AN ABSTRACT OF THE THESIS OF

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Title: Behavioral responses of Rocky Mountain Elk (*Cervus elaphus*) to recreational disturbance

Abstract approved:

Robert G. Anthony

I measured responses of free-ranging Rocky Mountain elk (*Cervus elaphus*) to recreational disturbance at Starkey Experimental Forest and Range, Oregon from April to October, 2003 and 2004. Resting, feeding, and travel activities of 13 cow elk were recorded at 5-minute intervals using Actiwatch™ motion sensors. Elk were subjected to four types of recreational disturbance: all-terrain vehicles (ATV), mountain biking, hiking, and horseback riding. Individual disturbance activities were recorded for five consecutive days following a nine day control period of no human activity. Elk alternated their activity budgets between feeding and resting bouts during the controls, with little time spent traveling. Travel time increased during the disturbances and was highest in the mornings. Traveling was significantly different among disturbances and was greatest for ATV, followed by mountain biking, hiking, and horseback riding. Feeding time decreased during the ATV disturbance and resting decreased during mountain biking and hiking in 2003. Little or no reduction

in feeding or resting was evident during hiking in 2004 or for horseback riding during both years. Elk returned to behavior patterns similar to those of the controls once each disturbance ended. There was less travel time during disturbances in 2004 compared to 2003, suggesting that elk became habituated to these recreational activities. However, travel time during 2004 remained above that measured during the control periods.

For each of the four treatments I collected visual observations on the distance (m) from an observer that elk took flight (flight distance) and the type of vegetation elk occupied for each flight distance. Radio-collared elk locations were used to estimate mean distance (m) from observer GPS locations when elk displayed movements greater than the control periods (i.e., a flight response). Visual detection rate of elk was depended upon the treatment; the greatest numbers of elk observations were for horseback riding (128), followed by hiking (67), ATV (47), and mountain biking (35). Using direct visual observations, I found no significant difference between the four treatments in elk flight distance. This was in contrast to the activity sensors where a difference between treatments in the time elk spent traveling was detected. Direct observations also produced significantly shorter mean flight distances compared to those of the GPS/radio telemetry estimates. It is likely that direct observations of elk in this study underestimated the effects of recreational disturbance on their behavior patterns. The more detailed activity sensor and GPS/radio telemetry results provide managers with information that can be used for balancing objectives for off-road recreation with those for elk.

Behavioral Responses of Rocky Mountain Elk (*Cervus elaphus*) to Recreational Disturbance

by
Leslie M Naylor

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APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Leslie M. Naylor, Author

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GENERAL INTRODUCTION

Understanding the effects of human activity on wildlife populations is an important component in the management of public and private lands and has, therefore, been the subject of numerous studies. The use of public lands throughout North America has increased dramatically in recent years as recreation becomes an important part of the lives of a growing population. This influx of recreationists has produced a valuable source of income for many small rural communities. Ungulates in North America have long been of keen social interest and are seen as important species economically, but the effect of recreational activity on their behavior patterns is little understood.

Direct visual observations have traditionally been used to assess an animal's response to the approaching observer. This method has proven invaluable for some species by determining an area of influence within which the animal will be displaced or agitated by the intrusion. Direct observations of large ungulates have been used to assess the effects of recreational disturbance, especially for species inhabiting areas of open vegetation and uniform slope where they can be observed relatively easily. However, large free-ranging animals that occupy areas of dense vegetation with diversely sloping landscapes, such as Rocky Mountain elk in Northeast Oregon, can be difficult to observe directly or for sustained periods. To assess any disruptions in elk behavior patterns from recreational activity it would be advantageous to have the ability to remotely record elk behaviors beyond the range of direct observations during human activities.

This thesis details my study of the behavioral responses of Rocky Mountain elk to four types of recreational activity; all-terrain vehicle (ATV), mountain biking, hiking, and horseback riding. I used motion sensitive accelerometers housed in elk Global Positioning System (GPS) collars to estimate elk behaviors at 5–minute intervals during recreational activity and periods of no human activity (control). I used direct observations to estimate the mean distance between elk and an observer at which elk take flight for each of the recreational activities. Telemetry locations of elk and GPS locations of humans were used to estimate the mean distance at which elk exhibited a flight response during each of the four recreational activities.

By using direct observations with the technologically based methods of estimating behavior patterns and movement rates from activity sensor and radio telemetry systems, I was able to provide detailed information on the effect recreational activities have on elk behavior patterns. I also compared the direct observation results with those from the activity sensor and telemetry data to evaluate the suitability of visual assessments of elk responses in a densely vegetated diversely sloping landscape.

CHAPTER 1

ELK BEHAVIORAL RESPONSES TO RECREATIONAL ACTIVITY AS RECORDED BY ACTIWATCH™ MOTION SENSORS

INTRODUCTION

The recreational use of public lands in the United States has increased dramatically since the 1970's (USDA Forest Service 2004) and with it the potential for negative impacts on wildlife (Havlick 2002). A review of 166 articles on the effects of non-consumptive recreation on wildlife showed that 81% of the articles considered the effects to be negative (Boyle and Samson 1985); therefore, the impact of human recreation on wildlife is of increasing concern to natural resource managers (Knight and Gutzwiller 1995).

Published literature is dominated by the effect that recreation has on bird behavior and populations. For example, an increase in nestling predation when parents were disturbed by humans was demonstrated by Anderson (1988). A disturbance effect was recorded in 11 of 12 breeding bird species observed by van der Zande (1984) after the opening of a car park provided increased access to a lake shore. Larger flocks of waterfowl at Brent Reservoir (London) were more sensitive to human disturbance than smaller ones (Batten 1977). In contrast, Cooke (1980) found no marked difference in the distance an approaching observer could get to individuals or flocks of Rooks (*Corvus frugilegus*). However, in the same study passerines in suburban areas permitted an observer to get closer than in rural areas and smaller birds were more approachable than larger ones. Avoidance of human disturbance in foraging areas has been documented in Bald Eagles (*Haliaeetus* *leucocephalus*) by McGarigal et al. (1991) with the range of avoidance being between 200-900 m from an individual in a stationary boat. Bald eagles also spent more time protecting nestlings when disturbed by campers and displayed a one third decrease in prey consumed (Steidl and Anthony 2000).

The effect of roads and road use on ungulates has been well documented; both mule deer (*Odocoileus hemionus*) and elk reduced their use of meadow areas adjacent to main roads by 100 and 95%, respectfully (Perry and Overly 1977). Using pellet counts over an 8-yr. period as an index of habitat use, Lyon (1979) showed that forest roads open to traffic caused available habitat to be less than fully effective with an increase in elk avoidance of roads as tree density decreased. Displacement of elk during logging operations and selection of habitats distant from roads has also been demonstrated (Edge and Marcum 1985, Rowland et al. 2000). Spatial segregation of deer and elk in relation to traffic was reported by Wisdom et al. (2004a) with radio re-location data showing elk to be farther than deer from roads with traffic rates of >1 vehicle/12-hour period and closer when rates were <1 vehicle/12-hour period.

The effect of winter recreation on mule deer was recorded by Dorrance et al (1975) who showed that deer numbers decreased along trails when light snowmobile activity was present. Displacement of mule deer by snowmobiles or hikers was shown to be independent of group size (Freddy et al. 1986). White-tail deer (*Odocoileus virginianus*) avoided trails used by snow-mobiles in northern Wisconsin, but did not alter home range size (Eckstein and Rongstad 1973). Using aerial observations, track and pellet counts, Ferguson and Keith (1982) documented that Moose (*Alces alces*) and elk in Elk Island National Park, Alberta, Canada, tended to move away from areas near heavily used ski trails. The cross-country skiing during their study influenced the general over-winter distribution of moose but not elk abundance. Ski area expansion at Vail and Beaver Creek, Colorado, had an immediate negative effect on elk use of the area (with a 30% decrease in elk numbers seen at Vail compared to pre-development numbers). Elk numbers increased linearly each year after development, possibly indicating a partial acclimation to the disturbance (Morrison et al. 1995).

To study behavioral responses of wildlife to human disturbance, a number of previous studies have used visual observations of target animal's behavior when approached or when within sight of the observer. Previous studies also determined an "area of influence" within which the probability of a response can be predicted (McGarigal et al. 1991, Steidl and Anthony 1996, Taylor and Knight 2003a). However, it is difficult to observe ungulates in forested communities without disturbing them. Radio telemetry has allowed researchers to monitor changes in movement rates, animal speeds, distances traveled and home range utilization of ungulates in response to predation, competition, or human disturbance without having to rely on visual observations over large areas and difficult terrain (Dana et al. 1989, Edge and Marcum 1985, Johnson et al. 2000, Kie et al. 1991).

There are a number of examples in the published literature on elk responses and possible adaptations to human disturbance. When vehicular traffic was experimentally manipulated, Rocky Mountain elk moved away from high use roads and occupied areas near closed roads that had previously been high-use routes (Wisdom et al. 2004a). Home range size, core area size and daily movement of

Roosevelt elk (*Cervus elaphus roosevelti*) decreased in road management areas (RMA) where vehicular traffic was restricted, compared to the same areas pre-management (Cole et al. 1997). Survival of cow elk in the RMA was higher and was attributed to reduced human disturbance leading to reduced movement rates and reduced poaching incidents (Cole et al. 1997). Habituation of Rocky Mountain elk to human disturbance along roads was recorded in Rocky Mountain National Park, but elk took flight when people left the road to approach the herd (Schultz and Bailey 1978). They suggested that the lack of flight response to road traffic was a learned response of the un-hunted elk population and is in contrast to hunted elk populations (Rost 1975 as cited by Shultz and Bailey 1978). Habituation by elk to human disturbance in urban fringe areas may be a behavioral strategy developed to maximize reproductive fitness (Thompson and Henderson 1998).

To assess changes in elk behavior as a result of recreational disturbance, it was necessary to have a manipulative study that included experimental controls during which behavior could be recorded without the confounding presence of an observer or recreationist. As part of a larger study to analyze the responses of Rocky Mountain elk and mule deer to summer recreational use, an experiment was initiated in 2002 at the U.S. Forest Service Starkey Experimental Forest and Range, near La Grande, Oregon (Wisdom et al. 2004b). I was particularly interested in behavioral responses of cow elk to four kinds of recreational disturbance: all terrain vehicles (ATV), mountain biking (BIKE), hiking (HIKE) and horseback riding (HRS).

The purpose of my study was to assess the influences of off-road recreational activities on the behavior of cow elk and to determine if different types of human activity cause different behavioral responses. I developed four hypotheses to guide my research:

Hypotheses

1. Off-road recreational activity produces a change in elk behavior patterns.

   Question 1: Are there differences in the frequency and timing of feeding, resting and traveling behavior between disturbance and control periods?

2. Different types of human activity cause different behavioral responses in elk.

   Question 2: Do elk respond differently among the types of recreational activity?

3. The time required for elk to return to pre-disturbance behavior patterns varies with each disturbance type.

   Question 3: Is there variation among treatments in the time it takes elk to return to pre-disturbance behavior patterns?

4. Continuing exposure to disturbance leads to conditioning of elk to disturbance resulting in unaltered or reduced behavioral responses (i.e., habituation).

   Question 4: Does the mean difference between control and treatment behavior patterns decrease as a function of time and treatment type?

STUDY AREA

Research was carried out from April to October 2003 and 2004 at the U.S. Forest Service Starkey Experimental Forest and Range (hereafter Starkey, Figure 1), located 35 km southwest of La Grande in northeast Oregon, USA. In 1987, approximately 10,125 ha (25,000 acres) of elk summer range within the area was enclosed with a 2.4 m (8-foot) elk-proof fence to form the Starkey Project (Thomas 1989, Bryant et al. 1993, Rowland et al 1997). This project was designed to study the responses of deer and elk to cattle grazing, timber management, vehicular traffic, and recreation (Thomas 1989, Johnson et al. 1991). Data collection for my study was restricted to the northeast portion of Starkey (Northeast), which covers approximately 1,453 ha and was separated from the main study area by the same type of elk-proof fence (Rowland et al 1997, Stewart et al. 2002). Northeast was divided by the 2.4 m fence into two pastures, East (842 ha) and West (610 ha, Stewart et al. 2005). Vegetation was a mosaic of forest stands and open areas. The dominant tree species were ponderosa pine (*Pinus ponderosa*), grand fir (*Abies grandis*), Douglas fir (*Pseudotsuga menzeisii*), and lodgepole pine (*Pinus contorta*). The dominant grass species were bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*). For a full description of vegetation and soils see Burr (1960), Strickler (1965), and Bull and Wisdom (1992).

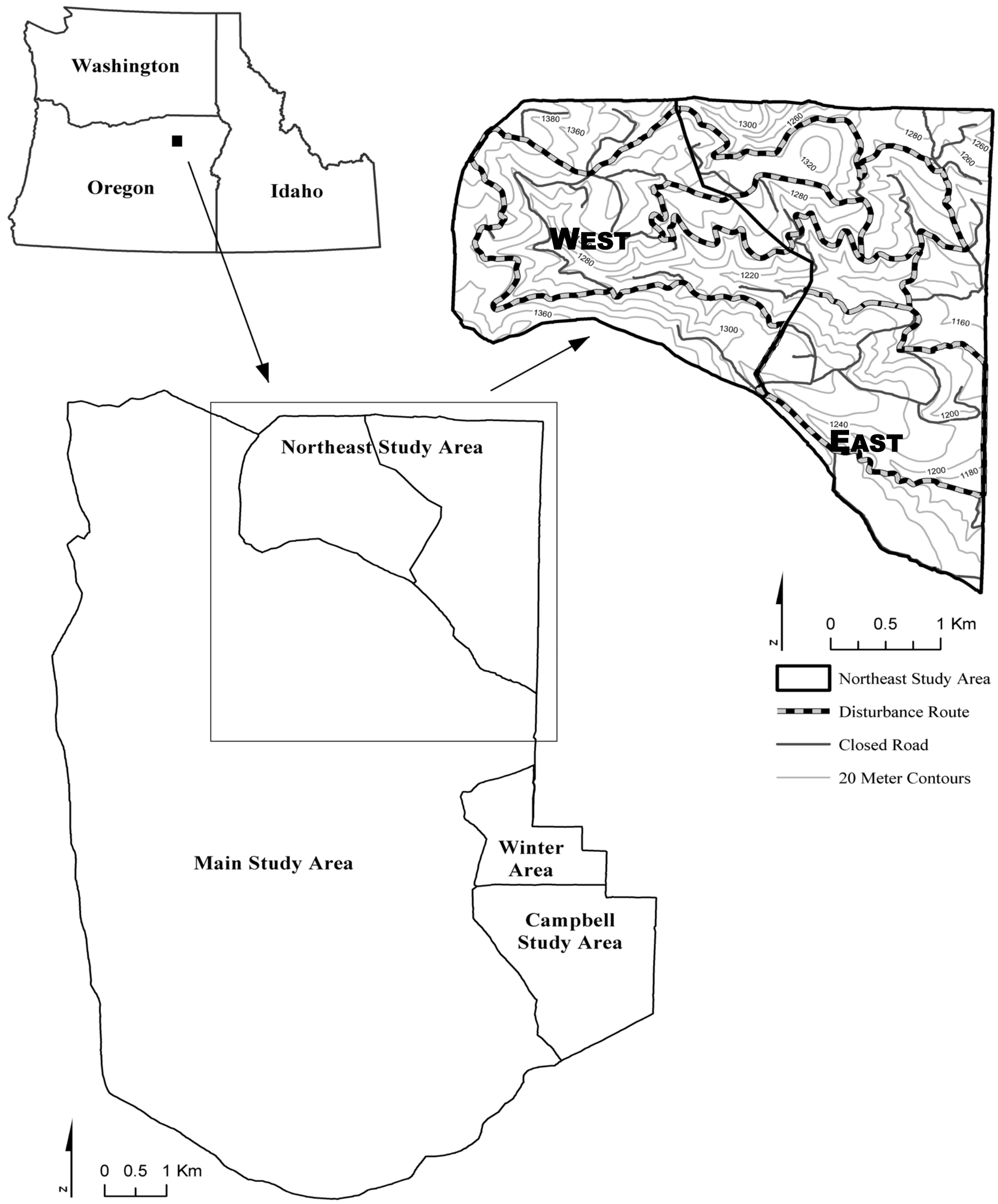

Figure 1: Location of the 1,453 ha Northeast study area.

Disturbance route used during 2003 and 2004 are shown within the Northeast area of Starkey Experimental Forest and Range, La Grande, OR.

METHODS

Actiwatch calibration

Motion sensitive accelerometers (Actiwatch™) were used to record elk behaviors. These sensors were housed in GPS collar battery packs and calibrated for three behaviors (feeding, resting, and traveling) using visual observations of tame elk.

To estimate cow elk behavior from Actiwatch activity recordings, two monitors were installed into a Lotek GPS collar fitted to tame elk and set to collect data at 1-minute intervals (for orientation of activity monitor in the GPS collar see Appendix A Table A1). Behaviors of these elk were recorded and compared to activity measures to calibrate the instruments for the three behavior classes. This was done following the methods used for Actiwatches and Loran-C collars by Naylor and Kie (2004). The elk used for the Actiwatch calibration were randomly selected from a herd of 60 tame cows.

Six cow elk equipped with activity sensors were observed for 1,073 minutes over 12 observation periods (Trials), ranging from 25 to 106 minutes each, during summer 2003. To ensure that only one behavior was causing the Actiwatch measure, data were selected when only one observed behavior occurred during the 1-minute interval, providing a total of 868 minutes of observations for the analysis (Appendix A Table A1). Elk behavior was categorized as feeding, resting, or travel during these observations (Gates and Hudson 1983, Kie et al. 1991). Behaviors were recorded onto a hand held personal digital assistant (Newton MessagePad™, Apple Computer, Inc., Cupertino, Calif.) running Ethoscribe™ dedicated software (Tima Scientific™, Nova Scotia, Canada). Break points (the range of Actiwatch measures associated with each behavior) were established for the 1-minute recording intervals.

Data analysis of Actiwatch™ calibration

A Discriminant Function Analysis (DFA) was used to establish the percent of correct classification of Actiwatch measures into one of the three behaviors (activity). The sample sizes and frequencies of behaviors were not equal; therefore, prior probabilities in the DFA were proportional to the sample sizes.

Activity monitors used on wild elk in my study recorded activity at 5-minute intervals; therefore, it was necessary to establish break points for this time frame. Actiwatch records the aggregate of motion over the record interval (Mini Mitter 1998) and not an average. Five-minute break points were estimated from the 1-minute interval data for each behavior by ordering the data chronologically and summing the recorded measure of each continuous 5-minute block where only one behavior occurred.

Disturbance method

Each winter, elk within the study area were baited into the winter-feeding and handling facility (Winter Area, Figure 1) and were released following the fitting of GPS collars in April. All animal handling followed protocols established by an Institutional Animal Use and Care Committee (Wisdom et al. 1993). Removing and re-releasing animals into the study area enabled population densities to be strictly controlled and ensured the retrieval of radio collars. The same adult cow elk were used throughout this study. Data collection was from April to October each year.

Sixteen cow elk per field season (8 animals for each pasture) were fitted with GPS radio collars containing Actiwatch activity monitors which were set to record at 5-minute intervals. Approximately 24 elk were released into the West Pasture of the study area and 97 into the East Pasture (B. Dick 2005. unpublished data). A series of routes were established that followed old road grades, as well as forested and open areas covering approximately 32 km (20 miles).

Following the release of elk in April each year there was a 14-day period when no human activity occurred in the study area (control period). Each disturbance treatment was replicated three times per field season (April to October). The treatment order was randomly assigned each year. Each disturbance was carried out, individually, for five consecutive days, to ensure that elk response was to one particular treatment and not confounded with responses to other human activities. Treatment periods were followed by nine days of control, during which no human activity occurred in the study area, thereby providing data on elk activity in the absence of human disturbance. Published literature has demonstrated that elk return to areas associated with disturbance within a few hours or days after the cessation of human activity (Stehn 1973, Rowland et al. 2000). Consequently the control period of 14 days at the beginning of the field season and the nine day period of control between treatments provided more than sufficient time to allow animals to return to their pre-disturbance activity patterns.

To allow coverage of the entire study area by treatments moving at different speeds, 3 routes were established for the hike and horseback treatments, 2 mountain bike routes and 1 ATV route (Wisdom 2004b). Each treatment followed a ‘tangential’ experimental approach in which observers did not directly pursue animals but remained along the pre-determined routes (Taylor and Knight 2003a). Disturbance teams were made up of one to three people traveling together under an ‘interrupted’ movement design which allows teams to momentarily stop to record observations and take short rest breaks (Wisdom et al. 2004b).

During data collection in 2003, one activity monitor failed and two were not retrieved from the study area; therefore, data from 13 cow elk were used for the analysis. During 2004, one monitor was not retrieved, and two cows crossed from the East Pasture to the West when a gate was left open at the end of a treatment week; therefore, these elk were removed from the data set leaving data from 13 elk for the analysis. The same adult cow elk were used throughout the study.

Data analysis

Data for each replicate were organized into ten-day periods, five days for each treatment and five for its prior control. Data for the control periods were plotted and provided a visualization of elk activity without the presence of human disturbance. Plots of the time (%) elk spent traveling, resting, and feeding were also made for each treatment and its prior control, to show any differences in elk activity. An activity difference was calculated for each elk as the percent of time spent in each behavior within the treatment period minus the percent of time spent in each behavior during the control for the same time periods. A positive number for the activity difference indicated elk spent more time in that behavior during the treatment compared to the control, and a negative number indicated less time was spent in that behavior during the treatment. Activity difference and 95% confidence intervals for each behavior per treatment, replicate, and year were plotted.

For the activity difference of each behavior a univariate procedure was used to check for a normal distribution of the residuals. The activity difference for each year was analyzed using a Proc Mixed Repeated Measures model (SAS 2001) to test for differences between treatments, replicate, and a treatment by replicate interaction, with each cow being repeatedly measured throughout the year. The mixed model repeated measures used was:

$$Y_{ijk} = \mu + \alpha_i + d_{ij} + \tau_k + (\alpha\tau)_{ik} + e_{ijk}$$

Where Y_{ijk} is the activity difference for replicate $k_{1,2,3}$ on elk $j_{1,2\ldots13}$ in treatment group $i_{1\ldots4}$, μ is the overall mean, α_i is a fixed effect of treatment i, d_{ij} is a random effect of elk j in treatment group i, τ_k is a fixed effect of replicate k, $(\alpha\tau)_{ik}$ is a fixed interaction effect of treatment i with replicate k, and e_{ijk} is a random error at time k on elk j in treatment i. Covariance structure for each model was determined using the lowest AIC score. For 2003, the covariance structure was a First-Order Ante-dependence (ANTE (1)); for 2004, a First-order autoregressive structure (AR (1)) was used.

A priori significance levels for all statistical tests were 0.05. Significance level of all pair-wise comparisons of least square means was adjusted using the Tukey Honestly Significant Difference (HSD) procedure (Harris 1998). Any difference identified in results were significant at 0.05.

The activity difference of travel, resting, and feeding for each year was also analyzed using a Proc Mixed Repeated Measures model (SAS 2001) to test for differences among pastures and time-of-day (morning or afternoon). This model included treatment, replicate, pasture, and time-of-day variables along with all interaction terms. Significance levels of all pair-wise comparisons were adjusted using a Bonferroni critical value (Harris 1998). The mixed model used was:

$$Y_{pijkl} = \mu + \alpha_i + d_{pij} + \tau_k + \tau_l + (\alpha\tau)_{pikl} + e_{pijkl}$$

Where Y_{pijkl} is the activity difference at time-of-day *l,* in replicate *k* on elk *j* in treatment group *i*, and pasture *p*, μ is the overall mean, α_i is a fixed effect of treatment *i*, d_{pij} is a random effect of elk *j* in treatment group *i,* pasture *p,* τ_k is a fixed effect of replicate k, τ_l is a fixed effect of time-of-day *l*, $(\alpha\tau)_{pikl}$ is a fixed interaction effect of time-of-day *l*, with replicate *k*, treatment *i* and pasture *p*, and e_{pijkl} is a random error at time-of-day *l,* replicate *k* on elk *j* in treatment *i* and pasture *p*.

RESULTS

Actiwatch Calibration in Lotek GPS collars

Discriminant Function Analysis based on 1-minute interval data correctly classified 96.8 % of all resting activity, 92.9% of feeding activity, and 90.3% of travel activity (Table 1), with an overall correct classification of 93.3%. These results have a greater correct classification rate for feeding and travel compared to those using the Actiwatch housed in a Loran-C radio collar (Naylor and Kie 2004). Ranges of Actiwatch measures for each 5-minute interval were estimated as: resting 0 – 1,896, feeding 1,900 – 5,135, and travel ≥ 6,166. Actiwatch measures that were between these intervals could not be correctly classified and were therefore discarded from the wild elk dataset (< 2% of the dataset).

Table 1: Results of Discriminant Function Analysis.

Results were based on Actiwatch recordings (from 868 1-minute record intervals collected over 12 trials) to discriminate among three behavior classes of Rocky Mountain elk at Starkey Experimental Forest and Range, La Grande, Oregon, USA during summer 2003. Prior probabilities were set to proportional in the Discriminant Function Analysis.

Observed behavior	**Classified behavior (mins)** Resting	Feeding	Traveling	Total	**Percent correct**
Resting	459	11	4	474	96.84%
Feeding	20	299	3	322	92.86%
Traveling	0	7	65	72	90.28%
Total	479	317	72	868	93.32%

Treatment and replicate differences

Cow elk behavior in the absence of human disturbance, averaged over all 24-hr periods, provided information on how elk allocate their activities (Figure 2). Elk spent little time traveling during all control periods (<5% of each hour). Consequently an increase in travel above that of the control was considered an indication of an elk response to a treatment. During the control periods, feeding and resting bouts composed the majority of elk activity over each 24 hour period and were directly complementary in their percentages. The percentage of time spent resting was highest at approximately 08:00 h (80% of their activity budget) and gradually decreased during daylight hours as bouts of feeding increased. Peak feeding activity was recorded at dawn and dusk and accounted for >70% of activity (Figure 2). Activity budgets for cow elk were similar for 2003 and 2004. Plots of the time (%) spent in each behavior for each treatment and its prior control for each hour, showed differences in elk behavior patterns (Appendix A Figure A2 thru Figure A13). Plots of residuals showed the data to be normally distributed (Appendix A Figure A14 and Figure A15).

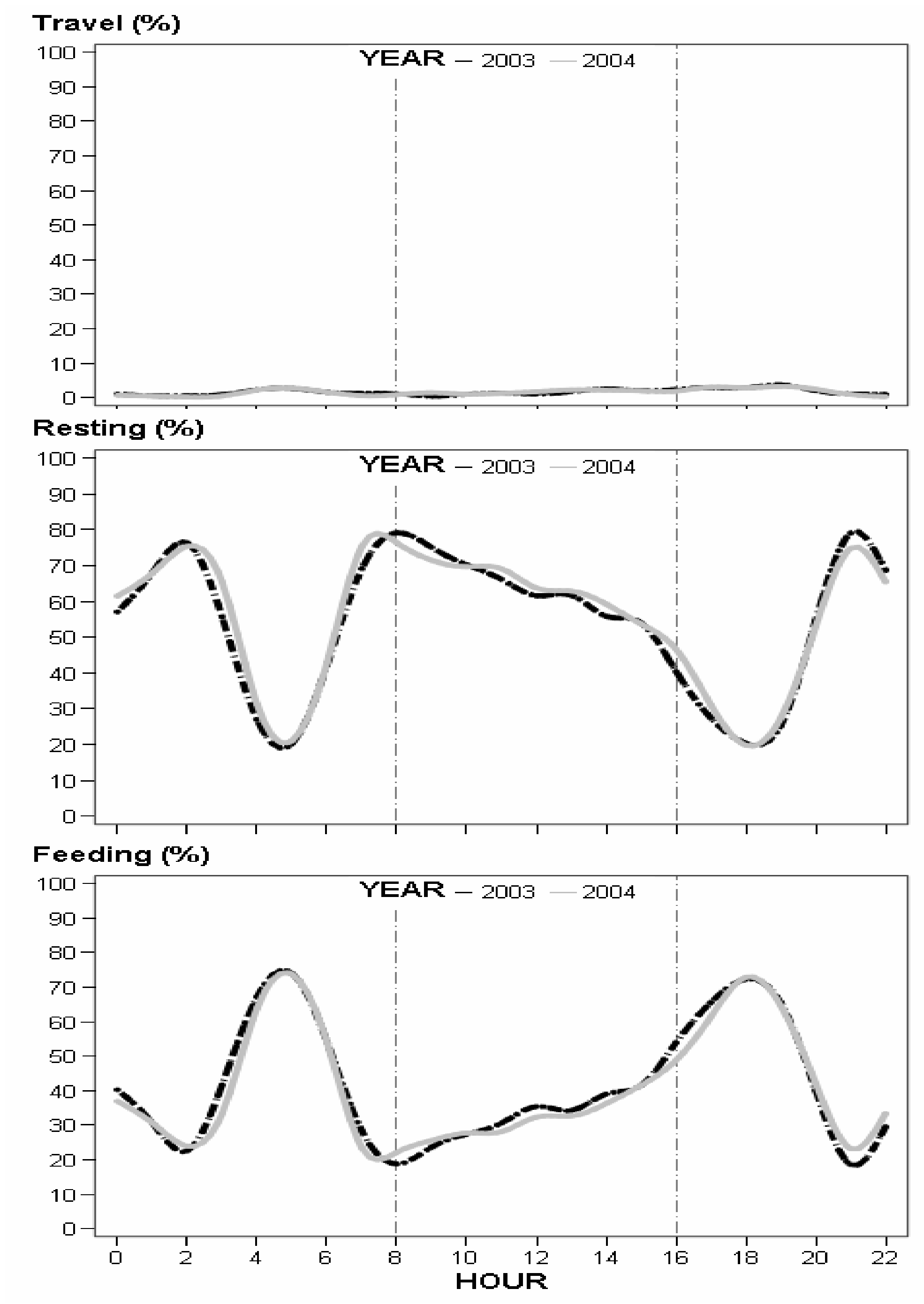

Figure 2: Activity budgets (percent time spent traveling, resting, and feeding) of cow elk averaged over 24-hour periods, expressed in Pacific Daylight Time.

From the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR, for 2003 and 2004 when no human disturbance occurred. Data are the combined average of all control periods.

Results of the mixed model repeated measures analysis of travel activity showed a significant treatment by replicate interaction term in both 2003 and 2004 (2003 $F_{6, 72} = 12.28$, $p < 0.0001$; 2004 $F_{6, 72} = 2.31$, $p = 0.0424$). There also were significant differences in the amount of travel activity among treatments for both years (2003: $F_{3, 36} = 32.25$, $p < 0.0001$; 2004: $F_{3, 36} = 7.65$, $p = 0.0004$). Differences in travel between replicates was evident in 2003 ($F_{2, 24} = 8.50$, $p = 0.0016$) but not in 2004 ($F_{2, 24} = 1.74$, $p = 0.1969$) (Table 2).

The treatment by replicate interaction term was also significant for resting (2003: $F_{6, 72} = 15.11$, $p < 0.0001$; 2004: $F_{6, 72} = 8.29$, $p < 0.0001$). There also were significant differences among treatments in resting time for both years (2003: $F_{3, 36} = 10.60$, $p < 0.0001$; 2004: $F_{3, 36} = 11.62$, $p < 0.0001$) and between replicates (2003: $F_{2, 24} = 11.19$, $p = 0.0004$; 2004: $F_{2, 24} = 6.36$, $p = 0.0061$) (Table 3).

Similarly, the time elk spent feeding was significantly different for the treatment by replicate interaction term (2003: $F_{6, 72} = 21.45$, $p < 0.0001$; 2004: $F_{6, 72} = 7.89$, $p < 0.0001$). As with travel and resting activity, the time spent feeding was also significantly different among treatments (2003: $F_{3, 36} = 16.41$, $p < 0.0001$; 2004: $F_{3, 36} = 13.35$, $p < 0.0001$ and replicates 2003: $F_{2, 24} = 30.05$, $p < 0.0001$; 2004: $F_{2, 24} = 9.87$, $p = 0.0007$), (Table 4).

Table 2: Results of a mixed model repeated measures analysis of travel time.

Test was for differences between treatments (TRT) and replicates of mean travel time by 13 cow elk in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR.

			Travel 2003		Travel 2004	
Effect	Num DF	Den DF	F value	P-value	F value	P-value
TRT*Replicate	6	72	12.28	<0.0001	2.31	0.0424
TRT	3	36	32.25	<0.0001	7.65	0.0004
Replicate	2	24	8.50	0.0016	1.74	0.1969

Table 3: Results of a mixed model repeated measures analysis of resting time.

Test was for differences between treatments (TRT) and replicates of mean resting time by 13 cow elk in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR

			Resting 2003		Resting 2004	
Effect	Num DF	Den DF	F value	P-value	F value	P-value
TRT*Replicate	6	72	15.11	<0.0001	8.29	<0.0001
TRT	3	36	10.60	<0.0001	11.62	<0.0001
Replicate	2	24	11.19	0.0004	6.36	0.0061

Table 4: Results of a mixed model repeated measures analysis of feeding time.

Test was for differences between treatments (TRT) and replicates of mean feeding time by 13 cow elk in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR

			Feeding 2003		Feeding 2004	
Effect	Num DF	Den DF	F value	P-value	F value	P-value
TRT*Replicate	6	72	21.45	<0.0001	7.89	<0.0001
TRT	3	36	16.41	<0.0001	13.35	<0.0001
Replicate	2	24	30.05	<0.0001	9.87	0.0007

Effects of All Terrain Vehicles

1. Time spent traveling

There were significant effects of ATVs on activity budgets of cow elk with increased travel time during all treatments periods (Figure 3). The percentage of time that elk traveled during ATV treatments was greater than the controls for each replicate during 2003, with a high in replicate 1 of 7.27%, 3.01% for replicate 2, and 2.88% for replicate 3 (Figure 3). ATV treatment had the highest effect on travel in replicate 1 of 2003, which was different than that for replicates 2 and 3 of that year (p <.0001). There was no difference in traveling between ATV replicates 2 and 3 (p = 1.000). See Appendix A Table A2 for differences in least square means. The time spent traveling during the ATV treatment for replicate 1 of 2003 was greater than the other treatments (p <0.0001 for each pair-wise comparison, Appendix A Table A2), with the next highest mean value of travel being 2.57% for the horseback treatment followed by 2.48% for mountain bikes and -0.70% for hiking (Appendix A Table A8). There was no difference in travel activity between ATV and the other treatments during replicate 2 of 2003 (Bike p = 0.3173, hike p = 0.9915, horseback p = 0.5466). For replicate 3 of 2003, travel by elk was not different than that of mountain bikes (p = 0.9999), but it was different from hiking (p = 0.0198) and horseback riding (p = 0.0020), with the greater travel response for the ATV treatment.

There was less travel by elk in response to the ATV treatment in 2004 compared to 2003 (Figure 3). Travel time for 2004, however remained greater than the controls (Appendix A Table A8). There was no difference in travel activity between replicates (differences between replicates 1 and 2 p = 0.4998, replicates 1 and 3 $p = 0.8903$, and replicates 2 and 3 $p = 1.0000$, Appendix A Table A5). For 2004, travel activity was not different among treatments except for the horseback riding during replicate 2, ($p = 0.0024$) with the greater travel response being for the ATV treatment (Appendix A Table A5).

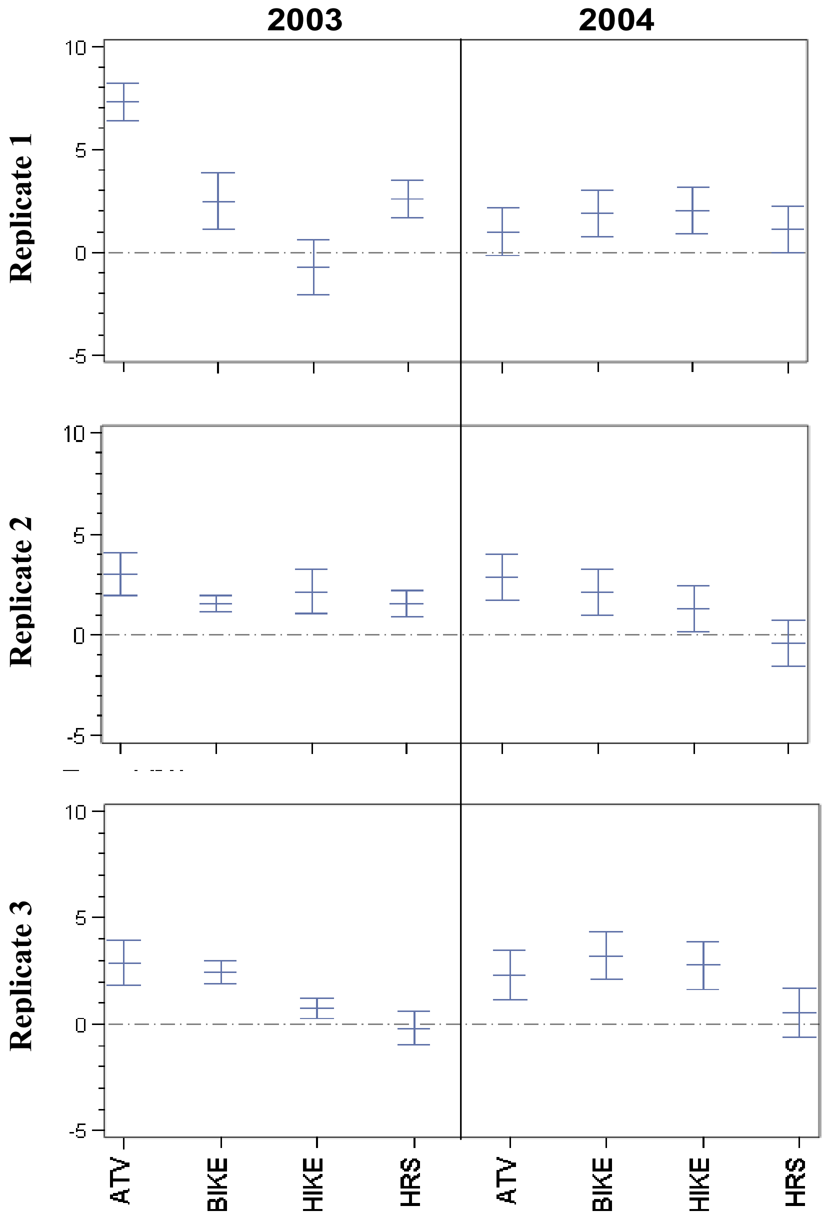

Figure 3: Mean and 95% confidence intervals of the difference in the percentage of time spent traveling between treatments and controls.

Data are for 13 cow elk in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR, 2003 and 2004. Activity difference was calculated as the percent time spent traveling during the treatment minus that during the control, so negative values indicate activity less than that of the control. Treatments were all terrain vehicle (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS).

2. Time spent resting

Elk spent more time resting in 4 of the 6 ATV treatment periods as compared to controls (Figure 4). Resting activity was greater than the controls for 2003 replicates 1 and 2. Replicate 3 had a resting activity difference of 0.15%, with 95% confidence intervals overlapping zero indicating little difference with the control period (Figure 4). There were no differences among replicates in the percentage of resting time during 2003 (Appendix A Table A3). During 2003, resting time for the ATV treatment was greater than that for horseback riding treatment during replicate 1 ($p = 0.0394$), and both mountain biking and hiking during replicate 2 ($p = 0.0090$, and $p = 0.0005$ respectively) (Appendix A Table A3). No other differences among treatments in cow elk resting were observed during 2003.

Resting activity for the 2004 ATV treatment was greater than the controls for replicates 1 and 3 (14.88% and 7.31% respectively) and less for replicate 2 (-4.60%), Figure 4. There were differences in resting time among each ATV replicate (for replicates 1 and 2: $p < 0.0001$; for replicates 1 and 3: $p = 0.0195$; for replicates 2 and 3: $p = 0.0004$). For 2004 the percent of time cow elk spent resting during the ATV treatment was greater than that of the other three treatments for replicate 1 ($p < 0.0001$), and greater than mountain biking and hiking for replicate 3 ($p = 0.0002$, and $p = 0.0033$ respectively), but less than the horseback treatment during replicate 2 ($p = 0.0118$) (Appendix A Table A6).

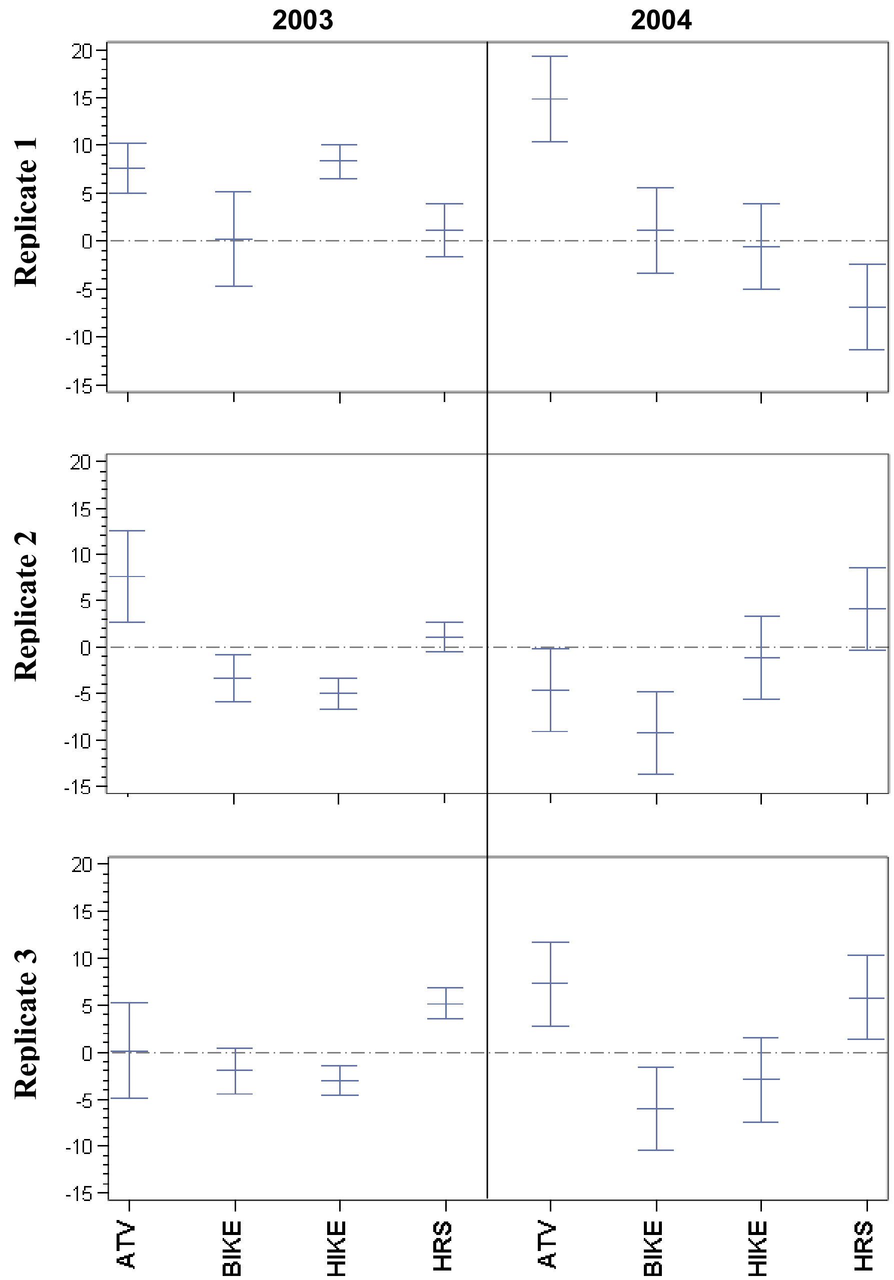

Figure 4: Mean and 95% confidence intervals of the difference in the percentage of time spent resting between treatments and controls.

Data are for 13 cow elk in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR, 2003 and 2004. Activity difference was calculated as the percent time spent resting during the treatment minus that during the control, so negative values indicate activity less than that of the control. Treatments were all terrain vehicle (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS).

3. Time spent feeding

In general elk spent more time traveling and resting during the ATV treatments and less time foraging (Figure 5). Greatest reduction in foraging was observed during 2003 for replicate 1 (-17.01%), followed by -10.21% in replicate 2, and -3.43% in replicate 3. These values were significantly different between replicates 1 and 3 ($p = 0.0002$). Feeding time by elk during the 2003 ATV treatment was significantly less than that of the other treatments for replicate 1, and less than the mountain biking and hiking treatments in replicate 2. There was no difference between ATV and the other treatments in the time elk spent feeding during replicate 3 of 2003 (Appendix A Table A4).

For 2004 the time elk spent feeding during the ATV treatment was below that of the controls for replicates 1 and 3 (-14.79% and -13.23% respectively) and no different from the control for replicate 2 (1.34%) (Figure 5). Feeding time during replicate 1 of 2004 was less than that of the other treatments, but was not different from them for replicate 2, and was only less than that for mountain biking during replicate 3 (Appendix A Table A7).

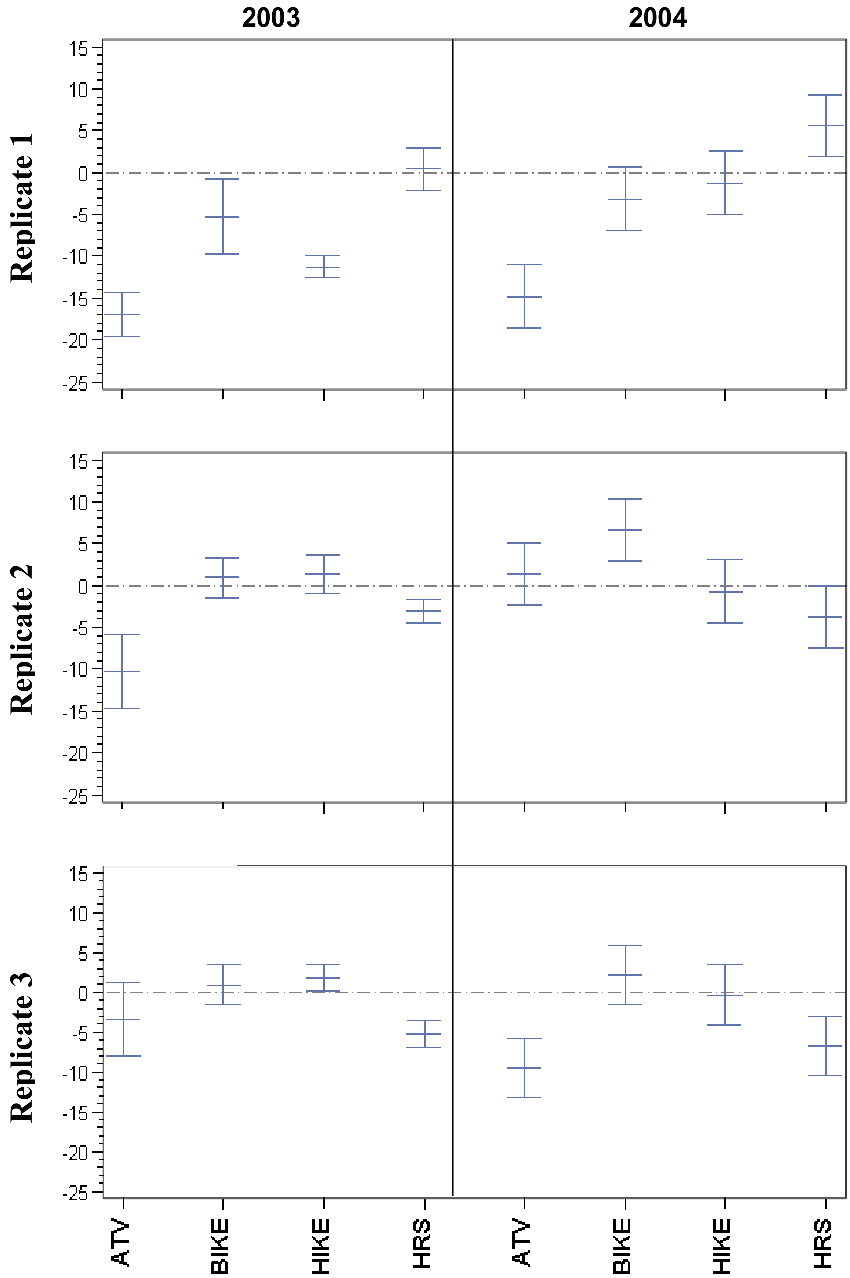

Figure 5: Mean and 95% confidence intervals of difference in the percentage of time spent feeding between treatments and controls.

Data are for 13 cow elk in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR, 2003 and 2004. Activity difference was calculated as the percent time spent feeding during the treatment minus that during the control, so negative values indicate activity less than that of the control. Treatments were all terrain vehicle (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS).

Effects of Mountain biking

1. Time spent traveling

Elk increased their travel time during all mountain bike periods (Figure 3). Travel activity for 2003 was above that of the control periods, with the highest mean value for replicate 1 (2.48%), lowest during replicate 2 (1.55%), and intermediate for replicate 3 (2.44%) (Appendix A Table A8). No differences in travel among mountain bike replicates were observed for 2003 (Appendix A Table A2). No difference in travel between mountain biking and hiking for replicate 1 ($p = 0.0754$) or replicate 2 ($p = 0.9962$) was observed. Travel time by elk was higher during mountain biking than during replicate 3 of horseback riding ($p <.0001$) (Figure 3). However, travel time during mountain biking was not different than that of horseback riding for replicates 1 and 2 ($p = 1.0000$).

Travel time during the mountain bike treatments in 2004 was greater than that of the controls (Figure 3). Travel time was greater than that of the horseback treatment for replicate 3 ($p = 0.0449$), but was not different during the other replicates or from that of the hiking treatment.

2. Time spent resting

Mountain biking caused a significant reduction in the amount of resting time by elk during 4 of the 6 treatment periods (Figure 4). There were no significant differences in resting time between replicates during the mountain bike treatment in 2003. Resting time during the mountain biking was significantly less than the horseback treatment for replicate 3 of 2003 (p = 0.0005), but was not different from the hiking or horseback treatments at other times (Appendix A Table A3).

No difference was observed for resting time of elk during replicate 1 of mountain biking in 2004 compared to the control (Figure 4). The time elk spent resting during replicate 1 of 2004 was different than that of both replicates 2 and 3 (p = 0.0016, and p = 0.0275 respectively). There was no difference in resting between replicate 2 and 3 (p = 0.3205). No difference was found for resting time during the 2004 mountain biking treatments and hiking treatment for replicates 1 and 3 (p = 0.6207, and p = 0.3292 respectively). However, elk spent less time resting during the biking treatment than during hiking replicate 2 (p = 0.0193). Elk spent more time resting during the mountain biking for replicate 1 compared to the horseback treatment (p = 0.0193), but less during both replicates 2 and 3 (p = 0.0001, and p = 0.0005 respectively) Figure 4.

3. Time spent feeding

Mountain biking caused a significant reduction in the time elk spent feeding during 2 of the 6 treatment periods compared to controls (Figure 5). Reduced feeding occurred during replicate 1 of both years. During 2003, however, no difference in feeding among replicates was observed (Appendix A Table A4). Elk spent more time feeding during the mountain biking treatment of 2003 compared to the replicate 3 horseback treatment. No other differences between feeding among mountain biking and horseback or hiking were observed during 2003.

During 2004 elk spent more time feeding during replicates 1 and 2 of the mountain biking treatments ($p = 0.0212$). Elk spent significantly more time feeding during replicate 2 of 2004 compared to the horseback treatment ($p = 0.0174$), but was not different during the other two replicates. No difference was observed among feeding time during mountain biking and hiking treatments during 2004.

Effects of Hiking

1. Time spent traveling

Hiking had a significant effect on activity budgets of elk with increased travel time during 5 of the 6 treatment periods (Figure 3). During replicate 1 of 2003, elk travel time was similar to the control period. Travel was greater than that of the controls in replicates 2 and 3 of 2003. However, no difference in travel among replicates was observed (Appendix A Table A2). Traveling by elk was less than the horseback treatment during replicate 1 of 2003 ($p = 0.0139$), and was not different from it during the other two replicates.

Travel time by elk during 2004 was greater than the controls in each replicate (Figure 3), with no difference among the replicates, or from the horseback treatment (Appendix A Table A5).

2. Time spent resting

The effect of hiking on resting behavior of elk was variable among the treatment periods (Figure 4). During replicate 1 of 2003, resting activity was greater than the control period (mean = 8.34%), but less than the controls for the remainder of 2003 (Figure 4). Increased resting activity for replicate 1 of 2003 was greater than the other two replicates ($p < 0.0001$) and greater than that of the horseback treatment ($p = 0.0015$), Appendix A Table A3. The time elk spent resting during replicates 2 and 3 of 2003 were less than that of the horseback treatment ($p < 0.0001$).

Resting by elk during all 2004 hiking replicates was not different from that of the controls (Figure 4). There also were no differences in resting activity among replicates. Elk spent more time resting during replicate 1 of 2004 compared to the horseback treatment ($p = 0.0450$), and less time during replicate 3 ($p = 0.0113$), (Appendix 1 Table A6).

3. Time spent feeding

The effect of hiking on cow elk feeding behavior was also variable among the treatment periods. During replicate 1 of 2003, feeding activity was less than that of the control period (Figure 5), feeding activity for the remainder of 2003 was similar to or greater than the controls. Feeding activity during replicate 1 of 2003 was also less than both replicates 2 and 3 ($p < 0.0001$). There was no difference in feeding activity between replicates 2 and 3 ($p = 1.0000$). Feeding activity during replicate 1 of 2003 was also less than that of the horseback treatment ($p < 0.0001$), but was greater during replicate 2 ($p = 0.0446$), and replicate 3 ($p < 0.0001$) (Figure 5).

Feeding activity of elk during the hiking treatments of 2004 was not different from that of the controls (Figure 5). There was also no difference during 2004 in feeding activity among hiking replicates, or with feeding time during horseback riding.

Effects of Horseback riding

1. Time spent traveling

The effects of horseback riding on activity of cow elk were variable among treatment periods and type of behavior (Figure 3 - Figure 5). In general, horseback riding had less effect on travel time than the other human disturbances. Travel times in 2003 for the horseback treatment was greater than that of the controls for replicates 1 and 2 but not replicate 3. Differences among replicates during horseback treatments in 2003 was evident only for replicates 1 and 3 ($p = 0.0014$). There were no differences among replicates for travel during the horseback treatments in 2004 (Figure 3).

2. Time spent resting

The effects of horseback riding on cow elk resting activity were variable among treatment periods. There was no difference from the control in resting activity during replicates 1 and 2 of 2003 (Figure 4). Replicate 3 of 2003 had the higher resting time and was greater than the control as well as replicate 2 ($p = 0.0287$), but was not greater than replicate 1 ($p = 0.3537$).

During 2004, resting time of elk was less than the control during replicate 1, not different during replicate 2 and higher during replicate 3 (Figure 4). Replicate 1 had significantly less resting time than replicate 2 ($p = 0.0012$), and replicate 3 ($p = 0.0001$). There was no difference in resting activity between replicates 2 and 3 ($p = 0.5850$), Appendix A Table A6.

3. Time spent feeding

The effect of horseback riding on cow elk feeding behavior was also variable among the treatment periods. Feeding time during replicate 1 of 2003 was not different from the control period, but was less than the controls for replicates 2 and 3 (Figure 5). However, there was no difference in the time elk spent feeding between replicates 1 and 2 of 2003 (p = 0.4392), or replicates 2 and 3 (p = 0.6588). Elk spent more time feeding during replicate 1 than replicate 3 (p = 0.0180).

During 2004, feeding activity was greater than the control period during replicate 1, not different during replicate 2 and less than the control during replicate 3 (Figure 5). There was a difference between replicates, with replicate 1 having the greater feeding time than both replicate 2 (p = 0.0505), and replicate 3 (p = 0.0010). There was no difference in feeding between replicates 2 and 3 (p = 0.9942).

Habituation

The difference in travel activity between the treatments and controls for the ATV and horseback treatments was progressively less as the replicates and years progressed (Figure 3). For example, the amount of travel by the elk was greater than the controls for all the ATV treatments in both years, but their response during 2003 became less each replicate, with the highest response in replicate 1 of 7.27% to 2.88% by replicate 3. The highest difference in travel activity between treatment and controls for the ATV treatment in 2004 (2.83%) was less than the lowest for 2003 (2.88%) indicating a reduced response by elk to the treatment in that year (Appendix A Table A8).

Elk reduced the amount of time they traveled during each horseback riding replicate in 2003 until there was no difference between the treatment and control in replicate 3 (-0.18%) (Appendix A Table A8). For 2004 travel response was less than that of 2003 and was only greater than the control for replicate 1 (1.11%); travel activity during replicates 2 and 3 were not different from the controls (Figure 3). Overall horseback riding caused the lowest travel response in elk compared to the other treatments.

In contrast, elk appeared to be consistent in their mean travel activity during the mountain biking treatment with travel time greater than the controls each replicate of each year (Figure 3), but with no difference among replicates.

The effect of the hiking treatment on travel time was variable. Differences in travel time among treatments and controls for 2003 fluctuated from no difference in replicate 1 (-0.70%) to a high of 2.14% for replicate 2 and back to little difference for replicate 3 (0.73%). All values of travel were higher than the controls for 2004, with the least response being for replicate 2 (1.26%) and the highest for replicate 3 (2.75%).

Pasture and time-of-day differences

Differences in travel response between the higher elk density (east pasture) and the lower density (west pasture), considering time-of-day (Part), replicate, and treatment, indicated that a four-way interaction of these variables was significant for both years (2003: $F_{6,\,132} = 21.94$, $p < 0.0001$; 2004: $F_{6,\,132} = 6.40$, $p < 0.0001$) (Table 5). All 3-way and most 2-way interactions were significant as were all individual effects (Table 5). For each treatment travel time by elk in the two pastures were similar during the mornings (Figure 6). Exceptions were ATV replicate 1 of 2003; the percent time that elk traveled for the east pasture was 11.48% and the west was 5.00%. For replicate 2 of the horseback treatment during 2003, the mean for the east pasture was 1.58% and the west 7.28%. The exception in 2004 was the hiking treatment in replicate 2; the percent time that elk traveled in the east pasture was 4.60% and the west -0.45% (Appendix A Table A11 thru Table A14).

Table 5: Differences in travel activity between treatments (trt), replicate, pasture, and time-of-day (part).

Results show the significance of the four-way interaction term in both 2003 and 2004. Data are from 13 cow elk each year. Treatments were all terrain vehicle, mountain biking, hiking, and horseback riding.

Type 3 Tests of Fixed Effects 2003 and 2004 Travel

			2003		**2004**	
Effect	**Num DF**	**Den DF**	**F Value**	**P - Value**	**F Value**	**P - Value**
Pasture	1	11	0.00	0.9720	18.04	0.0014
Replicate	2	22	25.31	<0.0001	3.35	0.0536
Pasture* replicate	2	22	9.02	0.0014	12.01	0.0003
Trt	3	99	29.43	<0.0001	11.61	<0.0001
Pasture*trt	3	99	0.84	0.4763	15.85	<0.0001
Replicate *treatment	6	99	5.61	<0.0001	4.47	0.0005
Pasture* replicate *trt	6	99	3.19	0.0067	2.34	0.0373
Part	1	132	111.47	<0.0001	57.57	<0.0001
Pasture*part	1	132	7.64	0.0065	18.23	<0.0001
Replicate *part	2	132	1.23	0.2969	1.81	0.1671
Pasture* replicate *part	2	132	7.12	0.0012	9.95	<0.0001
Trt*part	3	132	2.65	0.0514	12.20	<0.0001
Replicate *trt*part	6	132	7.42	<0.0001	2.82	0.0129
Pasture*trt*part	3	132	2.36	0.0745	17.28	<0.0001
Pasture* replicate *trt*part	6	132	21.94	<0.0001	6.40	<0.0001

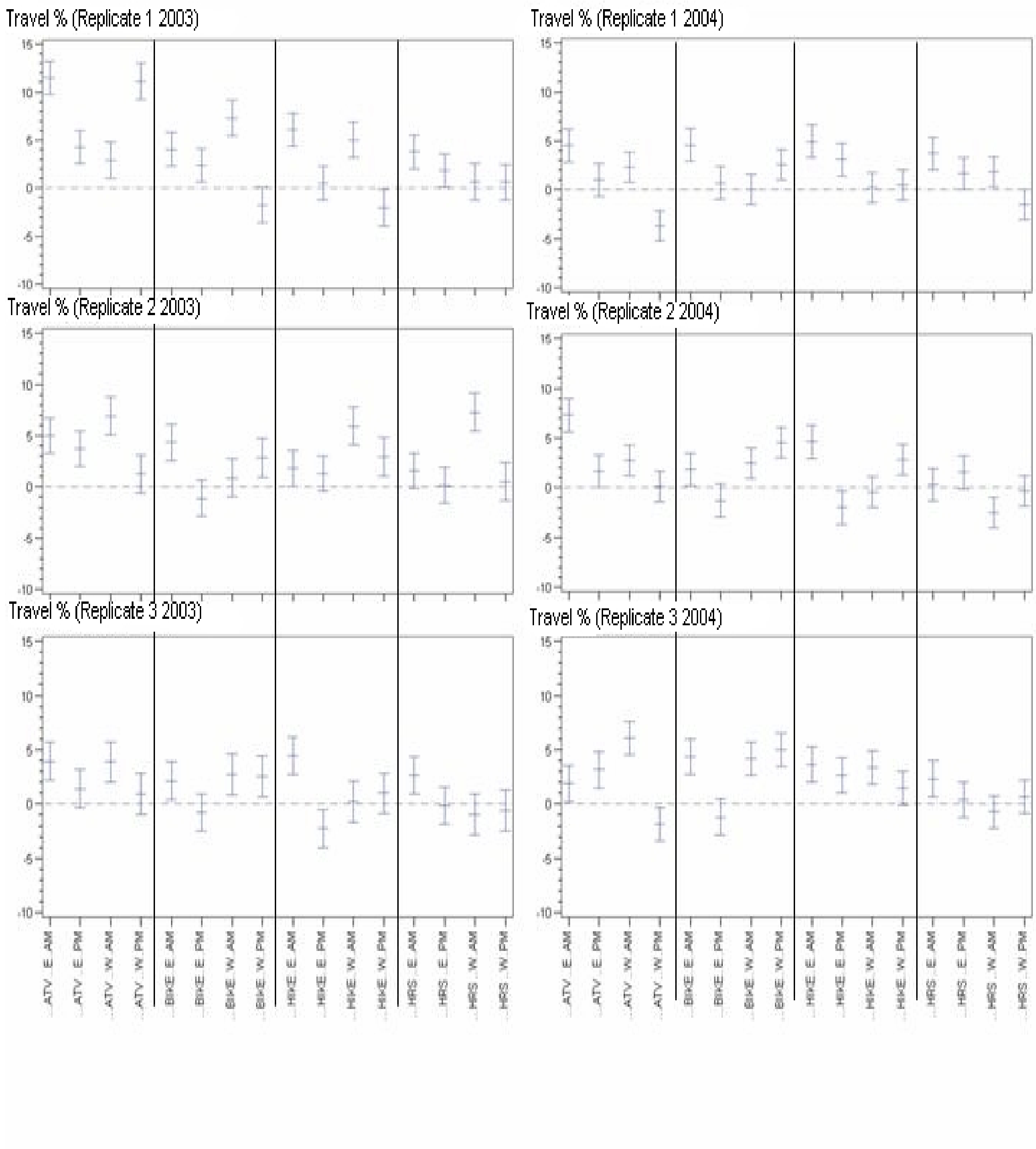

Figure 6: Activity difference for travel during morning and afternoons per treatment, pasture, and replicate.

Data are the percent time spent traveling by 13 elk during treatments minus the percent time spent traveling during controls for 2003 (left side) and 2004 (right side) at Starkey Experimental Forest and Range, La Grande, OR. A positive value indicates travel was greater during the treatment compared to the control. E = east pasture and W = west.

Differences in least square means between pastures during the afternoons for 2003 were predominantly not significant. Only one difference was found, that of replicate 1 of the ATV treatment ($p = 0.0004$) (Appendix A Table A15), with travel time higher in the west pasture (Appendix A Table A11).

Elk travel time also differed between pastures during the afternoons in 2004 for ATV replicate 3 ($p = 0.0257$), mountain bike replicates 2 and 3 ($p = 0.0012$, $p = 0.0003$ respectively), and hiking replicate 2 ($p = 0.0478$), (Appendix A Table A15 and Table A16). At these times, the east pasture had the greater travel time during the ATV treatment and the west pasture had the greater travel time during the biking and hiking.

Differences in travel time between morning and afternoon in the same pasture show some significant differences for 2003 with the morning disturbance causing the greater travel response (Figure 6). There were fewer instances of differences in mean travel activity between mornings and afternoons in 2004 for the same pasture (Appendix A Table A 18).

DISCUSSION

This project was the first study using Actiwatch activity sensors to examine behavioral responses of elk to recreational disturbance. These activity sensors provided estimates on the percentage of time that elk spent feeding, resting, and traveling during human activities and control periods when no human disturbance occurred.

Activity budgets of elk during control periods were consistent with the literature on elk circadian cycles between foraging and resting. For example, Green and Bear (1990) recorded peak feeding activity at dawn and dusk accounting for 36 – 60% of the total daily feeding time, for cow elk in Rocky Mountain National Park in Colorado. Elk activities during the control periods in my study were similar to their findings. These same circadian patterns were also demonstrated by Ager et al. (2003) in their study of movements and habitat use of elk, which used a large telemetry data set, collected over 6 years, to map elk activity within the main study area of Starkey. Similarly, when examining the effects of habitat patch and topography on movements of elk, Kie et al (2005) plotted movement vectors in meters per minute that highlighted the cycle of elk activity evident in the earlier studies. Speeds of elk (meters/minute) estimated from Loran-C relocation data during the 2002 phase of the recreational disturbance study provided further evidence of elk circadian patterns of movement in the absence of human disturbance Preisler et al. (2006). This information provided a basis for comparisons of activity budgets during periods of recreational activities in my study.

The aim of my research was to assess the influences of off-road recreational activities on cow elk behavior and to determine if different types of human activity cause different behavioral responses. I based my interpretation of the results on the evidence that elk traveled relatively little during all control periods; therefore, an increase in travel during the treatments was a response to the disturbance. Feeding and resting activity could be influenced by factors beyond the control of this experiment, such as seasonal changes in temperature, plant phenology, fluctuations in photoperiod, an increase or decrease in levels of precipitation, and seasonal differences in energetic requirements. Differences between treatments and controls in feeding and resting time could not necessarily be described as a direct 'response' to the treatment if they were not accompanied by changes in the percent time that elk traveled. In addition, traveling is the most costly behavior in terms of energy expenditure for elk, and thus was the behavioral activity of most interest.

My results were used to address the research hypotheses specifically and thereby provide information on the effects of recreational disturbance on elk behavior.

Hypothesis 1, which postulated that off-road recreational activity produces a change in elk behavior, was supported by my results. My study clearly demonstrated that activity budgets of elk were altered during recreational activity compared to those during control periods. There was an increase in travel activity during most treatments, which reduced the time that elk spent feeding and/or resting.

An increase in travel was recorded throughout the period of disturbance, but was generally greater in the mornings than in the afternoons. This response was similar to that recorded by Wisdom et al. (2004b), where movement rates (speed in meters/minute) of elk were higher than that of the controls in the hours immediately after initiation of the disturbance. The reduced response by elk to each treatment in the afternoons compared to the mornings was likely due to elk moving away from the disturbance routes and avoiding them for the remainder of the day, which reduced the need to expend more energy fleeing. The reduced travel by elk in the afternoons could also be due to the benefits of conserving energy by remaining in a particular habitat. Presumably, more time spent hiding would outweigh the loss of energy produced by fleeing from the disturbance. The results of my study did not include information on elk locations in relation to disturbance routes; therefore any shifts in habitat use during the treatments could not be determined. However, elk movement away from the routes to 'hiding' places near or against the fences was recorded by Preisler et al. (2006) in 2002.

Hypothesis 2, stating that different types of human activity cause different behavioral responses in elk, also was supported by my results. Findings demonstrated that travel response in elk was different among the treatments. ATVs generally had the largest difference in travel time between treatment and control periods, followed by mountain biking, hiking and horseback riding. Feeding activity was reduced during the ATV treatments as a result of increased traveling. Travel by elk during mountain biking appeared not to affect feeding but rather caused a reduction in the time elk were resting. Resting activity was also reduced during the hiking treatment in 2003, but any increase in travel in 2004 resulted in an evenly distributed loss between feeding and resting. For the horseback treatment, travel activity during 3 of the 6 treatment periods were not different from the controls, suggesting that elk were not greatly affected by this treatment. When elk displayed a travel response to the horseback treatment, the effects on resting and feeding time were mixed.

Hypothesis 3, stating that the time required for elk to return to pre-disturbance behavior patterns varies with disturbance type, was not supported by my results. For all treatments, elk returned to behavior patterns similar to those of the controls once the disturbance ended (Appendix A Figures A4, A7, A10, and A13). Feeding per hour during the controls rose steadily from 20% of the hour at 08:00 h to approximately 50% by 16:00 h and was typically less during the treatments. The reduction in foraging time during the treatments was not compensated for after the disturbance ended, as elk did not increase feeding intensity or duration beyond that of the controls.

The design of this study mimicked the times of typical human traffic disturbance (Wisdom 1998); therefore the treatments did not coincide with peak elk feeding activity during dawn and dusk. With their main intake of digestible material being unaffected by the disturbances, changes in the time spent foraging during the treatments may not have had significant short-term biological consequences for the elk (i.e., elk may have satisfied their immediate nutritional requirements before and after the disturbances occurred). There is, however, still a potential disadvantage to the elk; the energy expense of traveling during each disturbance coupled with a loss in forage intake and a shift away from the disturbance routes to areas of potentially lesser quality forage could have a cumulative effect on long-term body condition. Cook et al (2004) suggested that if a cow elk's body fat was reduced to below 9% as the animal enters the winter period, there is an increased probability of that individual not surviving the winter. Comparisons of elk body condition prior to and following each treatment were beyond the scope of this study. Consequently, the long term effects of repeatedly disturbing the elk from April to October each year for 3 years could not be assessed.

Hypothesis 4, stating that continued exposure to disturbance leads to conditioning of elk to the disturbance, resulting in unaltered or reduced behavioral responses (i.e., habituation) was partially supported by my findings. That is, I found a reduction and consistency in travel time for each replicate and between years for ATV and horseback riding.

Highest travel was in 2003 for the ATV treatment, but there was a gradual decline in values across replicates. Moreover, travel response by elk to the ATV treatment was reduced in 2004, with no difference found between ATV replicates or among ATV and the other treatments, except for horseback riding in replicate 2 of that year.

Travel by elk during horseback treatments was not different from the control periods in 2004. The similarity in travel time in 2004 to that of the controls suggests elk habituated to the horseback riding between years and among replicates within years. Alternately, elk could have simply avoided areas near the horseback routes during 2004, as was done by elk in response to ATV treatments over time (Preisler et al. 2006). Under this possibility, elk could have maintained the same activity patterns as during controls, but farther away from the routes.

Mountain biking had similar levels of travel time in both years, but was higher than those of horseback and hiking in the third replicate of 2003 and again higher than horseback riding in the third replicate of 2004. Travel time for the mountain bike treatment was above that of the controls for each year and was consistent between replicates demonstrating little or no habituation to this treatment.

I also detected no habituation to hiking by cow elk. With the exception of replicate 1 for 2003, elk travel time in response to hiking was above that of the control periods each replicate of each year, suggesting a similar response by elk to each hiking disturbance (i.e., no habituation).

Overall differences in travel times between treatments had more similarity in 2004 than 2003. This may be a function of annual fluctuations in behavior, as mentioned above, or could be evidence of habituation of elk to all disturbances resulting in a more uniform response to each type of recreational activity. Elk in each pasture generally had a higher travel response to the morning disturbances in both years.

MANAGEMENT IMPLICATIONS

My results clearly demonstrate that elk activity patterns can be substantially affected by off-road recreational activities. The percent time that elk spent feeding was reduced during ATV riding, mountain biking, and hiking for most replicates of these activities. Reduced feeding could, in turn, reduce the opportunity for elk to put on fat reserves during spring, summer, and fall that would be needed for winter survival.

Although more research is needed on this potential effect, my results show that elk did not compensate for lost feeding opportunities during other times of day when recreationists were not present in the study area. Consequently, a comprehensive approach for managing human activities to meet elk objectives would include careful management of off-road recreational activities, particularly ATV riding and mountain biking, which caused the largest reduction in elk feeding time. Watersheds or other large planning areas with objectives that emphasize or feature the elk resource would logically have more constraints placed on off-road recreation uses. Conversely, planning areas with low emphasis on maintaining elk would be logical areas for increased off-road recreation activities. Such resource allocations between elk management and off-road recreation management will become increasingly important as off-road recreation uses continue to increase on public lands.

CHAPTER 2

DIRECT OBSERVATION OF ELK RESPONSES TO RECREATIONAL ACTIVITY

INTRODUCTION

The use of public lands for recreation has increased dramatically (USDA Forest Service 2004) since the 1970s, and along with this increase comes the potential for negative effects on wildlife. In a review of 166 articles investigating the effects of non-consumptive recreation, Boyle and Samson (1985) found that 81% of articles reported a negative effect. There are many environmental implications concerning the continued growth in recreational use of public lands such as habitat alteration, disturbance, exploitation and pollution (Knight and Gutzwiller 1995). In 1991, approximately 109 million people 16 years and older participated in some form of wildlife-related recreation. Non-consumptive participation in wildlife-oriented recreation has been projected to increase by at least 63% over a 50-year period (U.S. Fish and Wildlife Service 1993).

Elk (*Cervus elaphus*) responses to human disturbance have been investigated to some extent with mixed results. In Rocky Mountain National Park, elk acclimated to existing levels of human disturbance along roads, but people leaving roads to approach elk caused them to flee (Schultz and Bailey 1978). They suggested that this acceptance of human activity along the roads was a learned response of an un-hunted population and was in contrast to responses seen in hunted populations (Rost 1975 as cited by Schultz and Bailey 1978). Elk compensate for site-specific environmental disturbance by shifts in home range, centers of activity, and use of habitat (Van Dyke and Klein 1996, Cole et al. 2004). Habituation by elk to disturbance in urban fringe areas is a behavioral strategy for maximizing reproductive fitness, and an increase in populations of habituated elk in the 21st century has been predicted (Thompson and Henderson 1998). By contrast, human disturbance caused a 30% decline in elk use of one area and 98% in another where ski slope development took place; elk use was lowest when human activity was highest (Morrison et al. 1995). In a traffic manipulation study at Starkey Experimental Forest and Range in Northeast Oregon, cow elk avoided roads in response to high to moderate traffic rates but displayed less avoidance of the same areas during nighttime or low traffic rates (Wisdom et al. 2004a). Elk moved away from high use roads and occupied areas near closed roads that had previously been the high use routes.

Many studies have focused on roads as conduits for human disturbance (Cole et al. 1997, 2004), but less is known about off-road disturbance. Because recreational use of public lands is not limited to one type of human activity, it is necessary to understand how multiple activities effect elk behavior, especially activities that use trails and are not limited to open roads, such as all terrain vehicles (ATV), mountain biking, hiking, and horseback riding. Visual assessments of animal responses to approaching disturbance have been used to determine an "area of influence" for bald eagles (*Haliatus leucocephalus*) (McGarigal et al. 1991, Steidl and Anthony 1996) from which it was possible to prescribe a buffer zone to minimize disturbance impacts.

The distance between an animal and an activity when the animal takes flight was defined by Taylor and Knight (2003a) as "flight distance". This variable has been used to assess responses of bison (*Bison bison*), mule deer (*Odocoileus hemionus*) and pronghorn antelope (*Antilocapra americana*) to hikers and mountain bikers in predominantly grassland and sagebrush (*Artemisia tridentata*) communities in Antelope Island State Park, Utah (Taylor and Knight 2003b). However, it is often difficult to observe large free ranging mammals in forested landscape when dense vegetation and topography hamper observations (Gillingham and Bunnell 1985). Consequently, telemetry-based observations of animal response to human disturbance may be needed in densely forested conditions.

To address this need a landscape scale study was begun at Starkey Experimental Forest and Range, La Grande, Oregon. The study was designed to assess responses of Rocky Mountain elk to multiple recreational activities using visual observations of flight distance and to compare results of those observations with radio telemetry and activity sensor information. I specifically developed the following hypotheses to evaluate elk responses to ATV, mountain biking, hiking, and horseback riding:

1. Flight frequency and flight distance will vary with type of recreational activity.
2. Mean elk flight distance differs with the habitat type occupied by elk.
3. Visual observations and radio telemetry will provide similar information on elk responses to recreational disturbance.

The specific objectives for this study were to:

1. Determine the frequency of flight and mean flight distances of elk exposed to four types of recreational activity
2. Assess potential differences in flight distance of elk among four habitat types.
3. Compare results of visual observations of elk responses to responses recorded with radio telemetry and activity sensors.

METHODS

During early April of each year, 22 elk were released from the Winter Area into the West Pasture (18 adult cows, 2 female calves, and 2 bulls, with 3 bulls having remained in the area over winter) and 98 into the East Pasture (69 adult cows, 10 female calves, 6 male calves, and 13 bulls. B. Dick 2005 unpublished data of the Northeast Study Area). A series of routes covering approximately 32 km (20 miles) were established that followed primitive roads, old road beds and off-road trails that were typically used by recreation enthusiasts on National Forests when riding ATV's, mountain bikes, horses, or hiking (Figure 1).

Following the release of elk in April there was a 14-day period of control when no human activity occurred in the study area. Treatments (ATV, mountain biking, hiking, and horseback riding) were replicated three times per year, and the order in which treatments occurred was randomly assigned. Treatment periods were followed by nine days of control, during which no human activity occurred in the study area. Each disturbance was carried out, individually, for five consecutive days, to ensure that elk response was to one particular treatment and not confounded with responses to other human activities.

To provide coverage of the 32 km (20 miles) of routes within the study area, it was necessary to have 3 sets of hikers and horseback riders, 2 sets of mountain bikers and 1 set of ATV riders. Research teams were equipped with a Bushnell™ Yardage Pro 1000 laser range finders and data sheets. Each treatment followed a "tangential" experimental approach in which observers did not directly target or pursue elk, but remained along the pre-determined routes (Taylor and Knight 2003a). Disturbance teams were made up of one to three people traveling together under an "interrupted" movement design which allows teams to momentarily stop to observe animals and record observations (Wisdom et al. 2004b). Once elk were sighted, one team member obtained a distance (meters) to the animals using the range finder, while the second member counted the number of visible animals. The nearest or most visible elk was used to obtain a distance for groups of elk. When this was impractical due to elk leaving the area, a tree nearest where they had been sighted was used to estimate the distance.

For each elk observation, teams recorded the date and time, pasture (East or West), treatment type, number of elk, distance to elk in meters, number of times the herd had been observed (1^{st}, 2^{nd} 3^{rd}, etc), weather conditions, habitat type occupied by elk, habitat type occupied by observers, and reaction of elk. The term "flight distance" is used in this study to refer to the distance between an elk (or group of elk) and the observers when the elk take flight, as defined by Taylor and Knight (2003a). Flight distance was considered a "response" by the elk to the recreational activity. Observations of elk being alert but not moving away or being unaware of the observers were recorded as "no-response."

A statistical method, referred to as a probabilistic flight response, was developed by Preisler et al. (2006) based on movement vectors of elk derived from Loran-C telemetry data during the 2002 stage of this study. Movements of 12 radio-collared cow elk were monitored with an automated animal tracking system (Rowland et. al. 1997). During each recreational treatment, locations of human were generated at 1-minute intervals using GPS units carried by each team. Locations of elk were simultaneously generated at 10-minute intervals during these periods. This use of the automated telemetry system to track animal movements, combined with the GPS units used to track human movements, provided a real-time, unbiased estimate of the distances between each collared elk and the human disturbance (Wisdom et. al. 2004b). When analyzing these animal and human locations, flight response by elk was defined as an observed speed greater than the upper 95th percentile of speeds observed during the control periods for the same hour of day, same elk, and adjusted for elapsed time (Preisler et. al. 2006). With this model the probability of an elk displaying a "response" during the control periods is approximately 5% (i.e., their movement rates were higher than 95% of those observed during control periods). Therefore, if the estimated probability of flight during a disturbance was >5%, it was assumed the animal had reacted to the treatment (Preisler et. al. in 2006).

By using only movement that was significantly greater than the controls, the probabilistic model was run to estimate mean and standard errors of flight distance for each of the four recreational activities. Means for both the probabilistic flight response model and the visual observations were compared using standard errors. Assuming the probabilistic model is an unbiased estimate of distances of flight responses by elk, any overlap in standard errors between it and the estimated flight distances obtained from visual observations would support hypothesis 3. However, no overlap in standard errors would indicate a bias in the visual observations.

Data analysis

The number of observations of elk per treatment and habitat type within treatments was calculated and plotted. The percentage of observations during morning versus afternoons, and for each pasture, was calculated. Analysis was limited to elk observed ≤500 m, due to the detection limitations at greater distances (vegetation and topographical obstacles) and not knowing whether elk were responding to the observers or another stimulus when >500 m. Summary statistics of elk flight distance (meters) were calculated and plotted for all treatments separately and for each habitat type (pooled across all treatments). Data were checked for normality using the Proc Univariate procedure in SAS (SAS Institute 2001) and log transformed to comply with normality assumptions of an Analysis of Variance (ANOVA) procedure (Appendix B Figure B1 and Figure B2). Uneven sample sizes meant that data did not meet the assumptions of a two-way analysis of variance. Consequently, a mixed model procedure was used to test for differences between log flight distance for treatments and habitat types occupied by elk, with an interaction term (Harris 1998, SAS 2001). I used the 0.05 level of significance for all statistical tests.

RESULTS

A total of 277 observations of elk were recorded during the four recreation treatments. The number of observations and percentage of total (in brackets) for each treatment were: bike = 35 (13%), ATV = 47 (17%), hike = 67 (24%), horse = 128 (46%). The number of observations and percent of total per habitat occupied by elk were: grassland = 32 (11.6%), cut site = 34 (12.3%), Douglas fir = 81 (29.2 %), ponderosa sites = 130 (46.9%). Of the 277 observations 81% (n = 255) were flight responses. The percentages of flight response per treatment were: ATVs 83%, biking 91%, hiking 84%, and horseback riding 77% (Figure 7). Sixty eight percent (n = 153) of all observations were in the morning and 74% (n = 166) were in the East pasture, which had the highest density of elk.

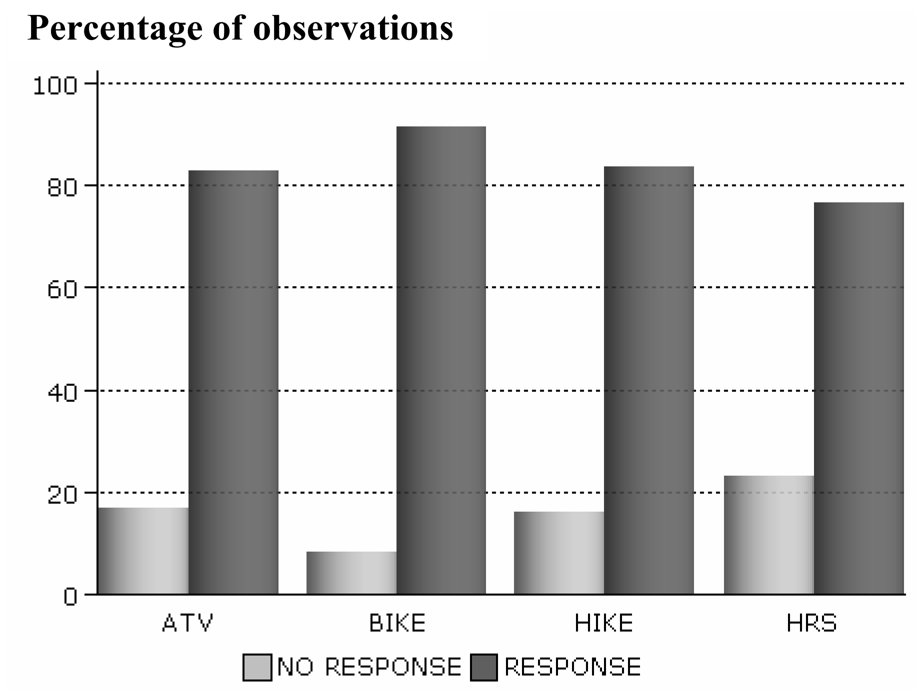

Figure 7: Percentage of elk responses per treatment based on visual observations.

Data was from the Northeast study area of Starkey Experimental Forest and Range, La Grande, Oregon, 2003 - 2004. Treatments were: all terrain vehicle (ATV), mountain bike (BIKE), hiking (HIKE), and horseback riding (HRS).

Flight distance by elk did not vary in relation to treatment (Figure 8) or habitat types (Figure 10 thru Figure 13). Moreover no interactions of treatment and vegetation ($F_{9, 209} = 1.15$, $p = 0.3265$) or treatments ($F_{3, 209} = 0.42$, $p = 0.7366$) were found.

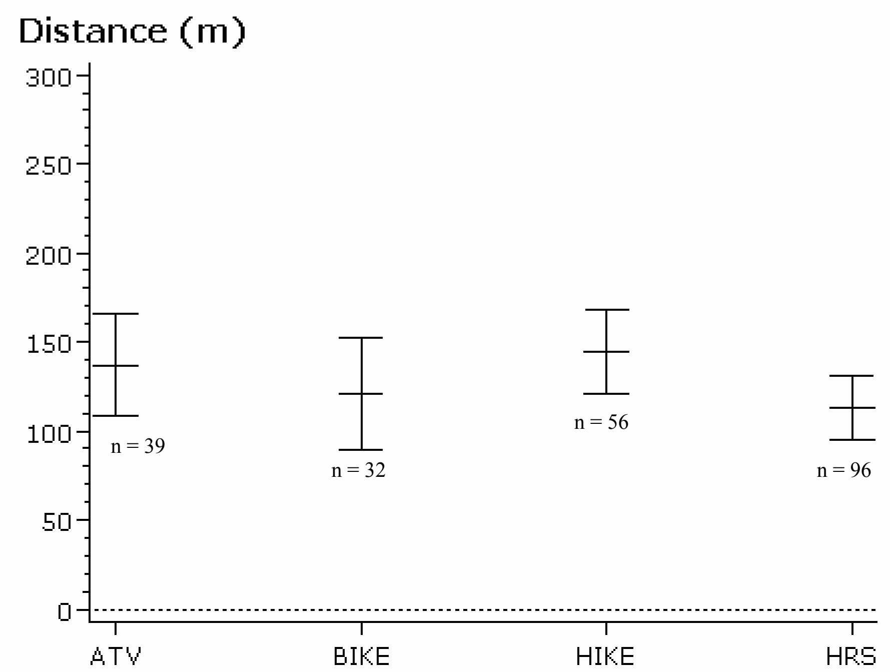

Figure 8: Mean elk flight distance per treatment.

Plots were based on visual observations in the Northeast study area of Starkey Experimental Forest and Range, La Grande, Oregon, 2003 - 2004. Error bars are 95% confidence intervals. Treatments were: All terrain vehicle (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS).

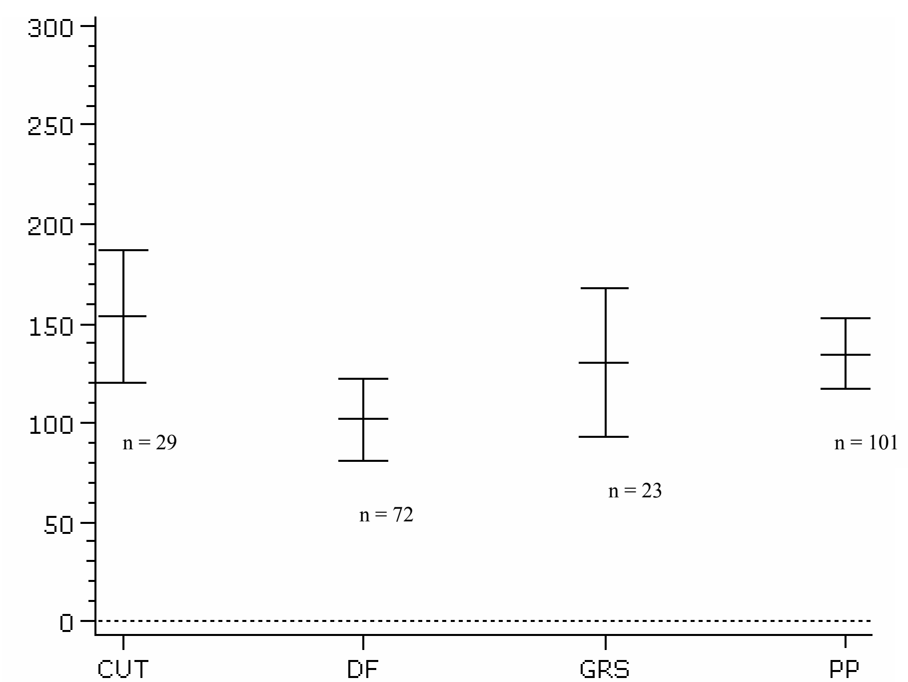

Figure 9: Mean elk flight distance per habitat type.

Error bars are 95% confidence intervals. DF= Douglas fir sites, GRS = grasslands, CUT = logged area with some tree re-growth, and PP = ponderosa pine sites. Data are based on visual observations in the Northeast study area of Starkey Experimental Forest and Range, La Grande, Oregon, 2003 - 2004.

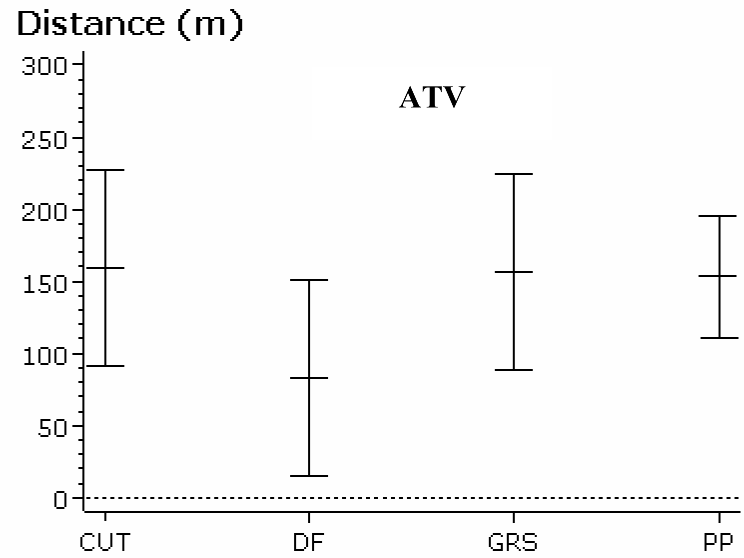

Figure 10: Mean elk flight distance (m) per habitat type from 39 observations during ATV activity.

Data collected at Starkey Experimental Forest and Range, La Grande, Oregon 2003 and 2004. DF= Douglas fir sites, GRS = grasslands, CUT = logged area with some tree re-growth, and PP = ponderosa pine sites. Error bars are 95% confidence intervals.

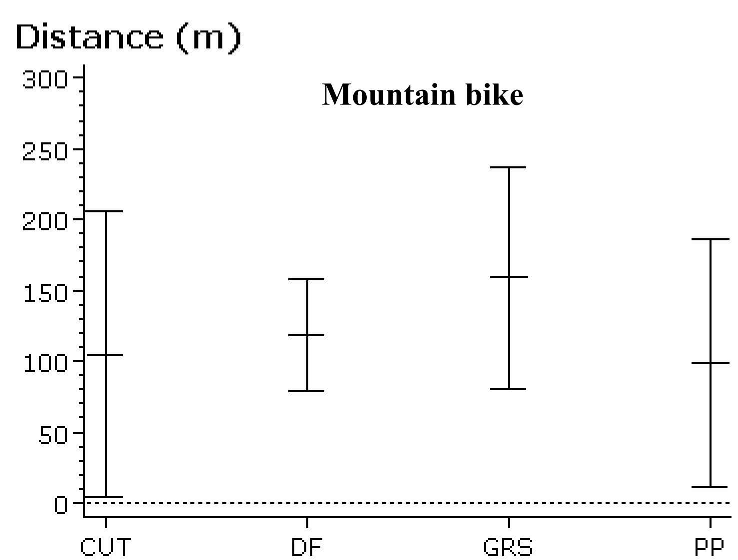

Figure 11: Mean elk flight distance (m) per habitat type from 32 observations during mountain bike activity.

Data collected at Starkey Experimental Forest and Range, La Grande, Oregon 2003 and 2004. DF= Douglas fir sites, GRS = grasslands, CUT = logged area with some tree re-growth, and PP = ponderosa pine sites. Error bars are 95% confidence intervals.

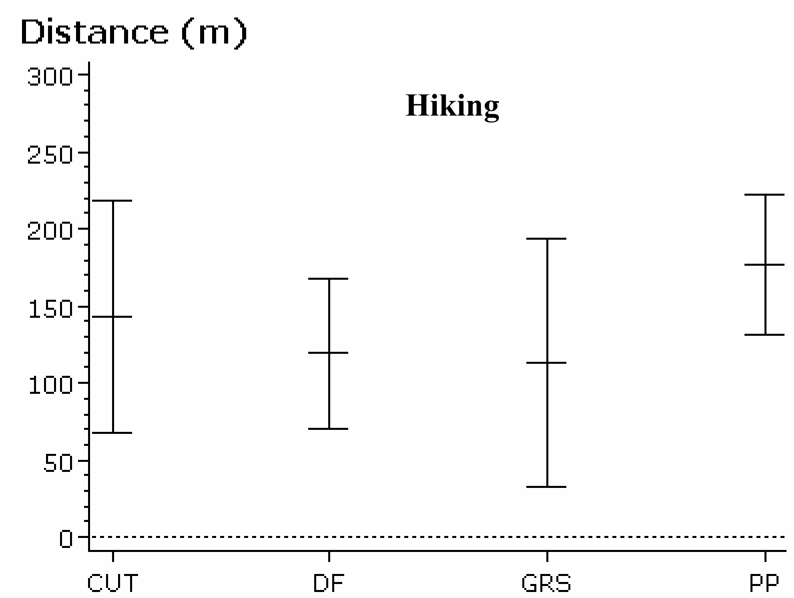

Figure 12: Mean elk flight distance (m) per habitat type from 56 observations during hiking activity.

Data collected at Starkey Experimental Forest and Range, La Grande, Oregon 2003 and 2004. DF= Douglas fir sites, GRS = grasslands, CUT = logged area with some tree re-growth, and PP = ponderosa pine sites. Error bars are 95% confidence intervals.

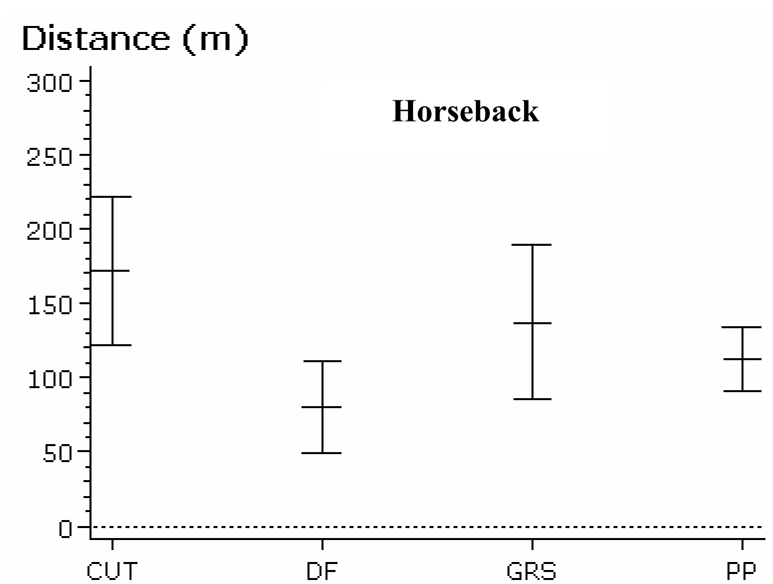

Figure 13: Mean elk flight distance (m) per habitat type from 98 observations during horseback riding activity.

Data collected at Starkey Experimental Forest and Range, La Grande, Oregon 2003 and 2004. DF= Douglas fir sites, GRS = grasslands, CUT = logged area with some tree re-growth, and PP = ponderosa pine sites. Error bars are 95% confidence intervals.

Mean flight distance of elk per disturbance was 6 to 8 times less when using visual observations compared to the telemetry based probabilistic models (Table 6). In the probabilistic model the greatest mean flight distance was for the ATV treatment, followed by mountain biking, horseback riding, and hiking. This is in contrast to the visual observations where no differences in flight distance were found.

Table 6: Comparison of mean elk flight distance (m) using visual observations and a probabilistic model based on telemetry data (one standard error in brackets).

Data are from the Northeast study area of Starkey Experimental Forest and Range, La Grande, Oregon, 2003 - 2004. Probabilistic model is from Preisler et al. (2006).

	Mean elk flight distance (m)	
Disturbance	**Visual observation**	**Probabilistic model**
ATV	136 (14.59)	1124 (67.27)
Mountain bike	120 (16.10)	1089 (63.56)
Hiking	144 (12.17)	856 (68.42)
Horseback riding	112 (9.20)	918 (62.92)

DISCUSSION

Assessment of visual observations

Hypothesis 1, stating that flight frequency and distance of elk will vary by type of recreational activity, was not supported by my results. I found no difference in flight frequency and distance among the four recreational activities. This is consistent with previous work using visual observations to assess responses of large ungulates to recreational disturbance. For example, little difference in mule deer (*Odocoileus hemionus*) flight response between hiking and mountain biking was found by Taylor and Knight (2003b). These authors estimated mean flight distance for mule deer during hiking and biking treatments to be 149 m and 118 m. Mean values of flight distance for elk in my study were similar, with hiking and mountain biking estimated flight distances of 144 m and 120 m.

It is likely that my visual estimates of flight distance are biased in part due to differences in the observer's ability to detect elk in a consistent manner among the four recreation activities. This is evident in the differences in sample sizes per treatment, with the largest number (n = 128) of visual observations acquired during horseback riding and the smallest number acquired during mountain biking (n = 35). The routes taken in this study were predominantly over rough terrain where even the old road grades were littered with large rocks. This meant that the mountain bikers in particular had to spend a great deal of time concentrating on the path and could easily have missed elk, particularly if the elk did not take flight from the disturbance but remained in cover.

Hypothesis 2, stating that mean elk flight distance differs with the habitat type occupied by the elk, was not supported, as differences in flight distance for each habitat type were not significant (p = 0.1874). Detection ability will be affected by the frequency at which elk use each habitat type (Figure 9). With habitats not used equally, either spatially (distribution across the landscape) or temporally (time of day use), it is likely that observations will be biased towards the habitats most frequently intercepted by the routes, the time of day treatments occurred, and the density of vertical hiding cover available. This is highlighted by 47% (n = 101) of all flight distance observations being recorded in ponderosa pine sites, which could be a function of elk habitat preferences at the times treatments occurred, but also would depend on the frequency at which that habitat was intercepted by the routes, or by the lack of vertical hiding cover making it easier for the observer to detect elk, and vice versa.

The highest number of detections of elk was in the East pasture during the morning. This may be a function of the higher density of elk present in that pasture or the study design. For example, the start point for ATV, mountain biking and horse back riding was from the same location, and observers spent the initial part of the route in the East pasture or close to the East/West boundary fence. Similarly, although hiking had three teams starting from two locations, observers spent the majority of their time on two of the routes in the East pasture while the third team remained solely in the West. In addition, the West route did not incorporate a portion of the Syrup Creek drainage which could have provided adequate shade and cover from disturbance.

Comparison of observations with telemetry and activity sensors

Hypothesis 3, stating that visual observations and radio telemetry will provide similar information on elk responses to recreation disturbance, was not supported by my results. Visual observations under-estimated the flight distance of elk for each recreational disturbance. The probabilistic model approach used GPS location data of the human participants and elk relocation data from an automated tracking system (ATS) to estimate distances between the two when elk displayed a flight response (Wisdom et al. 2004b), which quantified elk responses to human disturbance at a resolution well beyond previous work (Preisler et al. 2006).
By contrast, the effects of each treatment beyond the sight of the observer could not be estimated from my observational study. Whether elk responded before the observer saw them and left the vicinity of the trail, remained hidden in cover, or continued being disturbed after the observers moved on, cannot be determined from a study using visual observations alone. This could have led to an inaccurate conclusion that there were no differences in elk response to each disturbance.

Using activity sensors housed in radio-collars to classify elk activity into resting, feeding, and travel, following Naylor and Kie (2004), chapter one of this thesis highlighted the differences in the percentage of time elk spent traveling during each disturbance. Treatment differences were significant for both 2003 ($p < 0.0001$) and 2004 ($p = 0.0004$) with elk having the highest travel activity during ATV riding, followed in order by mountain biking, hiking, and horseback riding. These differences were less pronounced in 2004 than 2003 but were still evident (Figure 3). Also, differences in elk response to the four types of recreational activity were documented at Starkey for other studies. In an analysis of 10-minute relocation radio telemetry data from the 2002 stage of this study, Wisdom et al. (2004b) showed differences in elk movement rates; the highest movement rates were for ATVs followed by mountain biking, with lower rates for hiking and horseback riding. Movement rates were also higher during the mornings compared to the afternoons. These analyses provided information on elk activity at a detail far greater than that provided by visual observations.

To understand how elk respond to recreational disturbance, it is necessary to have some means of detecting elk movement and flight beyond the visual range of the observer, either by using radio telemetry or motion sensitive radio collars. Using only visual observations to estimate animal reactions to recreationists, such as estimating "area of influence", and prescribing associated buffer zones, may not be a suitable tool for management. Such methods do not allow for the possibility that animals that do not respond may go undetected and the chances of detecting those that do react are limited by vegetation, topography, and the recreational activity. Thus, guidelines for management of recreation cannot be based solely on visual observations if the environment and treatment do not allow an unbiased view of animal behavior. However, such studies are cost effective and can provide important information on wildlife behavior for species in environments where animal reactions can be observed in an unbiased manner. Managers of large herbivores, such as Rocky Mountain elk, need to consider the results of more detailed studies using radio telemetry and activity sensors to determine the effects of recreational pursuits.

THESIS SUMMARY

The presence of recreationists altered the behavior patterns of Rocky Mountain elk compared to periods of no human activity. The degree to which these patterns were altered was dependent upon the type of human activities. An increase in travel activity as a result of human disturbances was a typical response by elk. Elk displayed a general decrease in travel activity across treatment replicates and between years, and their travel time was greater during the mornings compared to the afternoons. This may indicate some habituation to the treatments or a learned avoidance of the routes after each initial morning pass. Although the time that elk spent traveling was always above that of the control periods during the ATV treatment, they did reduce the difference as the replicates and years progressed. Elk travel time during mountain biking remained consistently above the control periods, and they did not display any habituation to this treatment. A similar lack of habituation was also evident for the hiking treatment. Elk displayed the least travel time during the horseback riding and appeared to be effected very little by this activity.

Peak feeding times of elk were at dawn and dusk and were not interrupted during each human activity. Any reduced daytime feeding as a result of a disturbance was not compensated for after the disturbance ended. The energetic cost associated with an increase in the time spent traveling and the loss of feeding time could be compounded by forced shifts in habitat use to areas of poorer quality forage, but this requires further investigation.

Direct visual observations were hampered by varying topography and dense vegetation, and detection of elk was highly dependent upon the type of recreational activity. While direct observations have proven to be useful for evaluating species responses to human disturbance, and are relatively easy to implement, this method underestimated flight distances of Rocky Mountain elk in my study compared to the unbiased telemetry estimations. Differences among the treatments in elk responses were also not detected using visual observations. This was in contrast to both telemetry and motion sensor results.

These results have highlighted the limitations of using visual observations to assess elk responses to recreational disturbance. Using telemetry and motion sensors to estimate elk movement and activity patterns proved to be an effective and unbiased method of determining elk responses to human activity.

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APPENDICES

APPENDIX A

Figure A1: Position of Actiwatch activity monitors in Lotek 2000 GPS collar battery housing.

All Actiwatches were glued into place in the same orientation for the observation trials and when fitted to wild elk during 2003 and 2004 data collection at Starkey Experimental Forest and Range, La Grande, Oregon.

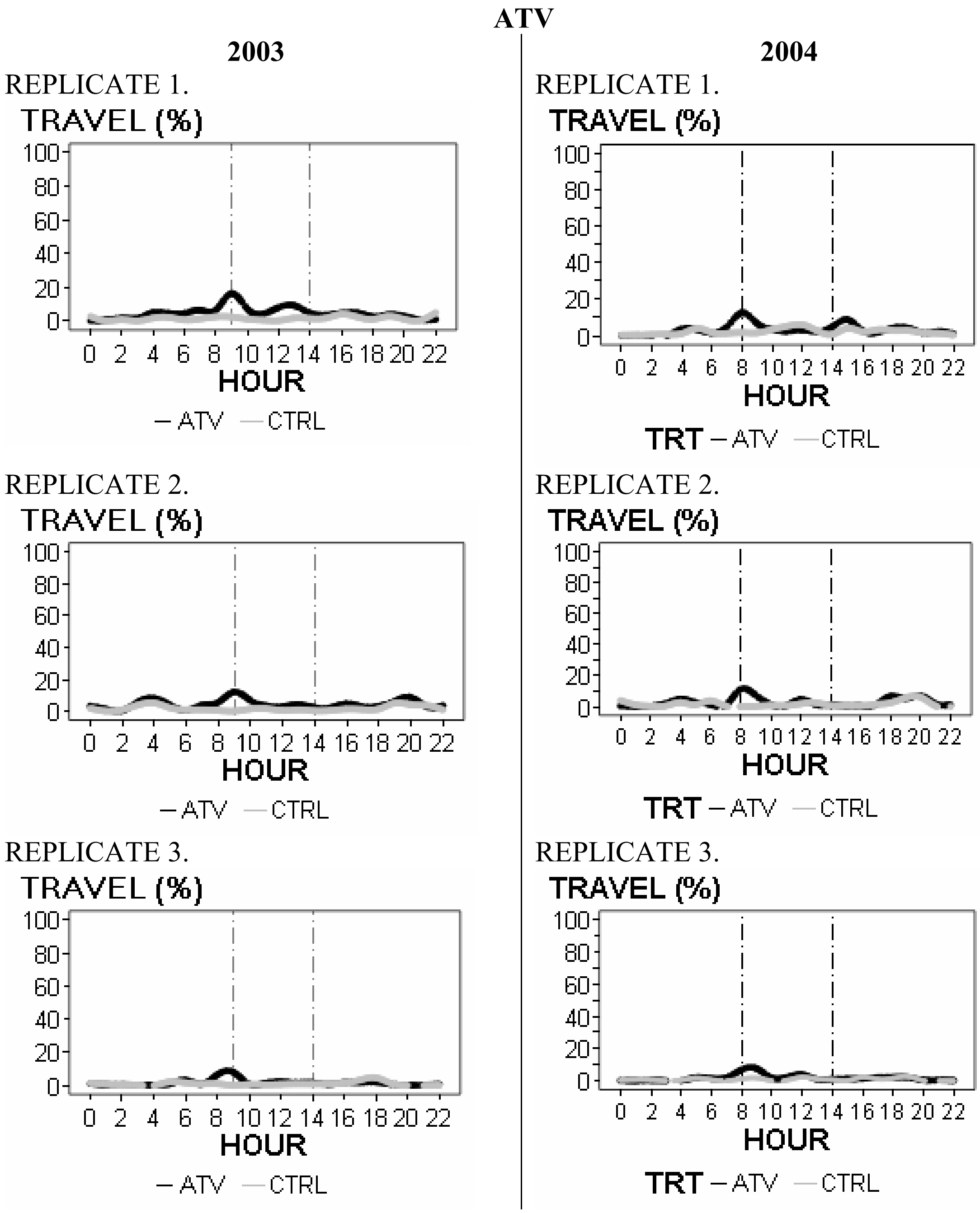


Figure A2: Percent time spent traveling by cow elk during the ATV treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 replicate 1 April 23rd to May 2nd, Replicate 2 June 18th - 27th, Replicate 3 September 10th - 19th. For 2004 dates were: Replicate 1 April 21st - 30th, Replicate 2 July 1st - 10th, Replicate 3 August 25th to September 3rd.

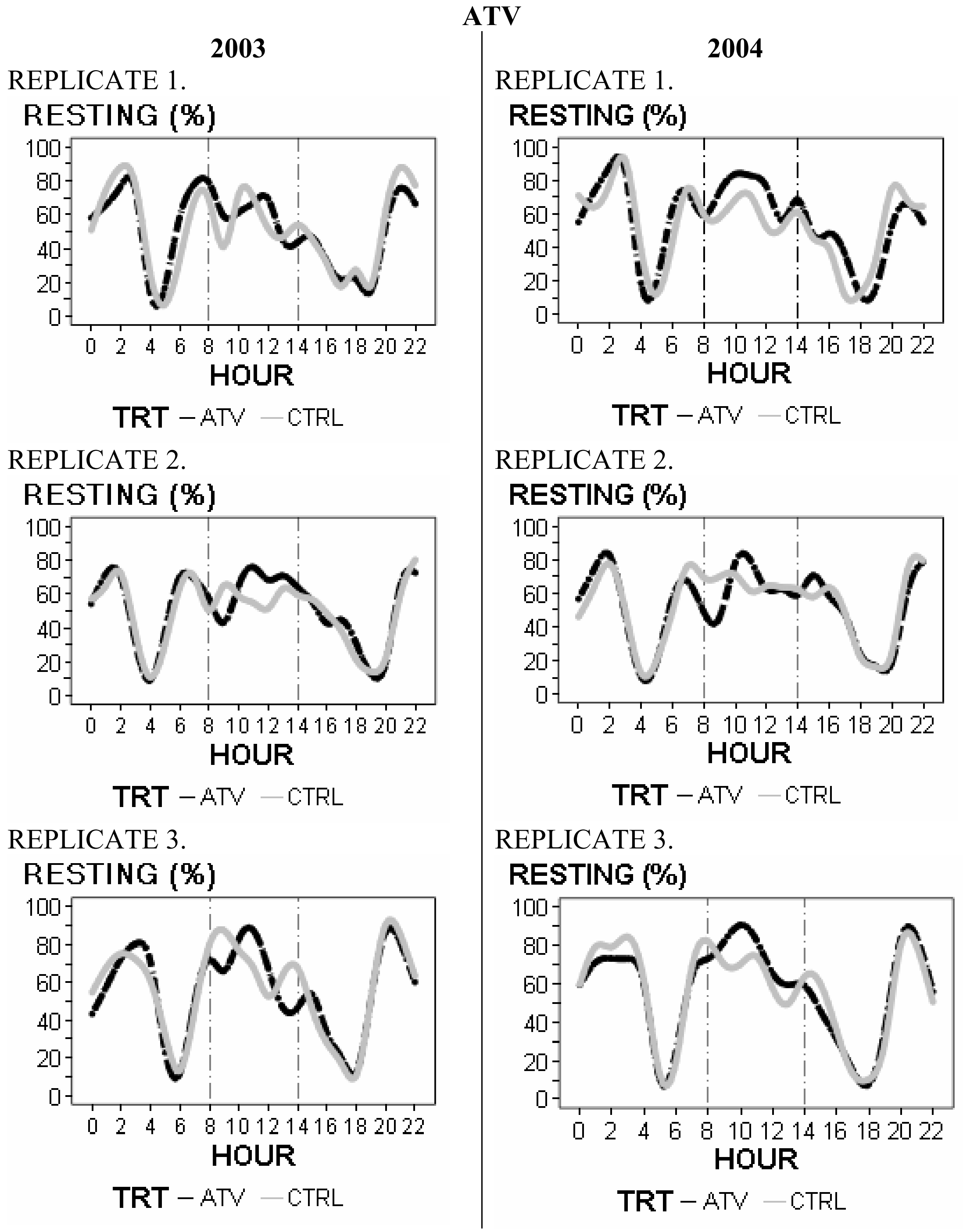


Figure A3: Percent time spent resting by cow elk during the ATV treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 Replicate 1 April 23rd to May 2nd, Replicate 2 June 18th - 27th, Replicate 3 September 10th - 19th. For 2004 dates were: Replicate 1 April 21st - 30th, Replicate 2 July 1st - 10th, Replicate 3 August 25th to September 3rd.

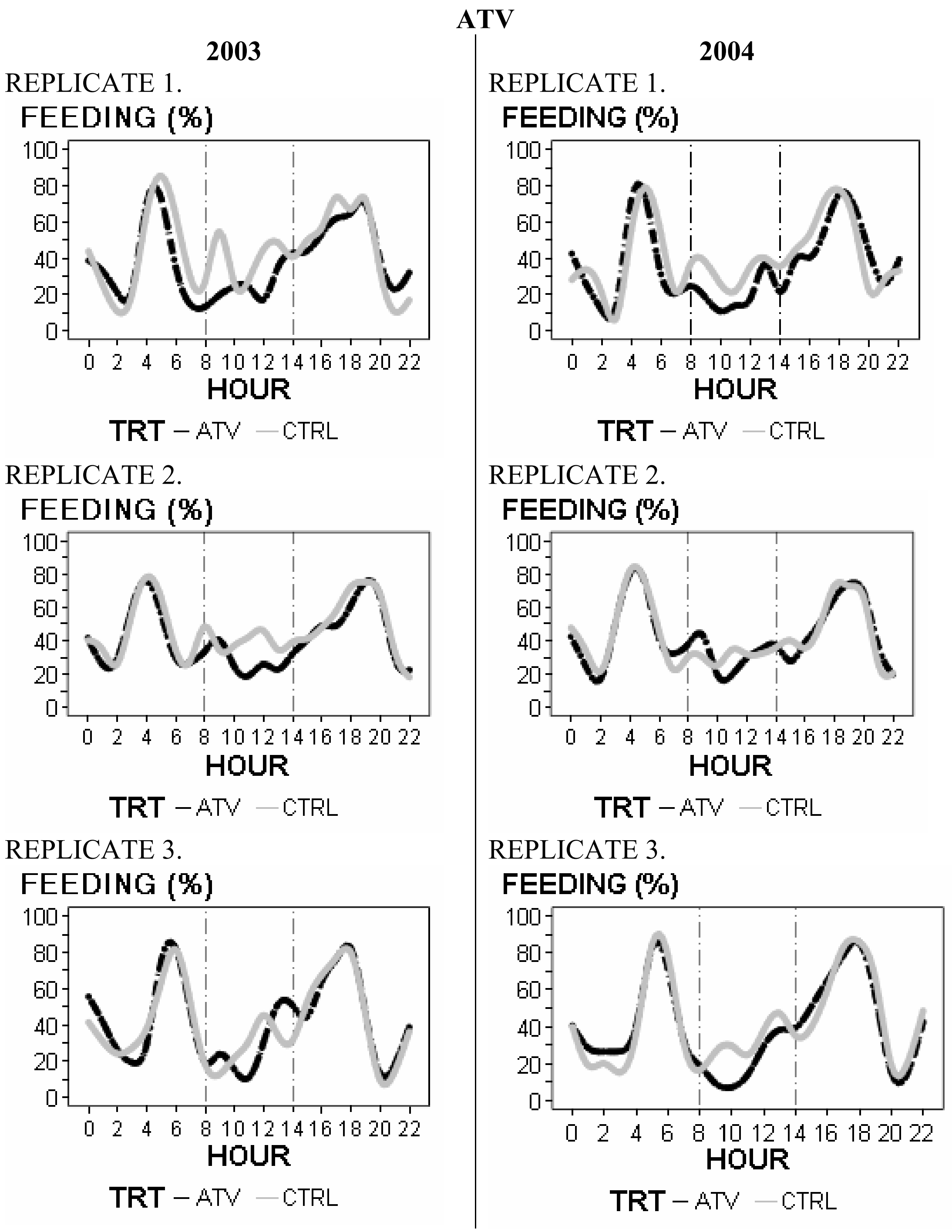


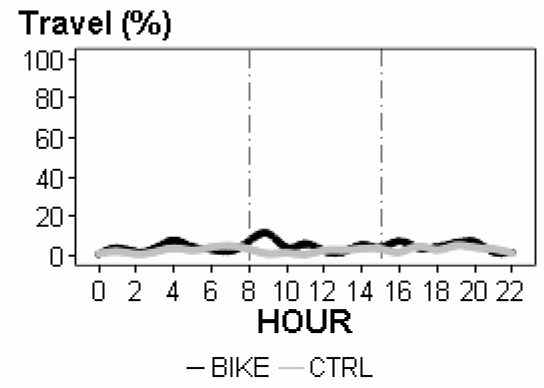
Figure A4: Percent time spent feeding by cow elk during the ATV treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 Replicate 1 April 23rd to May 2nd, Replicate 2 June 18th - 27th, Replicate 3 September 10th - 19th. For 2004 dates were: Replicate 1 April 21st - 30th, Replicate 2 July 1st - 10th, Replicate 3 August 25th to September 3rd.

BIKE

2003

REPLICATE 1.



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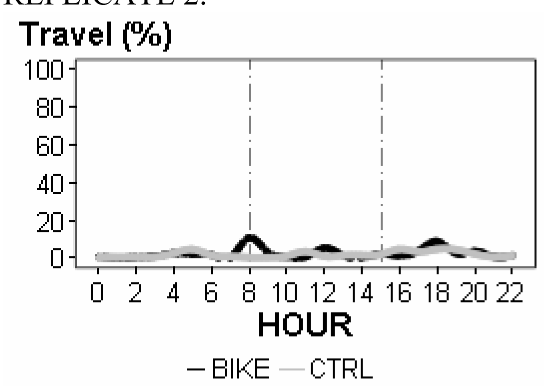

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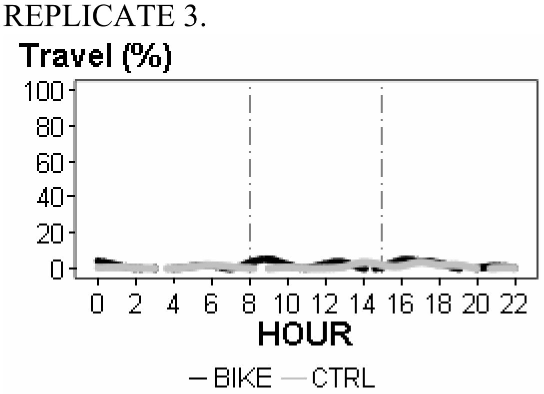

2004

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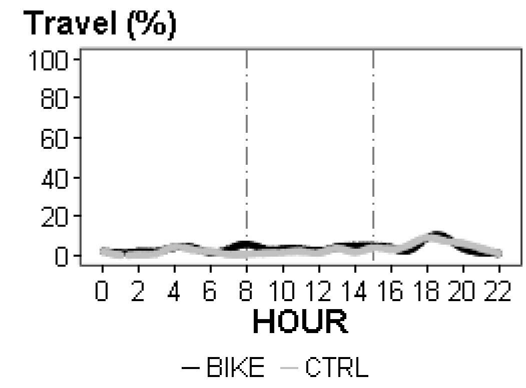

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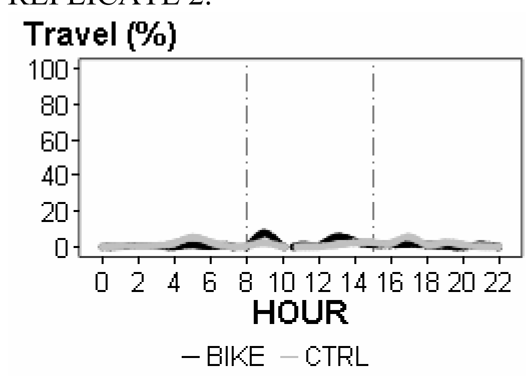

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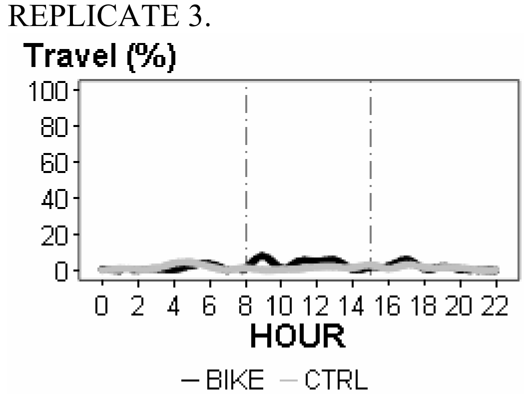


Figure A5: Percent time spent traveling by cow elk during the mountain bike treatments and controls.

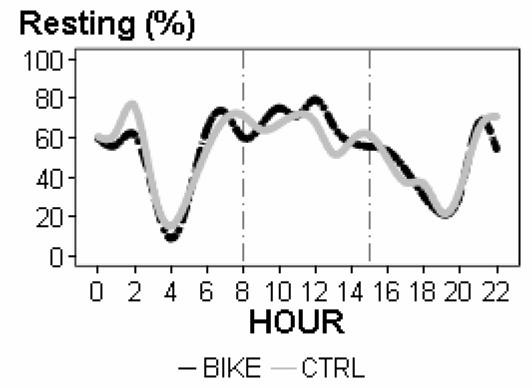
Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 June 4th – 13th, Replicate 2 July 30th to August 8th, Replicate 3 September 24th to October 3rd. For 2004 dates were: Replicate 1 May 19th – 28th, Replicate 2 September 28th to August 6th, Replicate 3 August 11th – 20th.

BIKE

2003	**2004**

2003

REPLICATE 1.



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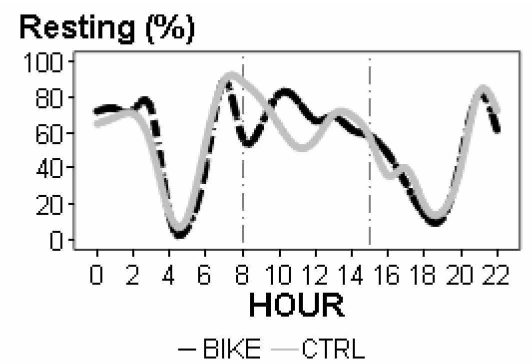

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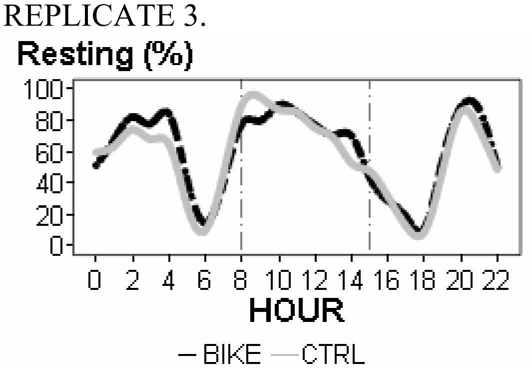

2004

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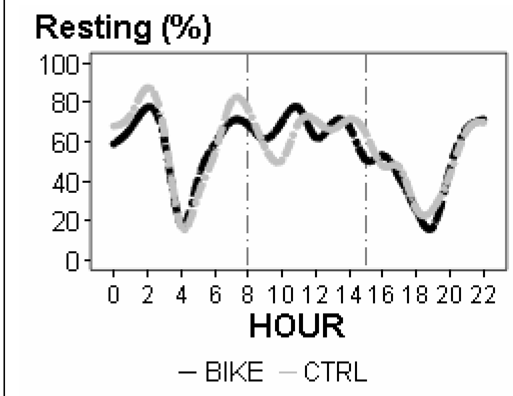

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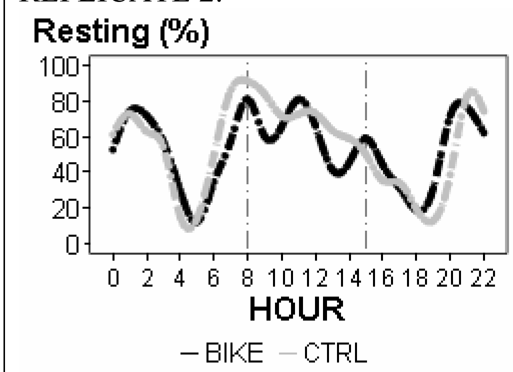

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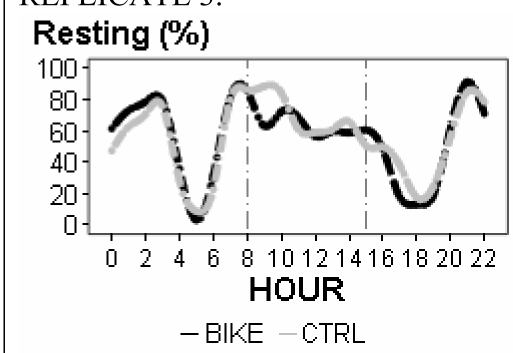

Figure A6: Percent time spent resting by cow elk during the mountain bike treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 June 4th – 13th, Replicate 2 July 30th to August 8th, Replicate 3 September 24th to October 3rd. For 2004 dates were: Replicate 1 May 19th – 28th, Replicate 2 September 28th to August 6th, Replicate 3 August 11th – 20th.

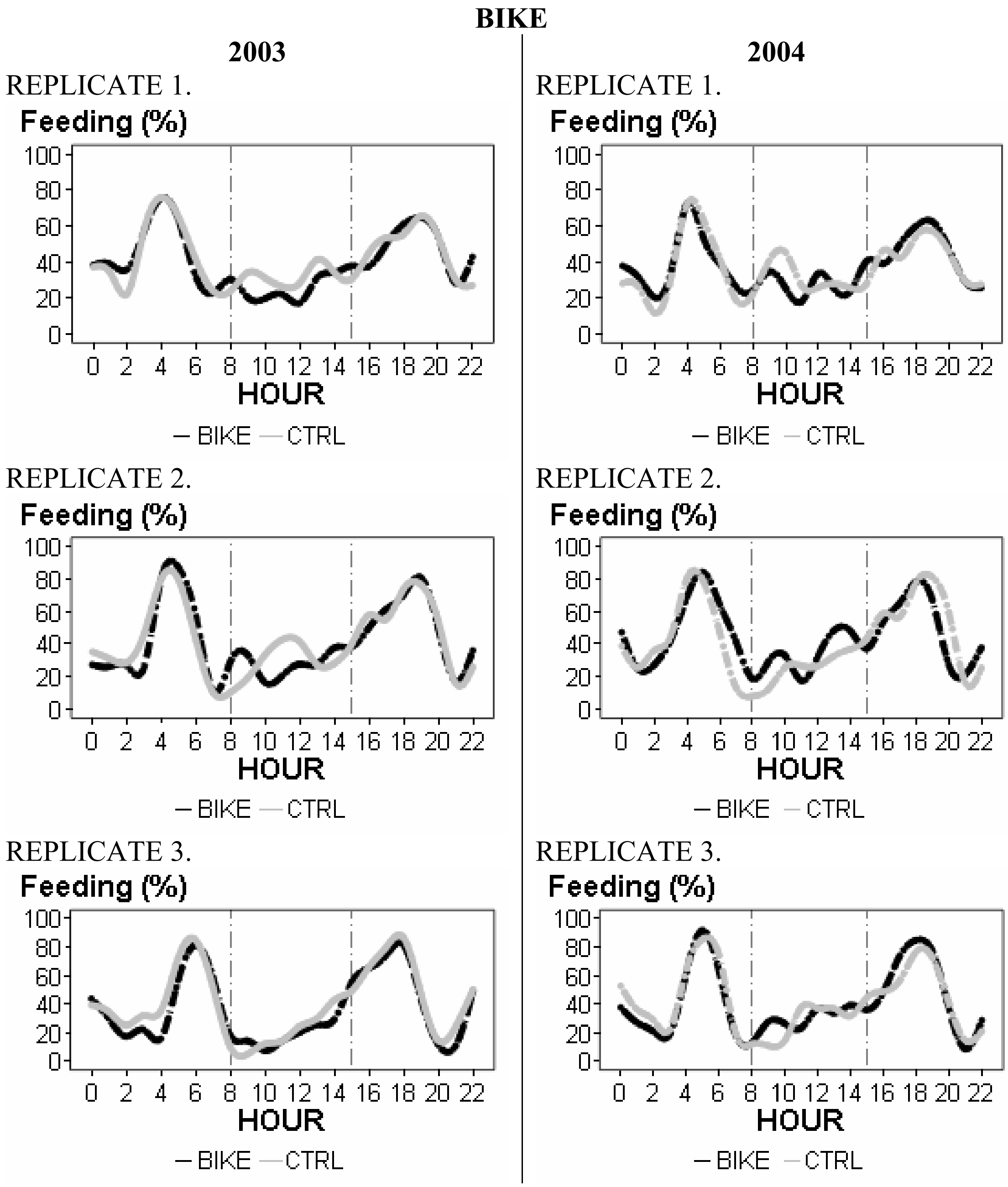

Figure A7: Percent time spent feeding by cow elk during the mountain bike treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 June 4th – 13th, Replicate 2 July 30th to August 8th, Replicate 3 September 24th to October 3rd. For 2004 dates were: Replicate 1 May 19th – 28th, Replicate 2 September 28th to August 6th, Replicate 3 August 11th – 20th.

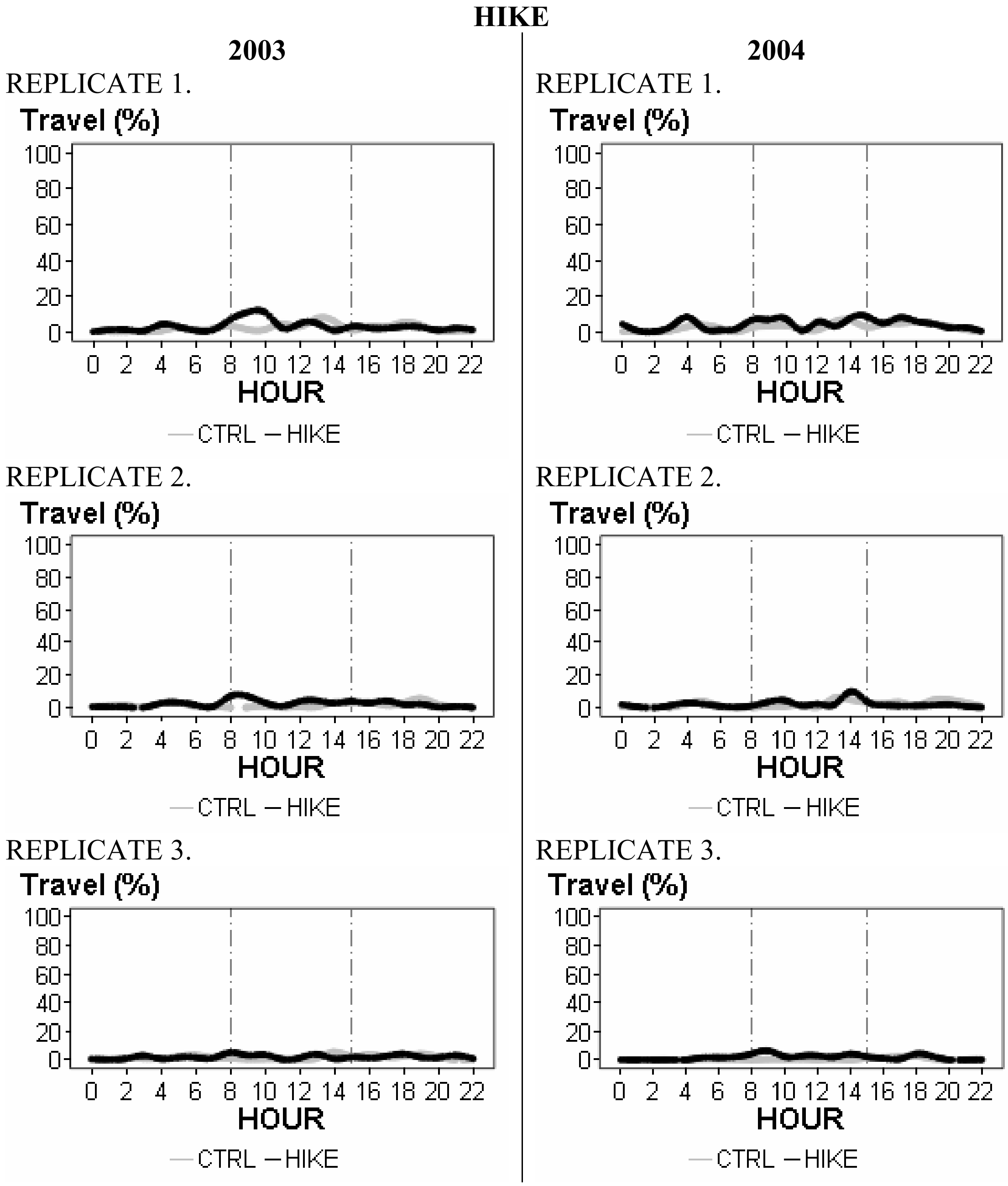

Figure A8: Percent time spent traveling by cow elk during the hiking treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 May 7th – 16th, Replicate 2 July 16th – 25th, Replicate 3 August 13th – 22nd. For 2004 dates were: Replicate 1 May 5th – 14th, Replicate 2 July 14th – 23rd, Replicate 3 September 8th – 17th.

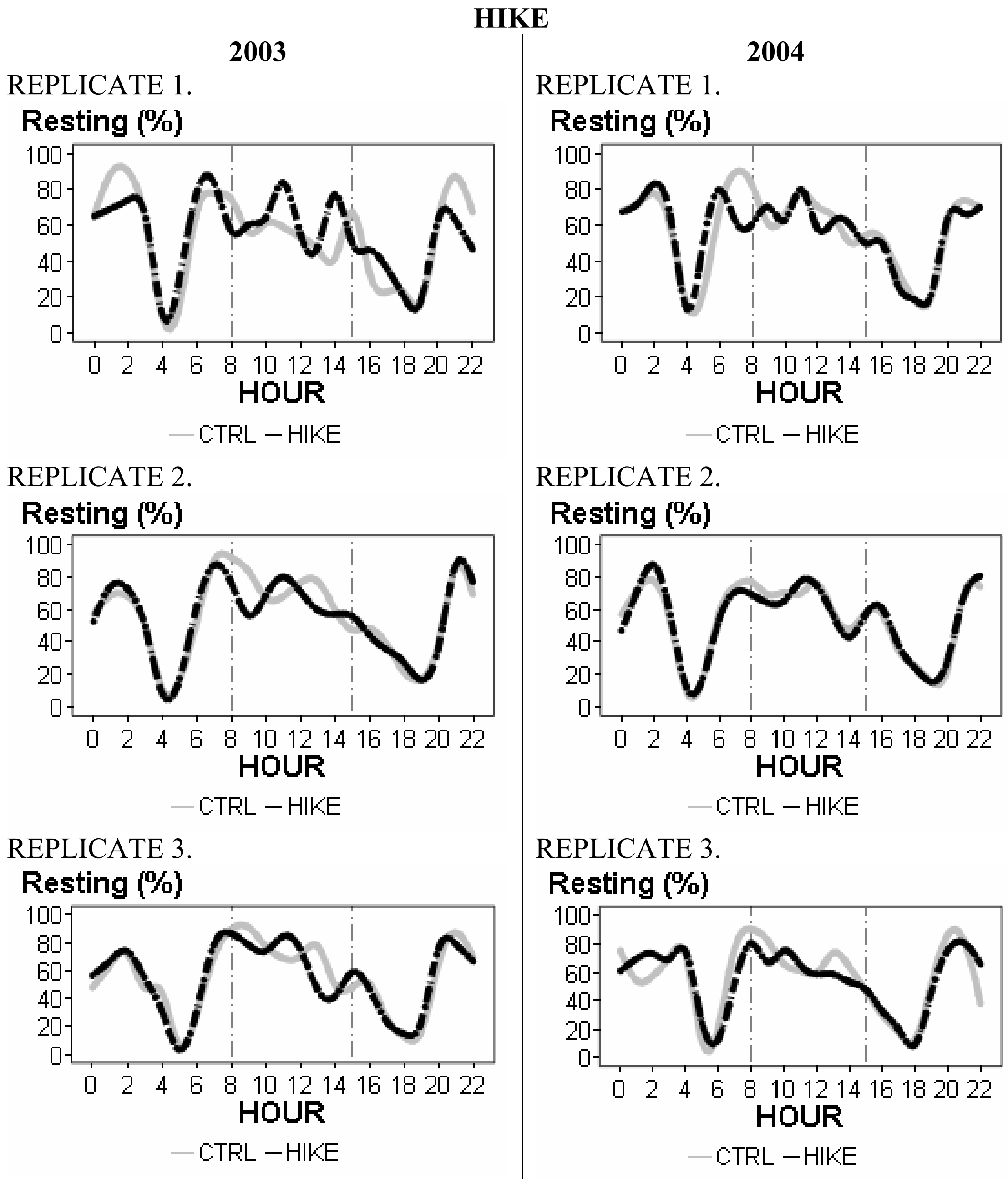

Figure A9: Percent time spent resting by cow elk during the hiking treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 May 7th – 16th, Replicate 2 July 16th – 25th, Replicate 3 August 13th – 22nd. For 2004 dates were: Replicate 1 May 5th – 14th, Replicate 2 July 14th – 23rd, Replicate 3 September 8th – 17th.

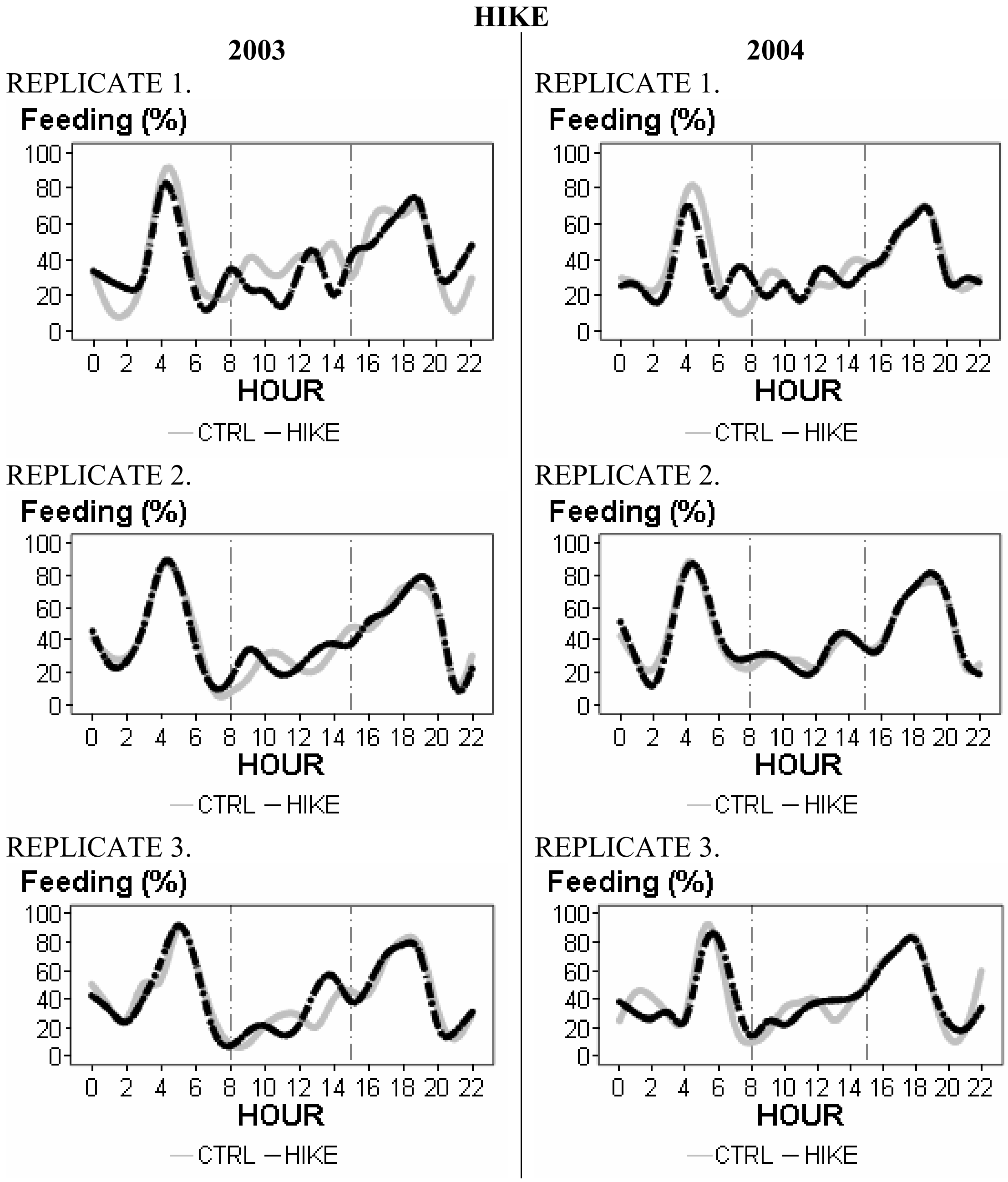

Figure A10: Percent time spent feeding by cow elk during the hiking treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 May 7th – 16th, Replicate 2 July 16th – 25th, Replicate 3 August 13th – 22nd. For 2004 dates were: Replicate 1 May 5th – 14th, Replicate 2 July 14th – 23rd, Replicate 3 September 8th – 17th.

HORSEBACK

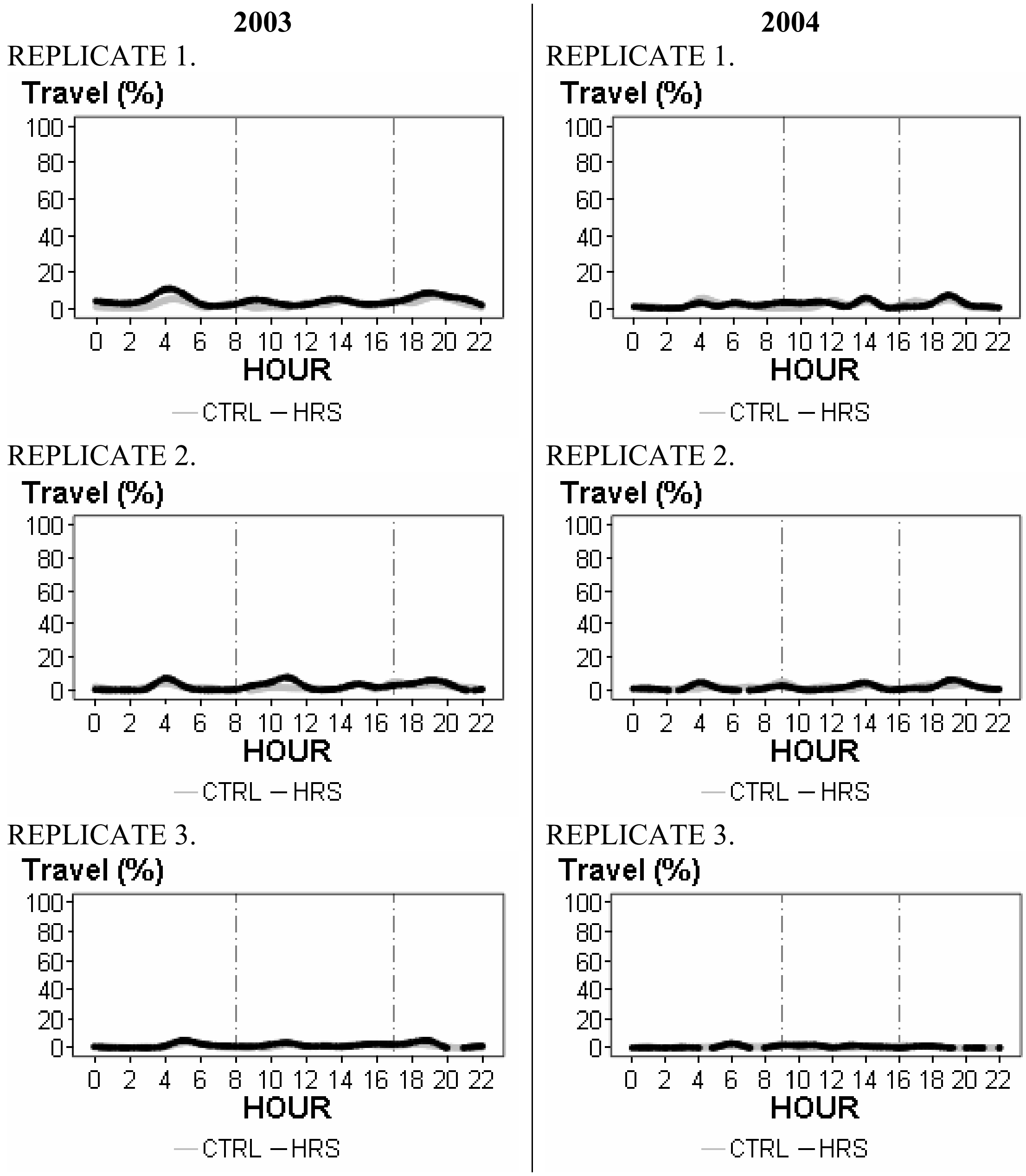

Figure A11: Percent time spent traveling by cow elk during the horseback treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 May 22nd – 31st, Replicate 2 July 2nd – 11th, Replicate 3 August 28th to September 6th. For 2004 dates were: Replicate 1 June 2nd – 11th, Replicate 2 June 16th – 25th, Replicate 3 September 22nd to October 1st.

HORSEBACK

2003

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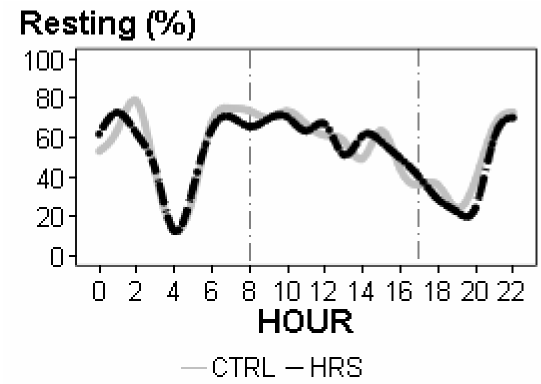

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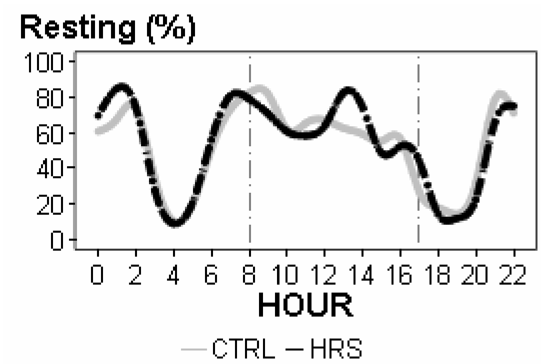

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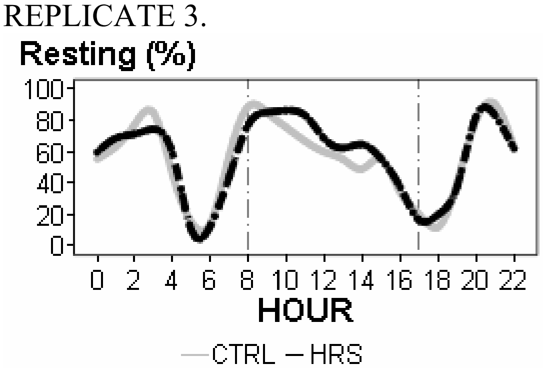
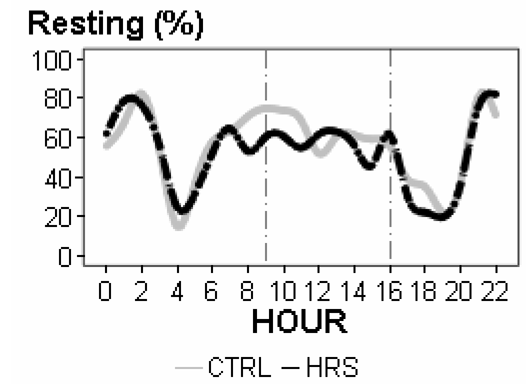


2004

REPLICATE 1.



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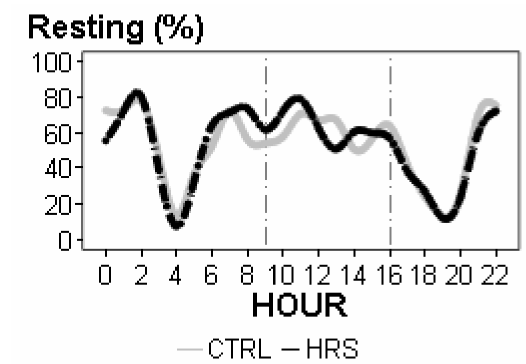

REPLICATE 3.

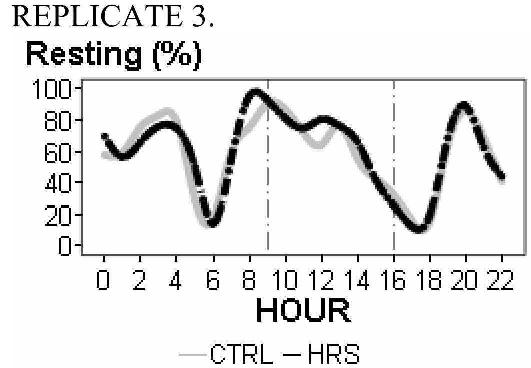

Figure A12: Percent time spent resting by cow elk during the horseback treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 May 22nd – 31st, Replicate 2 July 2nd – 11th, Replicate 3 August 28th to September 6th. For 2004 dates were: Replicate 1 June 2nd – 11th, Replicate 2 June 16th – 25th, Replicate 3 September 22nd to October 1st.

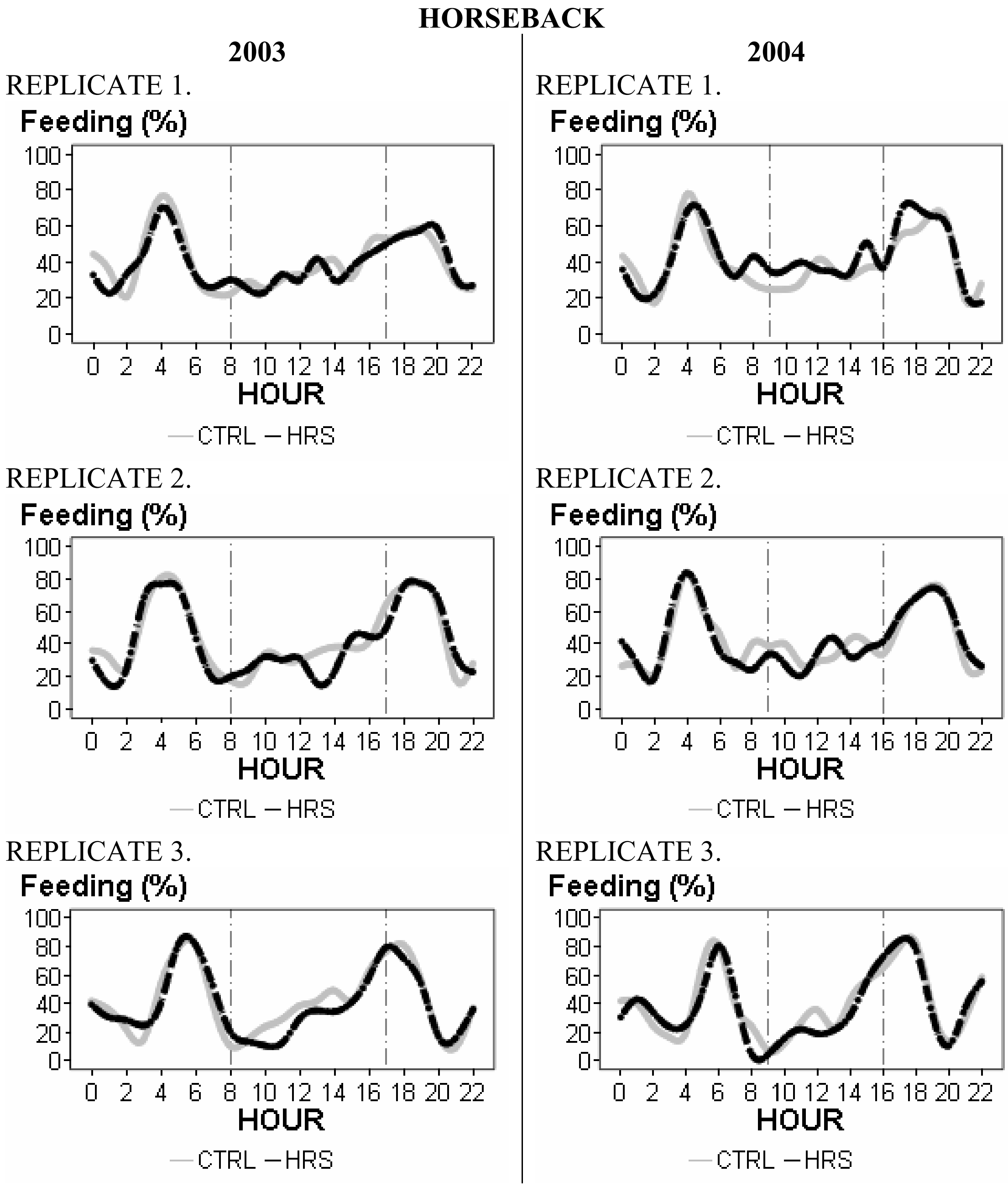

Figure A13: Percent time spent feeding by cow elk during the horseback treatments and controls.

Hours are expressed in Pacific Daylight Time. Data was from the Northeast study area of Starkey Experimental Forest and Range 2003 and 2004. Data are averages of 13 cow elk over each 5 day period of treatment and the prior control. Vertical dashed lines are the time periods within which human activities occurred. Data collection dates were: 2003 – Replicate 1 May 22nd – 31st, Replicate 2 July 2nd – 11th, Replicate 3 August 28th to September 6th. For 2004 dates were: Replicate 1 June 2nd – 11th, Replicate 2 June 16th – 25th, Replicate 3 September 22nd to October 1st.

```
         Histogram              #             Boxplot
13.5+*                          1                0
.*                              1                0
.*                              1                0
.
.*                              2                0
.***                            5                |
.***                            5                |
.***                            5                |
.******                        11                |
.******                        12                |
.*********                     18                |
.*************                 25             +-----+
 **************                27             |     |
.***************************   53             *--+--*
.**********************        43             |     |
.*****************             34             +-----+
.*************                 26                |
.********                      16                |
.********                      16                |
.**                             4                |
.**                             4                |
.*                              2                0
.
.
-10.5+*                         1                0
----+----+----+----+----+--
* may represent up to 2 counts
```

```
Normal Probability Plot
13.5+                                                  *
|                                                  *
|                                                 *
|
|                                              ** +
|                                           ***+++
|                                         **+++
|                                       **++
|                                     ***+
|                                   ***
|                                +***
|                             +****
1.5+                         ++***
|                        *****
|                     ****
|                 *****
|              ****
|           ****+
|       *****+
|     ***++
|  ****+
|**++
|+
|
-10.5+*
+----+----+----+----+----+----+----+----+----+----+
-2        -1         0         +1        +2
```

Figure A14: Probability plot of cow elk travel activity 2003, showing residuals to be normally distributed.

Data are from the Northeast study area of Starkey Experimental forest and Range, La Grande, OR.

```
         Histogram              #             Boxplot
8.5+*                           1                0
.**                             3                0
.**                             4                |
.***                            6                |
.*******                       14                |
.*******                       13                |
.****************              31                |
.******************            36             +-----+
.***********************       45             |  +  |
.***************************   54             *-----*
.***************               29             +-----+
.*****************             33                |
.*********                     18                |
.*******                       14                |
.*                              1                |
.****                           8                |
.*                              1                |
-8.5+*                          1                0
----+----+----+----+----+--
* may represent up to 2 counts


Normal Probability Plot
8.5+                                                  *
|                                                ***
|                                             ***++
|                                          ***+
|                                       ****
|                                    ***
|                                *****
|                             ****
|                         *****
|                     *****
|                  ****
|              *****
|           ****
|       *****
|     ++*
| ******
|*
-8.5+*
+----+----+----+----+----+----+----+----+----+----+
-2        -1         0        +1        +2
```

Figure A15: Probability plot of cow elk travel activity 2004, showing residuals to be normally distributed.

Data are from the Northeast study area of Starkey Experimental forest and Range, La Grande, OR.

Table A1: Duration of observation trials in minutes.

Data are for the six cow elk used to calibrate the Actiwatch™ activity monitors when housed in Lotek™ Global positioning systems (GPS) 2000 collars at Starkey Experimental Forest and Range, La Grande, Oregon, summer 2003. Data from 1073 minutes of observations were selected where only one behavior occurred during the Actiwatch record period. This reduced the total number of observations used to 868.

Trial #	Ear tag #	Duration (min) of observations used in calibration	Total time observing each elk (min)
1	26	59	
2	26	84	179
3	2	52	
4	2	63	142
5	65	101	
6	65	31	168
7	69	64	
8	69	107	225
9	32	88	
10	32	25	
11	32	104	253
12	15	90	106
Total time (min)		868	1073

Table A2: Differences in least square means of travel activity by 13 cow elk during 2003.

Data were from Starkey Experimental Forest and Range, La Grande, OR. P – values were adjusted using the Tukey Kramer method. LCI and Upper CI refer to the lower and upper 95% confidence intervals of the means. ATV = all terrain vehicle, BIKE = mountain biking, HIKE = hiking, HRS = horseback riding.

Differences of Least Squares Means Travel 2003										
Treatment	**Replicate**	**Treatment**	**Replicate**	**Mean**	**SE**	**DF**	**t Value**	**Adj P**	**L CI**	**U CI**
ATV	1	ATV	2	4.27	0.70	72	6.11	<0.0001	1.91	6.63
ATV	1	ATV	3	4.40	0.70	72	6.3	<0.0001	2.04	6.75
ATV	2	ATV	3	0.13	0.74	72	0.17	1.0000	-2.38	2.63
ATV	1	BIKE	1	4.80	0.84	72	5.7	<0.0001	1.95	7.64
ATV	1	HIKE	1	7.98	0.75	72	10.61	<0.0001	5.44	10.51
ATV	1	HRS	1	4.71	0.66	72	7.18	<0.0001	2.49	6.92
ATV	2	BIKE	2	1.45	0.57	72	2.57	0.3173	-0.46	3.36
ATV	2	HIKE	2	0.86	0.76	72	1.14	0.9915	-1.69	3.42
ATV	2	HRS	2	1.46	0.66	72	2.21	0.5466	-0.77	3.70
ATV	3	BIKE	3	0.44	0.61	72	0.72	0.9999	-1.62	2.49
ATV	3	HIKE	3	2.15	0.58	72	3.7	0.0198	0.19	4.12
ATV	3	HRS	3	3.06	0.69	72	4.41	0.0020	0.72	5.41
BIKE	1	BIKE	2	0.92	0.73	72	1.26	0.9815	-1.55	3.40
BIKE	1	BIKE	3	0.03	0.75	72	0.04	1.0000	-2.51	2.58
BIKE	2	BIKE	3	-0.89	0.34	72	-2.59	0.3071	-2.05	0.27
BIKE	1	HIKE	1	3.18	0.99	72	3.22	0.0754	-0.15	6.51
BIKE	1	HRS	1	-0.09	0.72	72	-0.13	1.0000	-2.52	2.33
BIKE	2	HIKE	2	-0.59	0.57	72	-1.04	0.9962	-2.50	1.32
BIKE	2	HRS	2	0.01	0.40	72	0.03	1.0000	-1.34	1.37
BIKE	3	HIKE	3	1.72	0.37	72	4.65	0.0008	0.47	2.96
BIKE	3	HRS	3	2.63	0.49	72	5.4	<0.0001	0.98	4.27
HIKE	1	HIKE	2	-2.84	0.86	72	-3.31	0.0595	-5.74	0.06
HIKE	1	HIKE	3	-1.43	0.71	72	-2.01	0.6834	-3.82	0.97
HIKE	2	HIKE	3	1.41	0.60	72	2.37	0.4394	-0.60	3.43
HIKE	1	HRS	1	-3.27	0.86	72	-3.82	0.0139	-6.16	-0.38
HIKE	2	HRS	2	0.60	0.63	72	0.95	0.9982	-1.52	2.72
HIKE	3	HRS	3	0.91	0.45	72	2.01	0.6822	-0.62	2.43
HRS	1	HRS	2	1.03	0.57	72	1.79	0.8175	-0.91	2.96
HRS	1	HRS	3	2.75	0.61	72	4.51	0.0014	0.69	4.81
HRS	2	HRS	3	1.72	0.53	72	3.25	0.0700	-0.07	3.52

Table A3: Differences in least square means of resting activity by 13 cow elk during 2003.

Data were from Starkey Experimental Forest and Range, La Grande, OR. P – values were adjusted using the Tukey Kramer method. LCI and UCI refer to the lower and upper 95% confidence intervals of the means. ATV = all terrain vehicle, BIKE = mountain biking, HIKE = hiking, HRS = horseback riding.

Differences of Least Squares Means Resting 2003										
Treatment	**Replicate**	**Treatment**	**Replicate**	**Mean**	**SE**	**DF**	**t Value**	**P-value**	**LCI**	**UCI**
ATV	1	ATV	2	0.00	2.80	72	0.00	1.0000	-9.47	9.47
ATV	1	ATV	3	7.46	2.86	72	2.61	0.2918	-2.18	17.11
ATV	2	ATV	3	7.46	3.56	72	2.10	0.6265	-4.56	19.49
ATV	1	BIKE	1	7.48	2.80	72	2.67	0.2627	-1.98	16.94
ATV	1	HIKE	1	-0.73	1.27	72	-0.57	1.0000	-5.02	3.57
ATV	1	HRS	1	6.50	1.88	72	3.46	0.0394	0.16	12.83
ATV	2	BIKE	2	11.00	2.78	72	3.95	0.0090	1.60	20.39
ATV	2	HIKE	2	12.65	2.63	72	4.81	0.0005	3.76	21.53
ATV	2	HRS	2	6.58	2.64	72	2.50	0.3576	-2.32	15.48
ATV	3	BIKE	3	2.16	2.74	72	0.79	0.9997	-7.08	11.41
ATV	3	HIKE	3	3.21	2.68	72	1.20	0.9875	-5.84	12.25
ATV	3	HRS	3	-5.02	2.81	72	-1.79	0.8198	-14.52	4.47
BIKE	1	BIKE	2	3.52	2.77	72	1.27	0.9806	-5.85	12.89
BIKE	1	BIKE	3	2.15	2.77	72	0.78	0.9997	-7.20	11.49
BIKE	2	BIKE	3	-1.37	1.75	72	-0.78	0.9997	-7.28	4.54
BIKE	1	HIKE	1	-8.21	2.65	72	-3.09	0.1041	-17.17	0.76
BIKE	1	HRS	1	-0.98	3.15	72	-0.31	1.0000	-11.62	9.66
BIKE	2	HIKE	2	1.65	1.51	72	1.09	0.9940	-3.44	6.73
BIKE	2	HRS	2	-4.41	1.49	72	-2.97	0.1392	-9.43	0.61
BIKE	3	HIKE	3	1.04	1.47	72	0.71	0.9999	-3.91	6.00
BIKE	3	HRS	3	-7.19	1.49	72	-4.82	0.0005	-12.22	-2.15
HIKE	1	HIKE	2	13.37	1.24	72	10.76	<0.0001	9.18	17.57
HIKE	1	HIKE	3	11.40	1.21	72	9.44	<0.0001	7.32	15.48
HIKE	2	HIKE	3	-1.97	1.17	72	-1.69	0.8671	-5.92	1.97
HIKE	1	HRS	1	7.23	1.61	72	4.49	0.0015	1.78	12.67
HIKE	2	HRS	2	-6.06	1.13	72	-5.38	<0.0001	-9.87	-2.26
HIKE	3	HRS	3	-8.23	1.11	72	-7.41	<0.0001	-11.98	-4.48
HRS	1	HRS	2	0.08	1.61	72	0.05	1.0000	-5.36	5.53
HRS	1	HRS	3	-4.06	1.62	72	-2.51	0.3537	-9.53	1.41
HRS	2	HRS	3	-4.14	1.16	72	-3.58	0.0287	-8.05	-0.23

Table A4: Differences in least square means of feeding activity by 13 cow elk during 2003.

Data were from Starkey Experimental Forest and Range, La Grande, OR. P – values were adjusted using the Tukey Kramer method. LCI and UCI refer to the lower and upper 95% confidence intervals of the means. ATV = all terrain vehicle, BIKE = mountain biking, HIKE = hiking, HRS = horseback riding.

Differences of Least Squares Means Feeding 2003										
Treatment	**Replicate**	**Treatment**	**Replicate**	**Mean**	**SE**	**DF**	**t value**	**P-value**	**LCI**	**UCI**
ATV	1	ATV	2	-6.80	2.57	72	-2.64	0.2758	-15.50	1.89
ATV	1	ATV	3	-13.58	2.68	72	-5.06	0.0002	-22.65	-4.52
ATV	2	ATV	3	-6.78	3.21	72	-2.11	0.6172	-17.63	4.07
ATV	1	BIKE	1	-11.72	2.62	72	-4.48	0.0015	-20.55	-2.88
ATV	1	HIKE	1	-5.75	1.38	72	-4.17	0.0044	-10.41	-1.10
ATV	1	HRS	1	-17.43	1.83	72	-9.51	<0.0001	-23.62	-11.24
ATV	2	BIKE	2	-11.15	2.50	72	-4.46	0.0017	-19.59	-2.71
ATV	2	HIKE	2	-11.54	2.48	72	-4.66	0.0008	-19.91	-3.18
ATV	2	HRS	2	-7.15	2.29	72	-3.13	0.0959	-14.87	0.57
ATV	3	BIKE	3	-4.37	2.55	72	-1.71	0.8572	-12.98	4.25
ATV	3	HIKE	3	-5.22	2.48	72	-2.11	0.6208	-13.61	3.16
ATV	3	HRS	3	1.84	2.57	72	0.72	0.9999	-6.85	10.54
BIKE	1	BIKE	2	-6.23	2.54	72	-2.46	0.3843	-14.81	2.34
BIKE	1	BIKE	3	-6.23	2.56	72	-2.43	0.4008	-14.89	2.43
BIKE	2	BIKE	3	0.01	1.70	72	0.00	1.0000	-5.74	5.75
BIKE	1	HIKE	1	5.97	2.36	72	2.53	0.3408	-2.01	13.94
BIKE	1	HRS	1	-5.71	2.96	72	-1.93	0.7394	-15.72	4.30
BIKE	2	HIKE	2	-0.39	1.68	72	-0.23	1.0000	-6.08	5.29
BIKE	2	HRS	2	4.00	1.37	72	2.91	0.1581	-0.64	8.64
BIKE	3	HIKE	3	-0.86	1.49	72	-0.58	1.0000	-5.89	4.17
BIKE	3	HRS	3	6.21	1.49	72	4.18	0.0043	1.19	11.22
HIKE	1	HIKE	2	-12.59	1.31	72	-9.61	<0.0001	-17.02	-8.17
HIKE	1	HIKE	3	-13.05	1.07	72	-12.24	<.0001	-16.66	-9.45
HIKE	2	HIKE	3	-0.46	1.41	72	-0.33	1.0000	-5.23	4.31
HIKE	1	HRS	1	-11.68	1.40	72	-8.36	<0.0001	-16.39	-6.96
HIKE	2	HRS	2	4.39	1.28	72	3.42	0.0446	0.05	8.73
HIKE	3	HRS	3	7.07	1.18	72	6.01	<0.0001	3.09	11.04
HRS	1	HRS	2	3.47	1.47	72	2.37	0.4392	-1.48	8.43
HRS	1	HRS	3	5.69	1.52	72	3.73	0.0180	0.54	10.84
HRS	2	HRS	3	2.21	1.08	72	2.05	0.6588	-1.43	5.86

Table A5: Differences in least square means of travel activity by 13 cow elk during 2004.

Data were from Starkey Experimental Forest and Range, La Grande, OR. P – values were adjusted using the Tukey Kramer method. LCI and UCI refer to the lower and upper 95% confidence intervals of the means. ATV = all terrain vehicle, BIKE = mountain biking, HIKE = hiking, HRS = horseback riding.

Differences of Least Squares Means Travel 2004										
Treatment	**Replicate**	**Treatment**	**Replicate**	**Mean**	**SE**	**DF**	**t Value**	**P-value**	**LCI**	**UCI**
ATV	1	ATV	2	-1.84	0.81	72	-2.28	0.4998	-4.58	0.89
ATV	1	ATV	3	-1.32	0.81	72	-1.63	0.8903	-4.06	1.41
ATV	2	ATV	3	0.52	0.81	72	0.64	1.0000	-2.21	3.26
ATV	1	BIKE	1	-0.88	0.80	72	-1.1	0.9938	-3.57	1.82
ATV	1	HIKE	1	-1.05	0.75	72	-1.39	0.9616	-3.59	1.49
ATV	1	HRS	1	-0.12	0.78	72	-0.15	1.0000	-2.75	2.51
ATV	2	BIKE	2	0.70	0.80	72	0.88	0.9991	-1.99	3.40
ATV	2	HIKE	2	1.57	0.75	72	2.09	0.6303	-0.97	4.12
ATV	2	HRS	2	3.27	0.75	72	4.35	0.0024	0.73	5.81
ATV	3	BIKE	3	-0.89	0.75	72	-1.19	0.9882	-3.43	1.64
ATV	3	HIKE	3	-0.44	0.75	72	-0.58	1.0000	-2.98	2.11
ATV	3	HRS	3	1.77	0.80	72	2.21	0.5457	-0.93	4.46
BIKE	1	BIKE	2	-0.26	0.81	72	-0.32	1.0000	-2.99	2.47
BIKE	1	BIKE	3	-1.34	0.81	72	-1.66	0.8812	-4.07	1.39
BIKE	2	BIKE	3	-1.08	0.78	72	-1.38	0.9632	-3.71	1.55
BIKE	1	HIKE	1	-0.17	0.75	72	-0.22	1.0000	-2.71	2.37
BIKE	1	HRS	1	0.76	0.75	72	1.01	0.9970	-1.78	3.30
BIKE	2	HIKE	2	0.87	0.75	72	1.16	0.9905	-1.67	3.41
BIKE	2	HRS	2	2.57	0.78	72	3.3	0.0613	-0.06	5.19
BIKE	2	HRS	3	1.58	0.81	72	1.97	0.7137	-1.14	4.30
BIKE	3	HIKE	3	0.46	0.80	72	0.57	1.0000	-2.24	3.15
BIKE	3	HRS	3	2.66	0.78	72	3.42	0.0449	0.03	5.29
HIKE	1	HIKE	2	0.78	0.81	72	0.96	0.9981	-1.96	3.51
HIKE	1	HIKE	3	-0.71	0.81	72	-0.88	0.9991	-3.45	2.02
HIKE	2	HIKE	3	-1.49	0.81	72	-1.84	0.7899	-4.23	1.24
HIKE	1	HRS	1	0.93	0.80	72	1.16	0.9901	-1.76	3.62
HIKE	2	HRS	2	1.70	0.80	72	2.13	0.6042	-1.00	4.39
HIKE	3	HRS	3	2.20	0.75	72	2.93	0.1523	-0.34	4.75
HRS	1	HRS	2	1.55	0.78	72	1.99	0.7008	-1.08	4.18
HRS	1	HRS	3	0.56	0.81	72	0.7	0.9999	-2.16	3.29
HRS	2	HRS	3	-0.98	0.81	72	-1.22	0.9857	-3.71	1.74

Table A6: Differences in least square means of resting activity by 13 cow elk during 2004.

Data were from Starkey Experimental Forest and Range, La Grande, OR. P – values were adjusted using the Tukey Kramer method. LCI and UCI refer to the lower and upper 95% confidence intervals of the means. ATV = all terrain vehicle, BIKE = mountain biking, HIKE = hiking, HRS = horseback riding.

Differences of Least Squares Means Resting 2004										
Treatment	Replicate	Treatment	Replicate	Mean	SE	DF	t Value	P-value	LCI	UCI
ATV	1	ATV	2	19.48	3.17	72	6.14	<0.0001	8.77	30.19
ATV	1	ATV	3	7.57	3.17	72	2.39	0.0195	-3.13	18.28
ATV	2	ATV	3	-11.91	3.17	72	-3.75	0.0004	-22.62	-1.19
ATV	1	BIKE	1	13.76	3.13	72	4.4	<0.0001	3.19	24.34
ATV	1	HIKE	1	15.44	3.37	72	4.58	<0.0001	4.06	26.82
ATV	1	HRS	1	21.82	3.27	72	6.68	<0.0001	10.78	32.86
ATV	2	BIKE	2	4.67	3.13	72	1.49	0.1396	-5.89	15.23
ATV	2	HIKE	2	-3.51	3.37	72	-1.04	0.3021	-14.90	7.89
ATV	2	HRS	2	-8.69	3.37	72	-2.58	0.0118	-20.06	2.68
ATV	3	BIKE	3	13.32	3.37	72	3.96	0.0002	1.95	24.68
ATV	3	HIKE	3	10.24	3.37	72	3.04	0.0033	-1.15	21.64
ATV	3	HRS	3	1.48	3.13	72	0.47	0.6378	-9.09	12.05
BIKE	1	BIKE	2	10.39	3.17	72	3.28	0.0016	-0.31	21.09
BIKE	1	BIKE	3	7.12	3.17	72	2.25	0.0275	-3.57	17.82
BIKE	2	BIKE	3	-3.26	3.26	72	-1	0.3205	-14.28	7.75
BIKE	1	HIKE	1	1.68	3.37	72	0.5	0.6207	-9.72	13.07
BIKE	1	HRS	1	8.06	3.37	72	2.39	0.0193	-3.31	19.42
BIKE	2	HIKE	2	-8.18	3.37	72	-2.43	0.0176	-19.55	3.19
BIKE	2	HRS	2	-13.36	3.26	72	-4.09	0.0001	-24.39	-2.34
BIKE	3	HIKE	3	-3.07	3.13	72	-0.98	0.3292	-13.63	7.49
BIKE	3	HRS	3	-11.84	3.27	72	-3.62	0.0005	-22.87	-0.80
HIKE	1	HIKE	2	0.53	3.17	72	0.17	0.8669	-10.19	11.25
HIKE	1	HIKE	3	2.38	3.17	72	0.75	0.4564	-8.34	13.10
HIKE	2	HIKE	3	1.84	3.17	72	0.58	0.5632	-8.88	12.56
HIKE	1	HRS	1	6.38	3.13	72	2.04	0.045	-4.18	16.94
HIKE	1	HRS	2	-4.65	3.17	72	-1.47	0.1465	-15.36	6.05
HIKE	2	HRS	2	-5.19	3.13	72	-1.66	0.1016	-15.75	5.38
HIKE	3	HRS	3	-8.76	3.37	72	-2.6	0.0113	-20.15	2.62
HRS	1	HRS	2	-11.03	3.26	72	-3.38	0.0012	-22.05	-0.02
HRS	1	HRS	3	-12.77	3.16	72	-4.04	0.0001	-23.45	-2.08
HRS	2	HRS	3	-1.74	3.16	72	-0.55	0.585	-12.42	8.95

Table A7: Differences in least square means of feeding activity by 13 cow elk during 2004.

Data were from Starkey Experimental Forest and Range, La Grande, OR. P – values were adjusted using the Tukey Kramer method. LCI and UCI refer to the lower and upper 95% confidence intervals of the means. ATV = all terrain vehicle, BIKE = mountain biking, HIKE = hiking, HRS = horseback riding.

Differences of Least Squares Means Feeding 2004										
Treatment	**Replicate**	**Treatment**	**Replicate**	**Mean**	**SE**	**DF**	**t value**	**P-value**	**LCI**	**UCI**
ATV	1	ATV	2	-16.13	2.66	72	-6.06	<0.0001	-25.12	-7.14
ATV	1	ATV	3	-5.32	2.66	72	-2.00	0.6913	-14.30	3.66
ATV	2	ATV	3	10.81	2.66	72	4.06	0.0064	1.82	19.81
ATV	1	BIKE	1	-11.62	2.59	72	-4.49	0.0015	-20.36	-2.88
ATV	1	HIKE	1	-13.54	2.90	72	-4.67	0.0008	-23.34	-3.75
ATV	1	HRS	1	-20.34	2.78	72	-7.32	<0.0001	-29.72	-10.95
ATV	2	BIKE	2	-5.25	2.58	72	-2.03	0.6686	-13.98	3.47
ATV	2	HIKE	2	2.02	2.91	72	0.70	0.9999	-7.79	11.84
ATV	2	HRS	2	5.12	2.89	72	1.77	0.8285	-4.65	14.89
ATV	3	BIKE	3	-11.57	2.89	72	-4.00	0.0078	-21.34	-1.80
ATV	3	HIKE	3	-9.12	2.91	72	-3.14	0.0938	-18.93	0.70
ATV	3	HRS	3	-2.81	2.59	72	-1.08	0.9945	-11.55	5.94
BIKE	1	BIKE	2	-9.77	2.65	72	-3.68	0.0212	-18.73	-0.80
BIKE	1	BIKE	3	-5.27	2.65	72	-1.99	0.6997	-14.23	3.69
BIKE	2	BIKE	3	4.49	2.76	72	1.63	0.8936	-4.84	13.83
BIKE	1	HIKE	1	-1.92	2.91	72	-0.66	0.9999	-11.74	7.90
BIKE	1	HRS	1	-8.72	2.89	72	-3.01	0.1259	-18.49	1.05
BIKE	2	HIKE	2	7.28	2.89	72	2.52	0.3467	-2.49	17.05
BIKE	2	HRS	2	10.37	2.77	72	3.74	0.0174	1.01	19.73
BIKE	3	HIKE	3	2.46	2.58	72	0.95	0.9982	-6.26	11.18
BIKE	3	HRS	3	8.77	2.78	72	3.16	0.0891	-0.61	18.15
HIKE	1	HIKE	2	-0.57	2.66	72	-0.21	1.0000	-9.57	8.43
HIKE	1	HIKE	3	-0.89	2.66	72	-0.34	1.0000	-9.89	8.11
HIKE	2	HIKE	3	-0.33	2.66	72	-0.12	1.0000	-9.32	8.67
HIKE	1	HRS	1	-6.80	2.58	72	-2.63	0.2821	-15.52	1.93
HIKE	2	HRS	2	3.09	2.58	72	1.20	0.9875	-5.63	11.82
HIKE	3	HRS	3	6.31	2.90	72	2.18	0.5718	-3.48	16.10
HRS	1	HRS	2	9.32	2.76	72	3.37	0.0505	-0.01	18.66
HRS	1	HRS	3	12.21	2.65	72	4.61	0.0010	3.27	21.15
HRS	2	HRS	3	2.89	2.65	72	1.09	0.9942	-6.06	11.83

Table A8: Mean and 95% confidence intervals of travel activity difference (in percent) for 13 cow elk during 2003 (top half of table) and 2004.

Data were for each treatment and replicate at Starkey Experimental Forest and Range, Oregon. ATV = all terrain vehicle, BIKE = mountain bike, HIKE = hiking, HRS = horseback riding. Activity difference was calculated as the weekly percent time elk spent traveling during the treatment minus the weekly percent time spent traveling during the control at the times treatments occurred. Positive difference indicates more time spent traveling, while a negative difference indicates less time traveling.

Replicate	Treatment	Year	Travel Activity Mean Difference	Lower CI	Upper CI
1	ATV	2003	7.27	6.36	8.19
1	BIKE	2003	2.48	1.08	3.88
1	HIKE	2003	-0.70	-2.03	0.62
1	HRS	2003	2.57	1.66	3.48
2	ATV	2003	3.01	1.96	4.05
2	BIKE	2003	1.55	1.14	1.97
2	HIKE	2003	2.14	1.06	3.22
2	HRS	2003	1.54	0.86	2.23
3	ATV	2003	2.88	1.83	3.92
3	BIKE	2003	2.44	1.90	2.99
3	HIKE	2003	0.73	0.24	1.22
3	HRS	2003	-0.18	-0.99	0.62
1	ATV	2004	0.99	-0.14	2.13
1	BIKE	2004	1.86	0.72	3.01
1	HIKE	2004	2.03	0.89	3.18
1	HRS	2004	1.11	-0.025	2.24
2	ATV	2004	2.83	1.69	3.97
2	BIKE	2004	2.13	0.99	3.26
2	HIKE	2004	1.26	0.12	2.40
2	HRS	2004	-0.43	-1.57	0.70
3	ATV	2004	2.31	1.17	3.45
3	BIKE	2004	3.20	2.07	4.34
3	HIKE	2004	2.75	1.61	3.89
3	HRS	2004	0.54	-0.59	1.68

Table A9: Mean and 95% confidence intervals of percent resting activity difference for 13 cow elk during 2003 (top half of table) and 2004.

Data were for each treatment and replicate at Starkey Experimental Forest and Range, Oregon. ATV = all terrain vehicle, BIKE = mountain bike, HIKE = hiking, HRS = horseback riding. Activity difference was calculated as the weekly percent time elk spent resting during the treatment minus the weekly percent time spent resting during the control at the times treatments occurred. Positive difference indicates more time spent resting, while a negative difference indicates less time resting.

			Resting activity		
Replicate	**Treatment**	**Year**	**Mean Difference**	**Lower CI**	**Upper CI**
1	ATV	2003	7.61	5.04	10.18
1	BIKE	2003	0.13	-4.81	5.07
1	HIKE	2003	8.34	6.54	10.14
1	HRS	2003	1.11	-1.66	3.89
2	ATV	2003	7.61	2.65	12.57
2	BIKE	2003	-3.39	-5.87	-0.90
2	HIKE	2003	-5.03	-6.73	-3.34
2	HRS	2003	1.03	-0.59	2.65
3	ATV	2003	0.15	-4.93	5.23
3	BIKE	2003	-2.02	-4.47	0.43
3	HIKE	2003	-3.06	-4.65	-1.47
3	HRS	2003	5.17	3.52	6.82
1	ATV	2004	14.88	10.42	19.34
1	BIKE	2004	1.12	-3.36	5.59
1	HIKE	2004	-0.56	-5.03	3.91
1	HRS	2004	-6.94	-11.39	-2.48
2	ATV	2004	-4.60	-9.07	-0.13
2	BIKE	2004	-9.27	-13.73	-4.82
2	HIKE	2004	-1.09	-5.57	3.38
2	HRS	2004	4.09	-0.36	8.55
3	ATV	2004	7.31	2.83	11.78
3	BIKE	2004	-6.01	-10.46	-1.55
3	HIKE	2004	-2.94	-7.41	1.54
3	HRS	2004	5.83	1.36	10.29

Table A10: Mean and 95% confidence intervals of percent feeding activity difference for 13 cow elk during 2003 (top half of table) and 2004.

Data were for each treatment and replicate at Starkey Experimental Forest and Range, Oregon. ATV = all terrain vehicle, BIKE = mountain bike, HIKE = hiking, HRS = horseback riding. Activity difference was calculated as the weekly percent time elk spent feeding during the treatment minus the weekly percent time spent feeding during the control at the times treatments occurred. Positive difference indicates more time spent feeding, while a negative difference indicates less time feeding.

Replicate	Treatment	Year	Feeding activity Mean Difference	Lower CI	Upper CI
1	ATV	2003	-17.01	-19.65	-14.38
1	BIKE	2003	-5.30	-9.78	-0.81
1	HIKE	2003	-11.26	-12.57	-9.96
1	HRS	2003	0.41	-2.15	2.97
2	ATV	2003	-10.21	-14.61	-5.81
2	BIKE	2003	0.94	-1.41	3.28
2	HIKE	2003	1.33	-0.93	3.59
2	HRS	2003	-3.06	-4.46	-1.66
3	ATV	2003	-3.43	-8.09	1.22
3	BIKE	2003	0.93	-1.52	3.38
3	HIKE	2003	1.79	0.11	3.47
3	HRS	2003	-5.28	-6.91	-3.64
1	ATV	2004	-14.79	-18.53	-11.05
1	BIKE	2004	-3.17	-6.92	0.59
1	HIKE	2004	-1.25	-5.00	2.51
1	HRS	2004	5.55	1.82	9.27
2	ATV	2004	1.34	-2.41	5.10
2	BIKE	2004	6.60	2.87	10.32
2	HIKE	2004	-0.68	-4.44	3.07
2	HRS	2004	-3.78	-7.50	-0.05
3	ATV	2004	-9.47	-13.23	-5.72
3	BIKE	2004	2.10	-1.62	5.83
3	HIKE	2004	-0.36	-4.11	3.40
3	HRS	2004	-6.67	-10.40	-2.93

Table A11: Percent time spent traveling by pasture and time-of-day, plus standard errors (SE) and 95% confidence intervals, of 13 cow elk during ATV and mountain biking treatments 2003.

Data were from the 1,453 ha Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Elk numbers were 97 in the east pasture (E) and 24 in the West (W). Data was sorted by pasture, time-of-day (part), treatment (TRT), and replicate.

Travel 2003 ATV, and Bike							
Pasture	**TRT**	**Part**	**Replicate**	**Mean**	**SE**	**Lower CI**	**Upper CI**
E	ATV	AM	1	11.48	0.88	9.75	13.21
E	ATV	PM	1	4.27	0.88	2.54	6.00
E	ATV	AM	2	5.00	0.88	3.26	6.73
E	ATV	PM	2	3.72	0.88	1.99	5.46
E	ATV	AM	3	3.94	0.88	2.21	5.68
E	ATV	PM	3	1.43	0.88	-0.30	3.17
W	ATV	AM	1	2.94	0.95	1.07	4.81
W	ATV	PM	1	11.15	0.95	9.28	13.02
W	ATV	AM	2	6.93	0.95	5.06	8.80
W	ATV	PM	2	1.27	0.95	-0.60	3.14
W	ATV	AM	3	3.89	0.95	2.02	5.76
W	ATV	PM	3	0.96	0.95	-0.91	2.83
E	BIKE	AM	1	4.05	0.88	2.31	5.78
E	BIKE	PM	1	2.40	0.88	0.67	4.14
E	BIKE	AM	2	4.34	0.88	2.60	6.07
E	BIKE	PM	2	-1.10	0.88	-2.84	0.63
E	BIKE	AM	3	2.14	0.88	0.41	3.87
E	BIKE	PM	3	-0.75	0.88	-2.48	0.98
W	BIKE	AM	1	7.29	0.95	5.42	9.16
W	BIKE	PM	1	-1.74	0.95	-3.61	0.13
W	BIKE	AM	2	0.89	0.95	-0.98	2.76
W	BIKE	PM	2	2.84	0.95	0.97	4.71
W	BIKE	AM	3	2.75	0.95	0.88	4.62
W	BIKE	PM	3	2.57	0.95	0.70	4.44

Table A12: Percent time spent traveling by pasture and time-of-day, plus standard errors (SE) and 95% confidence intervals, of 13 cow elk during hiking and horseback treatments 2003.

Data were from the 1,453 ha Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Elk numbers were 97 in the east pasture (E) and 24 in the West (W). Data was sorted by pasture, time-of-day (part), treatment (TRT), and replicate.

Travel 2003 Hike, and Horseback							
Pasture	**TRT**	**Part**	**Replicate**	**Mean**	**SE**	**Lower CI**	**Upper CI**
E	HIKE	AM	1	6.09	0.88	4.36	7.82
E	HIKE	PM	1	0.52	0.88	-1.21	2.26
E	HIKE	AM	2	1.80	0.88	0.07	3.54
E	HIKE	PM	2	1.27	0.88	-0.46	3.00
E	HIKE	AM	3	4.44	0.88	2.70	6.17
E	HIKE	PM	3	-2.26	0.88	-3.99	-0.53
W	HIKE	AM	1	5.03	0.95	3.16	6.90
W	HIKE	PM	1	-2.03	0.95	-3.90	-0.16
W	HIKE	AM	2	5.94	0.95	4.07	7.81
W	HIKE	PM	2	2.93	0.95	1.06	4.80
W	HIKE	AM	3	0.21	0.95	-1.66	2.08
W	HIKE	PM	3	1.00	0.95	-0.87	2.87
E	HRS	AM	1	3.78	0.88	2.05	5.51
E	HRS	PM	1	1.83	0.88	0.10	3.56
E	HRS	AM	2	1.58	0.88	-0.15	3.31
E	HRS	PM	2	0.16	0.88	-1.57	1.89
E	HRS	AM	3	2.63	0.88	0.90	4.36
E	HRS	PM	3	-0.15	0.88	-1.89	1.58
W	HRS	AM	1	0.65	0.95	-1.22	2.52
W	HRS	PM	1	0.63	0.95	-1.24	2.50
W	HRS	AM	2	7.28	0.95	5.41	9.15
W	HRS	PM	2	0.52	0.95	-1.35	2.39
W	HRS	AM	3	-0.96	0.95	-2.83	0.92
W	HRS	PM	3	-0.59	0.95	-2.46	1.28

Table A13: Percent time spent traveling by pasture and time-of-day, plus standard errors (SE) and 95% confidence intervals, of 13 cow elk during ATV and mountain biking treatments 2004.

Data were from the 1,453 ha Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Elk numbers were 97 in the east pasture (E) and 24 in the West (W). Data was sorted by pasture, time-of-day (part), treatment (TRT), and replicate.

Travel 2004 ATV, and Bike							
Pasture	**TRT**	**Part**	**Replicate**	**Mean**	**SE**	**Lower CI**	**Upper CI**
E	ATV	AM	1	4.51	0.83	2.86	6.17
E	ATV	PM	1	1.01	0.83	-0.64	2.66
E	ATV	AM	2	7.31	0.83	5.66	8.96
E	ATV	PM	2	1.67	0.83	0.02	3.32
E	ATV	AM	3	1.91	0.83	0.26	3.56
E	ATV	PM	3	3.16	0.83	1.51	4.81
W	ATV	AM	1	2.26	0.77	0.73	3.79
W	ATV	PM	1	-3.68	0.77	-5.21	-2.15
W	ATV	AM	2	2.76	0.77	1.23	4.29
W	ATV	PM	2	0.12	0.77	-1.41	1.65
W	ATV	AM	3	6.10	0.77	4.57	7.63
W	ATV	PM	3	-1.84	0.77	-3.37	-0.31
E	BIKE	AM	1	4.58	0.83	2.92	6.23
E	BIKE	PM	1	0.69	0.83	-0.96	2.35
E	BIKE	AM	2	1.85	0.83	0.20	3.50
E	BIKE	PM	2	-1.30	0.83	-2.95	0.35
E	BIKE	AM	3	4.35	0.83	2.70	6.00
E	BIKE	PM	3	-1.19	0.83	-2.84	0.46
W	BIKE	AM	1	0.00	0.77	-1.53	1.53
W	BIKE	PM	1	2.53	0.77	1.00	4.06
W	BIKE	AM	2	2.46	0.77	0.93	3.99
W	BIKE	PM	2	4.52	0.77	3.00	6.05
W	BIKE	AM	3	4.21	0.77	2.68	5.74
W	BIKE	PM	3	5.02	0.77	3.49	6.55

Table A14: Percent time spent traveling by pasture and time-of-day, plus standard errors (SE) and 95% confidence intervals, of 13 cow elk during hiking and horseback treatments 2004.

Data was from the 1,453 ha Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Elk numbers were 97 in the east pasture (E) and 24 in the West (W). Data was sorted by pasture, time-of-day (part), treatment (TRT), and replicate.

Travel 2004 Hike, and Horseback							
Pasture	**TRT**	**Part**	**Replicate**	**Mean**	**SE**	**Lower CI**	**Upper CI**
E	HIKE	AM	1	4.94	0.83	3.29	6.59
E	HIKE	PM	1	3.08	0.83	1.43	4.73
E	HIKE	AM	2	4.60	0.83	2.95	6.25
E	HIKE	PM	2	-1.98	0.83	-3.64	-0.33
E	HIKE	AM	3	3.65	0.83	1.99	5.30
E	HIKE	PM	3	2.65	0.83	1.00	4.30
W	HIKE	AM	1	0.20	0.77	-1.33	1.73
W	HIKE	PM	1	0.47	0.77	-1.06	1.99
W	HIKE	AM	2	-0.45	0.77	-1.98	1.08
W	HIKE	PM	2	2.83	0.77	1.31	4.36
W	HIKE	AM	3	3.35	0.77	1.82	4.88
W	HIKE	PM	3	1.52	0.77	-0.01	3.04
E	HRS	AM	1	3.70	0.83	2.05	5.35
E	HRS	PM	1	1.67	0.83	0.02	3.32
E	HRS	AM	2	0.31	0.83	-1.34	1.96
E	HRS	PM	2	1.53	0.83	-0.12	3.18
E	HRS	AM	3	2.31	0.83	0.66	3.97
E	HRS	PM	3	0.41	0.83	-1.24	2.06
W	HRS	AM	1	1.83	0.77	0.30	3.35
W	HRS	PM	1	-1.49	0.77	-3.02	0.04
W	HRS	AM	2	-2.51	0.77	-4.04	-0.98
W	HRS	PM	2	-0.36	0.77	-1.89	1.17
W	HRS	AM	3	-0.73	0.77	-2.26	0.80
W	HRS	PM	3	0.70	0.77	-0.83	2.23

Table A15: Least square means test for travel activity differences between pastures during the mornings (top half of table), and the afternoons for 13 cow elk during 2003.

Data were from the 1,453 ha Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Disturbances were all terrain vehicles (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS). Significance levels of differences in least square means were adjusted using the Bonferroni procedure.

Travel 2003 differences in least square means									
Comparison	**Treatment**	**Replicate**	**Mean Difference**	**SE**	**DF**	**t value**	**Adj P**	**LCI**	**UCI**
East and West AM	ATV	1	8.54	1.29	132	6.63	<0.0001	3.09	13.98
East and West AM	ATV	2	-1.93	1.29	132	-1.5	1.0000	-7.38	3.51
East and West AM	ATV	3	0.05	1.29	132	0.04	1.0000	-5.39	5.49
East and West AM	BIKE	1	-3.24	1.29	132	-2.52	1.0000	-8.69	2.20
East and West AM	BIKE	2	3.45	1.29	132	2.68	1.0000	-2.00	8.89
East and West AM	BIKE	3	-0.61	1.29	132	-0.47	1.0000	-6.05	4.84
East and West AM	HIKE	1	1.06	1.29	132	0.82	1.0000	-4.39	6.50
East and West AM	HIKE	2	-4.14	1.29	132	-3.21	1.0000	-9.58	1.31
East and West AM	HIKE	3	4.23	1.29	132	3.28	1.0000	-1.22	9.67
East and West AM	HRS	1	3.13	1.29	132	2.43	1.0000	-2.31	8.58
East and West AM	HRS	2	-5.70	1.29	132	-4.42	0.0229	-11.14	-0.25
East and West AM	HRS	3	3.58	1.29	132	2.78	1.0000	-1.86	9.03
East and West PM	ATV	1	-6.88	1.29	132	-5.34	0.0004	-12.32	-1.43
East and West PM	ATV	2	2.46	1.29	132	1.91	1.0000	-2.99	7.90
East and West PM	ATV	3	0.48	1.29	132	0.37	1.0000	-4.97	5.92
East and West PM	BIKE	1	4.15	1.29	132	3.22	1.0000	-1.30	9.59
East and West PM	BIKE	2	-3.94	1.29	132	-3.06	1.0000	-9.38	1.50
East and West PM	BIKE	3	-3.32	1.29	132	-2.57	1.0000	-8.76	2.13
East and West PM	HIKE	1	2.56	1.29	132	1.98	1.0000	-2.89	8.00
East and West PM	HIKE	2	-1.65	1.29	132	-1.28	1.0000	-7.10	3.79
East and West PM	HIKE	3	-3.26	1.29	132	-2.53	1.0000	-8.70	2.18
East and West PM	HRS	1	1.20	1.29	132	0.93	1.0000	-4.25	6.64
East and West PM	HRS	2	-0.36	1.29	132	-0.28	1.0000	-5.80	5.09
East and West PM	HRS	3	0.44	1.29	132	0.34	1.0000	-5.01	5.88

Table A16: Least square means test for travel activity differences between pastures during the mornings (top half of table), and the afternoons for 13 cow elk during 2004.

Data were from the 1,453 ha Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Disturbances were all terrain vehicles (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS). Significance levels of differences in least square means were adjusted using the Bonferroni procedure.

Travel 2004 differences in least square means									
Comparison	**Treatment**	**Replicate**	**Mean Difference**	**SE**	**DF**	**t value**	**Adj P**	**LCI**	**UCI**
East and West AM	ATV	1	2.25	1.14	132	1.98	1.0000	-2.55	7.06
East and West AM	ATV	2	4.55	1.14	132	4.00	0.1172	-0.25	9.36
East and West AM	ATV	3	-4.19	1.14	132	-3.68	0.3755	-9.00	0.61
East and West AM	BIKE	1	4.58	1.14	132	4.02	0.1089	-0.23	9.38
East and West AM	BIKE	2	-0.61	1.14	132	-0.53	1.0000	-5.41	4.20
East and West AM	BIKE	3	0.15	1.14	132	0.13	1.0000	-4.66	4.95
East and West AM	HIKE	1	4.74	1.14	132	4.17	0.0626	-0.07	9.55
East and West AM	HIKE	2	5.05	1.14	132	4.44	0.0215	0.24	9.85
East and West AM	HIKE	3	0.30	1.14	132	0.26	1.0000	-4.51	5.10
East and West AM	HRS	1	1.88	1.14	132	1.65	1.0000	-2.93	6.68
East and West AM	HRS	2	2.82	1.14	132	2.48	1.0000	-1.98	7.63
East and West AM	HRS	3	3.04	1.14	132	2.67	1.0000	-1.76	7.85
East and West PM	ATV	1	4.69	1.14	132	4.12	0.0741	-0.12	9.50
East and West PM	ATV	2	1.55	1.14	132	1.36	1.0000	-3.26	6.35
East and West PM	ATV	3	5.00	1.14	132	4.39	0.0257	0.19	9.80
East and West PM	BIKE	1	-1.84	1.14	132	-1.61	1.0000	-6.64	2.97
East and West PM	BIKE	2	-5.82	1.14	132	-5.12	0.0012	-10.63	-1.01
East and West PM	BIKE	3	-6.21	1.14	132	-5.46	0.0003	-11.01	-1.40
East and West PM	HIKE	1	2.61	1.14	132	2.30	1.0000	-2.19	7.42
East and West PM	HIKE	2	-4.82	1.14	132	-4.24	0.0478	-9.62	-0.01
East and West PM	HIKE	3	1.14	1.14	132	1.00	1.0000	-3.67	5.94
East and West PM	HRS	1	3.15	1.14	132	2.77	1.0000	-1.65	7.96
East and West PM	HRS	2	1.88	1.14	132	1.66	1.0000	-2.92	6.69
East and West PM	HRS	3	-0.29	1.14	132	-0.26	1.0000	-5.10	4.51

Table A17: Differences between morning and afternoon travel per pasture, grouped by treatment and replicate, 2003.
East pasture results are in the top half of the table and west pasture results at the bottom. Data are from 13 cow elk during 2003 in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Disturbance treatments were all terrain vehicle (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS). Significance levels of all pair-wise comparisons were adjusted using the Bonferroni procedure.

			Travel 2003 differences in least square means						
Comparison	**Treatment**	**Replicate**	**Mean**	**SE**	**DF**	**t value**	**Adj P**	**LCI**	**UCI**
East AM and PM	ATV	1	7.21	1.18	132	6.13	<0.0001	2.24	12.17
East AM and PM	ATV	2	1.27	1.18	132	1.08	1.0000	-3.69	6.24
East AM and PM	ATV	3	2.51	1.18	132	2.14	1.0000	-2.45	7.47
East AM and PM	BIKE	1	1.64	1.18	132	1.4	1.0000	-3.32	6.60
East AM and PM	BIKE	2	5.44	1.18	132	4.63	0.0098	0.48	10.40
East AM and PM	BIKE	3	2.89	1.18	132	2.46	1.0000	-2.07	7.86
East AM and PM	HIKE	1	5.56	1.18	132	4.74	0.0063	0.60	10.53
East AM and PM	HIKE	2	0.53	1.18	132	0.45	1.0000	-4.43	5.50
East AM and PM	HIKE	3	6.69	1.18	132	5.7	<0.0001	1.73	11.66
East AM and PM	HRS	1	1.95	1.18	132	1.66	1.0000	-3.01	6.92
East AM and PM	HRS	2	1.42	1.18	132	1.21	1.0000	-3.54	6.39
East AM and PM	HRS	3	2.78	1.18	132	2.37	1.0000	-2.18	7.75
West AM and PM	ATV	1	-8.21	1.27	132	-6.47	<.0001	-13.57	-2.85
West AM and PM	ATV	2	5.66	1.27	132	4.46	0.0195	0.30	11.02
West AM and PM	ATV	3	2.94	1.27	132	2.31	1.0000	-2.43	8.30
West AM and PM	BIKE	1	9.03	1.27	132	7.12	<0.0001	3.67	14.39
West AM and PM	BIKE	2	-1.95	1.27	132	-1.54	1.0000	-7.31	3.41
West AM and PM	BIKE	3	0.18	1.27	132	0.14	1.0000	-5.18	5.54
West AM and PM	HIKE	1	7.06	1.27	132	5.57	0.0002	1.70	12.43
West AM and PM	HIKE	2	3.01	1.27	132	2.37	1.0000	-2.35	8.37
West AM and PM	HIKE	3	-0.79	1.27	132	-0.63	1.0000	-6.16	4.57
West AM and PM	HRS	1	0.02	1.27	132	0.01	1.0000	-5.35	5.38
West AM and PM	HRS	2	6.76	1.27	132	5.33	0.0005	1.40	12.12
West AM and PM	HRS	3	-0.37	1.27	132	-0.29	1.0000	-5.73	5.00

Table A18: Differences between morning and afternoon travel per pasture, grouped by treatment and replicate, 2004.

East pasture results are in the top half of the table and west pasture results at the bottom. Data are from 13 cow elk during 2004 in the Northeast study area of Starkey Experimental Forest and Range, La Grande, OR. Disturbance treatments were all terrain vehicle (ATV), mountain biking (BIKE), hiking (HIKE), and horseback riding (HRS). Significance levels of all pair-wise comparisons were adjusted using the Bonferroni procedure.

Travel 2004 differences in least square means									
Comparison	**Treatment**	**Replicate**	**Mean**	**SE**	**DF**	**t value**	**Adj P**	**LCI**	**UCI**
East AM and PM	ATV	1	3.50	1.17	132	3.00	1.0000	-1.42	8.43
East AM and PM	ATV	2	5.64	1.17	132	4.84	0.0040	0.72	10.57
East AM and PM	ATV	3	-1.25	1.17	132	-1.07	1.0000	-6.17	3.68
East AM and PM	BIKE	1	3.88	1.17	132	3.33	1.0000	-1.05	8.81
East AM and PM	BIKE	2	3.15	1.17	132	2.7	1.0000	-1.78	8.07
East AM and PM	BIKE	3	5.54	1.17	132	4.75	0.0058	0.62	10.47
East AM and PM	HIKE	1	1.86	1.17	132	1.59	1.0000	-3.07	6.78
East AM and PM	HIKE	2	6.58	1.17	132	5.65	0.0001	1.66	11.51
East AM and PM	HIKE	3	0.99	1.17	132	0.85	1.0000	-3.93	5.92
East AM and PM	HRS	1	2.04	1.17	132	1.75	1.0000	-2.89	6.96
East AM and PM	HRS	2	-1.22	1.17	132	-1.05	1.0000	-6.15	3.71
East AM and PM	HRS	3	1.91	1.17	132	1.63	1.0000	-3.02	6.83
West AM and PM	ATV	1	5.94	1.08	132	5.5	0.0002	1.38	10.50
West AM and PM	ATV	2	2.64	1.08	132	2.44	1.0000	-1.92	7.20
West AM and PM	ATV	3	7.94	1.08	132	7.36	<0.0001	3.38	12.50
West AM and PM	BIKE	1	-2.53	1.08	132	-2.34	1.0000	-7.09	2.03
West AM and PM	BIKE	2	-2.06	1.08	132	-1.91	1.0000	-6.62	2.50
West AM and PM	BIKE	3	-0.81	1.08	132	-0.75	1.0000	-5.37	3.75
West AM and PM	HIKE	1	-0.27	1.08	132	-0.25	1.0000	-4.83	4.29
West AM and PM	HIKE	2	-3.28	1.08	132	-3.04	1.0000	-7.84	1.28
West AM and PM	HIKE	3	1.83	1.08	132	1.70	1.0000	-2.73	6.39
West AM and PM	HRS	1	3.31	1.08	132	3.07	1.0000	-1.25	7.87
West AM and PM	HRS	2	-2.16	1.08	132	-2.00	1.0000	-6.72	2.40
West AM and PM	HRS	3	-1.43	1.08	132	-1.32	1.0000	-5.99	3.13

APPENDIX B

```
Stem Leaf                                         #             Boxplot
    38 3                                          1                *
    36
    34 66                                         2                *
    32
    30 0                                          1                *
    28
    26
    24 3                                          1                0
    22 5489                                       4                0
    20 11462                                      5                0
    18 16                                         2                0
    16 29457                                      5                0
    14 158936                                     6                0
    12 5                                          1                |
    10 146898                                     6                |
     8 062246689                                  9                |
     6 00823346899                               11                |
     4 23773899                                   8                |
     2 22244668890178                            14             +-----+
     0 01223334566677788990002467889             29             |  +  |
    -0 8665443321110087651                       19             |     |
    -2 9998888777766553333333220988766544432222221 43           *-----*
    -4 9999888777766543222099999887777654443221  40             |     |
    -6 98765433211999988877666433333222211000    38             +-----+
    -8 886654321187654422100                     21                |
   -10 86421198520                               11                |
       ----+----+----+----+----+----+----+----+---
   Multiply Stem.Leaf by 10**+1
```

Figure B1: Stem and leaf plot of elk flight distance showing data are not normally distributed.

Data were from visual observations of elk during four recreational disturbances (ATV, mountain biking, hiking, and horseback riding) for 2004 at Starkey Experimental Forest and Range, La Grande, Oregon.

```
Stem Leaf                                         #             Boxplot
    16 9                                          1                0
    14 66                                         2                |
    12 4571369                                    7                |
    10 1128802445589                             13                |
     8 0111248267                                10                |
     6 023334456891133444589                     21                |
     4 122335690136688                           15                |
     2 0233345666667777899900112455667899        34             +-----+
     0 1234455667891111234444455689              28             |  +  |
    -0 99966544444400099988877765444432111100    38             *-----*
    -2 997665555433321100876555433333310000      36             |     |
    -4 997532211097655332210                     21             +-----+
    -6 8533331987766533211111100                 25                |
    -8 5320987430                                10                |
   -10 9873                                       4                |
   -12 95540                                      5                |
   -14 227632                                     6                |
   -16
   -18
   -20
   -22 6                                          1                0
       ----+----+----+----+----+----+----+---
   Multiply Stem.Leaf by 10**-1
```

Figure B2: Stem and leaf plot of log transformed flight distance of elk showing a normal distribution of the data.

Data were from visual observations of elk during four recreational disturbances (ATV, mountain biking, hiking, and horseback riding) for 2004 at Starkey Experimental Forest and Range, La Grande, Oregon.