td>0.25</td>
<td>-0.15</td>
<td>-0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-crepuscular</td>
<td>0.11</td>
<td>0.42</td>
<td>-0.06</td>
<td>-0.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crepuscular</td>
<td>0.14</td>
<td>0.06</td>
<td>0.16</td>
<td>-0.06</td>
<td>-0.05</td>
<td>-0.06</td>
</tr>
<tr>
<td>Non-crepuscular</td>
<td>0.14</td>
<td>0.22</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When the data sets were divided by season and activity period there was insufficient data to compare spring conditions (Table 12).

Habitat selection in the Summer during all activity periods was dependent on distance to cover, water, and roads before the treatment. However, it was only dependent on distance to roads after the treatment. Again, the change from positive to negative relationship indicated by the coefficients may be due to the increased proximity of most pixels to open roads after construction and rehabilitation of the road system.

Habitat selection in the Fall was dependent on all distances both before and after treatment during crepuscular periods. The coefficients indicate no change in relationship other than in distance to roads, again most likely to the more extensive road system found after harvesting. During non-crepuscular periods, habitat selection in the Fall depended on distance to water and roads before treatment and distance to cover and roads after treatment.

From these comparisons, it appears that cover became more important to the elk after the treatment – perhaps because there was less of it. Considering the correlation between location of cover and of forage, it could also be assumed that distance to forage
was similarly significant in determination of habitat use. This may be due to the increased
production of forage due to primary succession of vegetation in the cut units where the
canopy was opened.

EVALUATING THE RELATIONSHIP BETWEEN ACTIVITY PATTERNS AND
TREATMENT

SUMMARY OF STUDY DEVELOPMENT

There were three hypotheses proposed in the conceptual stage of the Starkey
project that dealt with movement and activity patterns of the Northeast elk. These were:
1) There is no difference between the amount of movement by the elk before, during and
   after the silvicultural treatment,
2) There is no difference between the amount of time spent by the elk resting and
   moving before, during and after silvicultural treatment, and
3) There is no difference in the degree of activity between day, night and crepuscular
   conditions for the elk before, during and after the silvicultural treatment.
However, as data were collected, the study team identified several limitations of the data
that would make the original study methods proposed impractical. First, distances moved
between subsequent locations may not represent the true movement of the animal. For
instance, if an elk was located at point A, traveled 5 meters to the east, then 6 meters to
the west, and was then relocated, the distance traveled would be only 1 meter to the west.
Pooling distances over 24-hour periods, in case of a circular movement away and then
back to a bedding location, might result in a distance measurement close to zero. Second,
due to the varying number of collars paged by the telemetry system per unit of time, time
between subsequent locations varied. Third, concern was raised over definition of resting and moving. Due to telemetry error, subsequent observations might appear to be 60 meters apart and classified as moving when in fact they occurred at the same exact location and should be classified as resting.

The study team agreed that comparison of elk velocities would provide a sufficient preliminary examination of activity patterns of the elk in Northeast. Velocity is a measure of change in distance per unit time. Distances between successive elk locations could be measured and divided by the amount of time the movement took. Variations in paging cycles by the telemetry system would then not be a problem. Increases in velocities would be used to infer increased activity due to logging activities or changes in cover or forage. Data would be divided by years, treatment (before, during and after) and seasons (spring, summer, and fall, excluding hunts). Velocities could then be related to data divisions through models (treatment period or season) and these models compared to examine the relevance of the treatment to variation in elk velocity.

METHODS

Location data for elk in Northeast was divided into years before (1990 and 1991), during (1993 and 1994) and after treatment (1995 and 1996). The ten collars having the most observations were chosen for each year. For each individual data set, subsets related to season were created. Spring locations included observations from the time of release of the elk on to Northeast through June 15th of each year. Summer data sets included all observations from June 15th through August 15th. Fall data sets included all observations from August 30th through the end of the study for that year. The dates in August between
the 15th and 30th were excluded from the study to avoid including variation in velocities due to hunts in Northeast.

Velocities were calculated for each data subset using TELVIS software (Ager and McGaughey, in press). Mean velocities were calculated for each radio-collared elk data set with S-PLUS software (MathSoft Inc. 1999).
<table>
<thead>
<tr>
<th>SEASON</th>
<th>STUDY YEAR</th>
<th>TREATMENT BLOCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPRING: 10 x VELocities</td>
<td>1990</td>
<td>BEFORE TREATMENT: 60 MEAN VELOCITY MEASUREMENTS</td>
</tr>
<tr>
<td>SUMMER: 10 x VELocities</td>
<td>1991</td>
<td></td>
</tr>
<tr>
<td>FALL: 10 x VELocities</td>
<td></td>
<td>TRUE TREATMENT: 60 MEAN VELOCITY MEASUREMENTS</td>
</tr>
<tr>
<td>SPRING: 10 x VELocities</td>
<td>1993</td>
<td></td>
</tr>
<tr>
<td>SUMMER: 10 x VELocities</td>
<td>1994</td>
<td></td>
</tr>
<tr>
<td>FALL: 10 x VELocities</td>
<td></td>
<td>AFTER TREATMENT: 60 MEAN VELOCITY MEASUREMENTS</td>
</tr>
<tr>
<td>SPRING: 10 x VELocities</td>
<td>1995</td>
<td></td>
</tr>
<tr>
<td>SUMMER: 10 x VELocities</td>
<td>1996</td>
<td></td>
</tr>
<tr>
<td>FALL: 10 x VELocities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8: Blocking Design for Mean Velocity Modeling Study.
The purpose of the study was to evaluate whether timber-harvesting activities had any influence over the mean velocities of elk movements - hence the activity patterns of the studied elk. Models were selected before testing based on this purpose (See Table 17). They include simple relationships between study year (1990, 1991, 1993, 1994, 1995, and 1996), season (Spring, Summer, and Fall), and treatment (before, during and after harvests). The models created were compared with Akaike's information criterion (AIC) (Akaike 1973) to determine to what extent the information contained in the data collected could support the hypotheses represented by the models.

Velocities for study elk were calculated using TELVIS software (Ager and McGaughey, in press) from location data for each of 10 elk in each study year and each season (See Figure 8 for treatment breakdown). A mean velocity was then calculated from the data for each radio-collared animal for each season and year using S-PLUS (MathSoft Inc. 1999). Each mean velocity was then associated with dummy variables for study year, season and treatment block (Table 16). Models selected a priori were evaluated with measurements for AIC calculated by the S-PLUS program Inference was drawn based on AIC ranks and weights.
Table 16: Description and Values of Dummy Variables created for Mean Velocity study.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dummy Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study Year (YEAR)</td>
<td>0 = 1990</td>
</tr>
<tr>
<td></td>
<td>1 = 1991</td>
</tr>
<tr>
<td></td>
<td>3 = 1993</td>
</tr>
<tr>
<td></td>
<td>4 = 1994</td>
</tr>
<tr>
<td></td>
<td>5 = 1995</td>
</tr>
<tr>
<td></td>
<td>6 = 1996</td>
</tr>
<tr>
<td>Season (SEASON)</td>
<td>0 = Spring (all dates &lt; June 15&lt;sup&gt;th&lt;/sup&gt;)</td>
</tr>
<tr>
<td></td>
<td>1 = Summer (all dates including and between June 16&lt;sup&gt;th&lt;/sup&gt; and August 15&lt;sup&gt;th&lt;/sup&gt;)</td>
</tr>
<tr>
<td></td>
<td>2 = Fall (all dates &gt; August 30&lt;sup&gt;th&lt;/sup&gt;)&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>Treatment (CUT)</td>
<td>0 = Before Activities (Years 1990, 1991)</td>
</tr>
<tr>
<td></td>
<td>1 = During Activities (Years 1993, 1994)</td>
</tr>
<tr>
<td></td>
<td>2 = After Activities (Years 1995, 1996)</td>
</tr>
</tbody>
</table>

* All dates between August 15<sup>th</sup> and 30<sup>th</sup> excluded due to hunting activity.
A PRIORI MODEL SELECTION

Eight models were selected centering on the main supposition of the project: harvesting activities had a significant influence on the velocities of study elk. Variables of concern included treatment periods, study years, and season. Treatment periods included before timber management activity began, during the timber harvesting and regeneration activities when elk might be avoiding disturbances, and after the harvests were completed when elk were adjusting to the disturbed landscape. The factor of year of study was considered a source of variation for several reasons.

First, as the elk included in the Starkey project adjusted to the activities and fences on the range, some degree of effect might be evident. Second, the telemetry system itself underwent various upgrades and refinements as well as temporary interruptions due to lighting strikes or collar battery failures (Table 1). Finally, each year would include compounding effects of weather patterns. Such changes created inconsistencies within the data collected and might be expected to influence the velocity measurements.

Modeling year effects alone might show whether interpretations of timber cut effects would really be due to the treatment itself or to the pooling of two years of data to create that treatment block. Season was considered for effects on velocity from phenology and rutting behavior as well as project activities (e.g. date of spring release of the elk, fence inspections by project staff, fall recaptures and herding of elk back into winter pastures).
The initial model selected was the simple relationship of the dependent velocity (V) on the independent dummy of study year (Year). The second and third models were similarly simple relations between velocity and dummy variables for treatment (Cut) or season (Season). A fourth model was a relation of velocity to the interaction between season and cut. The remaining four models were derivations of relationships between cut, season, and the season x cut interaction term. For a list of models chosen see Table 17.

**Table 17: A Priori velocity model development expressing relationships between mean velocity (V) and study year (YEAR), treatment block (CUT) and season (SEASON).**

<table>
<thead>
<tr>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>V = (β)YEAR + ε</td>
</tr>
<tr>
<td>V = (β)CUT + ε</td>
</tr>
<tr>
<td>V = (β)SEASON + ε</td>
</tr>
<tr>
<td>V = (β)CUT*SEASON + ε</td>
</tr>
<tr>
<td>V = (β1)CUT + (β2)SEASON + ε</td>
</tr>
<tr>
<td>V = (β1)CUT + (β2)CUT*SEASON + ε</td>
</tr>
<tr>
<td>V = (β1)SEASON + (β2)CUT*SEASON + ε</td>
</tr>
<tr>
<td>V = (β1)CUT + (β2)SEASON + (β3)CUT*SEASON + ε</td>
</tr>
</tbody>
</table>
**AIC Weights**

When using AIC to compare model efficacy, that model with AIC value measurements minimized is said to be the “best model for empirical data at hand” (Anderson, Burnham, and Thompson 2000, p. 918). Akaike weights demonstrate a model’s strength compared to the other models tested. Weights are considered the “weight of evidence in favor” of a model given that a model in the set can be determined best in that set (Burnham and Anderson 1998, p. 124). Weights are based on the likelihood of a model given the data, and when normalized represent the probability that a given model is the best model in the set tested. The weights for each model tested in this study are reported along with AIC values and the comparative rank of each model ($\Delta_i$) in Table 18.

**Table 18: Model comparisons concerning the relationship between elk mean velocity and silvicultural treatment, study year, and study season. Models are designated by variables included (See Table 16 for definition of dummy variables).**

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>$\Delta_i$</th>
<th>$\omega_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>556.7293</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>Cut</td>
<td>661.6717</td>
<td>104.9424</td>
<td>1.6295E-23</td>
</tr>
<tr>
<td>Cut + Cut*Season</td>
<td>665.5724</td>
<td>108.8431</td>
<td>2.3175E-24</td>
</tr>
<tr>
<td>Season + Cut*Season</td>
<td>665.5724</td>
<td>104.8431</td>
<td>2.3175E-24</td>
</tr>
<tr>
<td>Cut + Season</td>
<td>667.9969</td>
<td>111.2676</td>
<td>6.8952E-25</td>
</tr>
<tr>
<td>Cut*Season</td>
<td>672.7394</td>
<td>116.0101</td>
<td>6.4376E-26</td>
</tr>
<tr>
<td>Cut + Season + Cut*Season</td>
<td>672.7394</td>
<td>116.0101</td>
<td>6.4376E-26</td>
</tr>
<tr>
<td>Season</td>
<td>707.7906</td>
<td>151.0613</td>
<td>1.5756E-33</td>
</tr>
</tbody>
</table>

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RESULTS AND DISCUSSION

The models were chosen to examine how much evidence existed within the data to support the conclusion that elk mean velocity was dependent on the varied effects of the timber harvesting activity more than any other factor. Based on the information about elk activity provided by the data available, it can be inferred through AIC model comparison that effects due to harvesting cannot be said to have any more influence on mean velocity than effects related to the year or season of any given year of the study. The Year model would be chosen as the best model from the set tested with a weight of 1.0.

The dramatic disparity between the model AIC values and the distances between all other models and that with AIC minimized (designated as $\Delta_I$) suggests that effects of variation from mechanical functions of the telemetry system, weather, or even elk adjustment to the Starkey project situation might be more explanatory of variation in mean velocity than effects of harvesting activities.

However, when mean velocities are compared across years and seasons, there is little evidence to support large differences in activity between years (Table 19). Typically elk moved at about 1 to 2 meters per minute. In 1996, the elk moved at > 6 m/min. There was some additional activity in Northeast due to preparations for a new study design in 1996. The difference is only slightly more than 2 m/min.
Table 19: Mean of mean elk velocity (m/min) measurements by year and season.

<table>
<thead>
<tr>
<th>Year</th>
<th>Spring</th>
<th>± SD</th>
<th>Summer</th>
<th>± SD</th>
<th>Fall</th>
<th>± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1.992</td>
<td>1.925</td>
<td>1.201</td>
<td>2.531</td>
<td>3.662</td>
<td>.695</td>
</tr>
<tr>
<td>1991</td>
<td>1.476</td>
<td>.587</td>
<td>2.229</td>
<td>.328</td>
<td>2.383</td>
<td>.387</td>
</tr>
<tr>
<td>1993</td>
<td>3.877</td>
<td>.343</td>
<td>2.924</td>
<td>.162</td>
<td>2.854</td>
<td>.180</td>
</tr>
<tr>
<td>1994</td>
<td>3.245</td>
<td>.432</td>
<td>2.006</td>
<td>.529</td>
<td>2.145</td>
<td>.522</td>
</tr>
<tr>
<td>1995</td>
<td>2.931</td>
<td>.405</td>
<td>2.218</td>
<td>.218</td>
<td>2.487</td>
<td>.279</td>
</tr>
<tr>
<td>1996</td>
<td>6.409</td>
<td>.448</td>
<td>6.788</td>
<td>1.864</td>
<td>5.872</td>
<td>.940</td>
</tr>
</tbody>
</table>

CONCLUSIONS

In general, the main purpose of the overall Northeast elk and timber harvest study was to discover to what extent intensive timber harvesting activities influence elk behavior when avoidance of the activity altogether was not an option. As discussed previously, past literature would suggest that elk avoidance of roads and harvesting was significant. Would elk then suffer greatly from exposure to activities they would otherwise attempt to avoid? Or, would animals adapt to the situation?

Ranging size appears unaffected by harvesting and regeneration activities when data is pooled by year. It is unlikely, however, that there was no effect at all. I would suggest that pooling the data across an entire year prevents detection of influences of specific activities such as road building, spring burns or summer replants on elk ranging behavior. However, when data was divided by season for the home range study there was insufficient numbers of locations to create a consistent study design. Further examination of the range size at seasonal or daily activity periods might be more informative.
Visual analysis of the ranging patterns of the elk (Appendix 1) may provide more convincing information on the effects of the harvesting activities. Elk in 1993 appear to be more selective when site manipulations included burns and planting. In 1994, when regeneration activities were not as intense, the elk return to more widespread ranging patterns. It would be informative to examine these ranging patterns at finer details with special attention to the intervals of time between locations and the specific activities taking place at that time.

The resource selection study produced expected relationships between habitat alteration and elk resource selection. Roads were often found significant and indicated changes in elk preference. However, increased open road coverage creates a false impression that elk selected habitat closer to roads after harvesting. There were simply more roads and more habitats in close proximity to those roads. Relationships between cover and forage location and elk resource selection were expected, as changes in the overstory would create denser forage coverage.

There does not appear to be much change in elk mean velocity due to harvesting or seasons. It might prove more useful to examine velocity during daily feeding and resting periods. However, at this scale we might expect to find year effects more important in determining mean velocity of elk. Different activities took place in each year such as harvest planning in 1991, burning in 1993 and plantings in 1994. Pooling data across those years into treatment units may mask variation that occurred in elk response to the varied human disturbance intensities of the activities.

Elk were released into Northeast each year in like condition (Dick 2001) and do not appear to have been impacted health-wise as shown by the comparison of weights for
adult cows in Main study and Northeast pastures. Pregnancy rates were similarly not
affected appreciably by the timbering activities. Perhaps a stronger indication of the
effects of the harvesting activity on elk is in their bodily response. Increased activity
levels or differential location of cover and forage do not appear to have had large impacts
on elk physical health.
LITERATURE CITED


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Swihart, R. K. and N. A. Slade 1985a. Influence of sampling interval on estimates of


APPENDIX ONE:

CALHOME HOME RANGE OUTPUT
Datafile: X91RSO.THT
Output File: X9UR3S.OUT
Display Units: meters
Adaptive Kernel
98PX 1925.0000 ha
75PX 682.8000 ha
58PX 248.8000 ha

6 of data points: 398
Mx: 376545.8
Min: 374195.8
Ymax: 5918670
Ymin: 5918678

Grid Size: 247.5 m
Avg. Dist: 673.2 m
Bandwidth: 682.3 m
LSCV score: 0.92883E+89

Datafile: X91RS3.THT
Output File: X91RS3.OUT
Display Units: meters
Adaptive Kernel
98PX 1133.0000 ha
75PX 766.2000 ha
58PX 276.3000 ha

6 of data points: 500
Mx: 376785.8
Min: 391395.8
Ymax: 5918678
Ymin: 5918678

Grid Size: 240.0 m
Avg. Dist: 2233.2 m
Bandwidth: 808.9 m
LSCV score: 0.17924E+10

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Datafile: X93R135.TKT
Output File: X93R135.QU
Display Units: meters
Adaptive Kernel
90% 1896.000 ha
75% 741.9000 ha
50% 481.1000 ha
# of data points: 588
Xmin: 376693.0
Xmax: 381493.0
Ymin: 381411.0
Ymax: 381867.0
Grid Size: 240.0 m
Avg. Dist: 1071.3 m
Bandwidth: 673.1 m
LSCV score: .10999E+10

Datafile: X93R138.TKT
Output File: X93R138.QU
Display Units: meters
Adaptive Kernel
90% 1302.000 ha
75% 891.1000 ha
50% 405.6000 ha
# of data points: 500
Xmin: 376635.0
Xmax: 381505.0
Ymin: 381276.0
Ymax: 381867.0
Grid Size: 293.5 m
Avg. Dist: 2344.9 m
Bandwidth: 820.8 m
LSCV score: .38887E+10

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1995 Radio 446

Datafile: X95R446.TXT
Output File: X95R446.OU
Display Units: meters
Adaptive Kernel
98% 1273.000 ha
75% 989.000 ha
50% 483.000 ha
# of data points: 500
Xmin: 376725.0
Xmax: 301535.0
Ymin: 2901345.0
Ymax: 5018640.
Grid Size: 241.3 m
Avg. Dist: 2063.3 m
Bandwidth: 74.2 m
LCCV score: 192666+10

1995 Radio 457

Datafile: X95R457.TXT
Output File: X95R457.OU
Display Units: meters
Adaptive Kernel
98% 1172.900 ha
75% 936.300 ha
50% 525.500 ha
# of data points: 500
Xmin: 376725.0
Xmax: 301535.0
Ymin: 2901345.0
Ymax: 5018640.
Grid Size: 248.0 m
Avg. Dist: 2152.7 m
Bandwidth: 753.3 m
LCCV score: 192666+10

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1995 Radio 450

Output File: X93R450.TXT
Display Units: meters
Adaptive Kernel
99% 1839.0000 ha
75% 659.4000 ha
50% 457.8000 ha
% of data points: 560
Xmin: 376635.0
Xmax: 381335.0
Ymin: 5014230.
Ymax: 5018670.
Grid Size: 244.3 m
Avg. Dist: 2697.9 m
Bandwidth: 734.3 m
LSCV score: 1.6649E+16

1995 Radio 452

Output File: X93R452.TXT
Display Units: meters
Adaptive Kernel
99% 1241.0000 ha
75% 634.3000 ha
50% 457.6000 ha
% of data points: 560
Xmin: 376695.0
Xmax: 381585.0
Ymin: 5014830.
Ymax: 5016070.
Grid Size: 244.3 m
Avg. Dist: 2696.6 m
Bandwidth: 739.5 m
LSCV score: 1.7859E+16

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1995 Radio 453

Datafile: K95R453.TXT
Output File: K95R453.OUT
Display Units: meters
Adaptive Kernel
95% 1145.000 ha
75% 796.1000 ha
50% 446.5000 ha

0 of data points: 568
Max: 3276885.8
Min: 381585.0
Mean: 5613948.
Vmax: 5356648.
Grid Size: 240.6 m
Avg. Dist: 2307.0 m
Bandwidth: 699.9 m
LBCV score: .16943E+18

1995 Radio 446

Datafile: K95R456.TXT
Output File: K95R456.OUT
Display Units: meters
Adaptive Kernel
95% 1127.000 ha
75% 793.000 ha
50% 373.000 ha

0 of data points: 368
Max: 3766895.0
Min: 381385.0
Mean: 5014478.
Vmax: 5016360.
Grid Size: 244.5 m
Avg. Dist: 2967.8 m
Bandwidth: 738.2 m
LBCV score: .19981E+18

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Datafile: K96R240.TXT
Output File: K96R240.OU
Display Units: meters
Adaptive Kernel
90% 1199.868 ha
75% 681.368 ha
50% 499.386 ha
# of data points: 560
Min: 376777.0
Max: 531864.0
Year: 531864.0
Grid Size: 247.5 m
Avg. Dist: 2135.4 m
Bandwidth: 778.3 m
LSDV score: .16779E+10

Datafile: K96R241.TXT
Output File: K96R241.OU
Display Units: meters
Adaptive Kernel
90% 1199.868 ha
75% 681.368 ha
50% 499.386 ha
# of data points: 560
Min: 376772.0
Max: 376772.0
Year: 376772.0
Year: 376772.0
Year: 376772.0
Grid Size: 246.8 m
Avg. Dist: 2045.1 m
Bandwidth: 728.3 m
LSDV score: .19988E+10

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1996 Radio 376

Datafile: K96R376.TXT
Output File: X96F376.0U
Display Units: meters
Adaptive Kernel

- 90% 1201.9000 ha
- 75% 858.9000 ha
- 50% 299.3000 ha

- of data points: 500

Xmin: 376735.0
Xmax: 381595.0
Ymin: 5013615.0
Ymax: 5018648.0
Grid Size: 574.5 m
Avg. Dist: 2072.1 m
Bandwidth: 747.8 m
LSCV score: 6.7264E+11

1996 Radio 378

Datafile: K96R378.TXT
Output File: X96F378.0U
Display Units: meters
Adaptive Kernel

- 90% 1882.8000 ha
- 75% 726.4300 ha
- 50% 379.7000 ha

- of data points: 580

Xmin: 376735.0
Xmax: 381615.0
Ymin: 5013678.0
Ymax: 5018678.0
Grid Size: 244.3 m
Avg. Dist: 324.3 m
Bandwidth: 695.2 m
LSCV score: 2.8465E+18

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