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Effects of Off-road Recreation on Mule Deer and Elk

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Introduction

Off-road recreation is increasing rapidly in the United States, especially on public land (Havlick 2002, U.S. Department of Agriculture Forest Service 2004). An expansive network of roads provides easy access to much public land, which facilitates off-road uses in the form of all-terrain vehicles (ATVs), horses, mountain bikes and foot traffic. No research, however, has evaluated effects of these off-road activities on vertebrate species in a comparative and experimental manner (see review by Gaines et al. 2003). One recent study (Taylor and Knight 2003a) evaluated bison (*Bison bison*), pronghorn (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*) responses to mountain biking and hiking. This study, however, did not include ATV or horseback riding, nor did it include experimental controls needed to assess cause-effect relations.

To address these knowledge gaps, we initiated a manipulative, landscape experiment in 2002 to measure effects of off-road recreation on mule deer and elk (*Cervus elaphus*), two charismatic species of keen recreational, social and economic interest across western North America. Our objectives were to (1) document cause-effect relations of ATV, horseback, mountain bike and hiking activities on deer and elk, using these off-road activities as experimental treatments and periods of no human activity as experimental controls; (2) measure effects with response variables that index changes in animal or population performance, such as movement rates, flight responses, resource selection, spatial distributions and use of foraging versus security areas; (3) use these response variables to estimate the energetic and nutritional costs associated with each activity and the resultant effects on deer and elk survival; and (4) interpret results for recreation management.

Our research began in 2002 and ended in 2004. In this paper, we present findings from 2002 to address parts of objectives 1, 2 and 4. We specifically focus on changes in movement rates and flight responses of mule deer and elk in relation to the off-road activities, compared to periods of no human activity. We then describe potential uses of the results for recreation management.

We present findings from our first year of study because of the urgent need for timely management information to address the rapid growth in off-road recreation (U. S. Department of Agriculture, Forest Service 2004). For example, ATV use on public land has increased seven-fold during the past 20 years, and many conservation groups are calling for widespread restrictions on ATV travel (U. S. Department of Agriculture, Forest Service 2004). Yet, no studies have evaluated the role of ATVs compared to other off-road activities, such as mountain biking and horseback riding, which also are increasing rapidly. Without comprehensive studies of ATV effects in relation to other recreation, the debate over ATV use is likely to intensify. Our study was designed to measure a variety of ungulate responses to address this debate, so results can be used to identify compatible mixes of different off-road recreational opportunities in relation to deer and elk management.

Throughout our paper, we refer to off-road recreation, both motorized and nonmotorized, that occurs on trails, primitive (unpaved) roads, or areas without trails or roads. This definition complements the phrase off-highway vehicle (OHV) use, which refers to motorized vehicle use on any surface beyond highways (U. S. Department of Agriculture, Forest Service 2004), but which does not include other forms of nonwinter recreation that typically occur on primitive roads and trails, such as hiking, horseback riding, and mountain biking.

Study Area and Technologies

We conducted our research in northeastern Oregon at the Starkey Experimental Forest and Range (Starkey, Figure 1), a facility equipped to evaluate real-time and landscape-level responses of deer and elk to human activities under controlled experimentation (Rowland et al. 1997, Wisdom et al. 2004a). The facility encompasses spring, summer and fall ranges typical of those used by mule deer and elk in the western United States. Timber harvest, livestock grazing, motorized traffic, hunting, camping and other public uses of Starkey also are managed like those on national forests in the western United States, providing a large inference space for research findings (Rowland et al. 1997, Wisdom et al. 2004a).

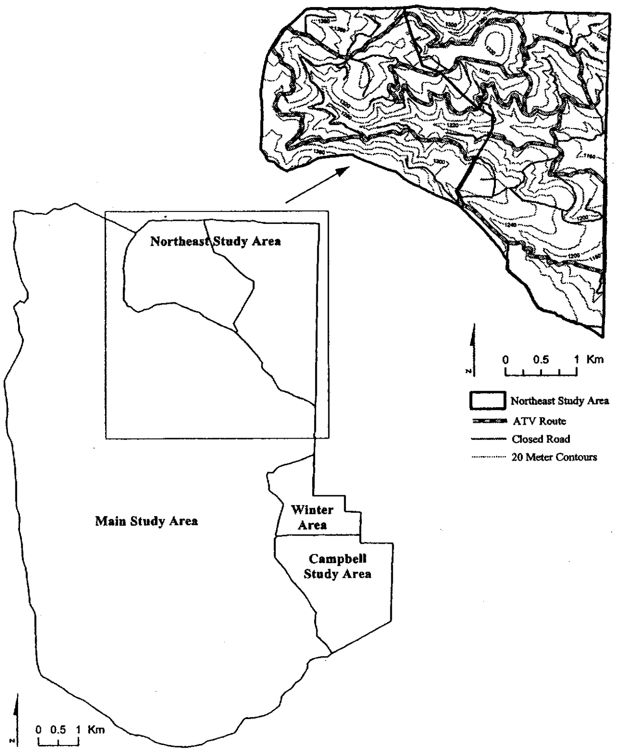


Figure 1. Boundaries of ungulate-proof enclosures at the Starkey Experimental Forest and Range in northeastern Oregon (bottom left) and location of transects used for ATV activities in the 3,590-acre (1,453-ha) Northeast Study Area (upper right), the site of the off-road recreation study. Transects were similar in length and location for mountain biking, hiking and horseback riding as those shown here for ATV activities.

An essential research component at Starkey is the ungulate-proof enclosure, one of the largest in the world, which allows scientists to evaluate ungulate responses to human activities over large areas and under controlled conditions (Bryant et al. 1993, Rowland et al. 1997). Another key technology is the automated tracking system (ATS), which can generate up to one animal location every 20 seconds, 24 hours a day, from April through December each year (Rowland et al. 1997, Kie et al. 2004). Additional technologies include maps and databases of more than 100 environmental variables to relate animal movements to the landscape experiments, as well as supporting methods and software to analyze these data (Rowland et al. 1997, 1998).

Implementing the Recreation Treatments

To meet our objectives, a network of off-road transects was established and run in 2002, using ATV, horseback, mountain bike and hiking activities as experimental treatments in the 3,590-acre (1,453-ha) Northeast Study Area (Figure 1). Approximately 20 miles (32 km) of transects were established (Figure 1), over which ATV, horseback, mountain bike and foot traffic was experimentally applied from mid-April through October. Locations of each transect were established with global positioning system (GPS) units (Figure 1). Transects were located on flat or moderate terrain typically used by off-road activities. Primitive roadbeds, like those often established by off-road vehicles (U. S. Department of Agriculture, Forest Service 2004), were included in the transects. Use of roadbeds and trails to implement human activities is referred to as a tangential experimental approach because animals are not targeted directly by the activities (Taylor and Knight 2003b). This is in contrast to a direct experimental approach, such as testing the reaction of nesting birds to designed encounters with humans at nest sites.

A sufficient number and length of transects were established to encompass all portions of the Northeast Study Area (Figure 1). Each off-road activity was run on a given transect twice daily, once in the morning and once in the afternoon, during a 5-day period; this daily frequency of activity corresponds to traffic frequency on Starkey roads that produced an avoidance response by elk in earlier research (Wisdom 1998, Wisdom et al. 2004b).

A particular activity for a given morning or afternoon was completed by one to three people who rode ATVs (four-wheelers or quads), mountain bikes, or horses, or who hiked as a group. On most days, group size consisted of two people moving as a pair; that is, by two people hiking or each riding ATVs, mountain bikes or horses. A group size of two, with a range of one to three people, often is typical for these recreation activities in nonwilderness portions of national forests (D. Barrett, personal communication 2002). Group size can vary substantially, however, with larger groups of 5 to 10 ATV riders or horseback riders, for instance. We had neither the resources nor the experimental options to include these larger groups as treatments in our study. Moreover, group size of mountain bikers and hikers often does not approach 5 to 10 people, and we wanted to maintain approximately the same group size across all four activities. A group size of two people, with a range of one to three people, provided this consistency.

For ATV travel, a pair of riders could easily cover the 20 miles (32 km) of transects during a given morning or afternoon. A pair of mountain bike riders, however, could cover about 50 percent of the 20 miles (32 km) in a morning or afternoon. Horseback riders and hikers could cover about 30 percent. Because we wanted to standardize the experiment by the same number of transect runs or passes (twice daily) among all four off-road activities, two different groups of mountain bikers and three groups of horseback riders or hikers were used to obtain complete coverage of transects for a given morning or afternoon. For mountain biking, the transects were divided in half, with each of the two groups assigned to ride a different half of the 20 miles (32 km) in a morning or afternoon. Similarly, three groups of horseback riders or hikers, each assigned to travel a different third of the transect length, were used for each morning and afternoon to obtain complete coverage of transects.

Each of the four off-road activities was implemented under an interrupted movement design, where humans were allowed to momentarily stop to view animals for less than 1 minute when animals were observed. This is in contrast to a continuous movement design, where human activities are not delayed or stopped when animals are observed (Taylor and Knight 2003b).

Each 5-day period of off-road activity was followed by a 9-day control period, during which no human activities occurred in the study area. This pattern was followed from mid-April through October, resulting in three replicates of each of the four off-road activities. Each 5-day replicate of an off-road activity thus was paired with a 9-day control period that immediately followed the replicate. Only one type of off-road activity (ATV, horseback, mountain bike or hiking) occurred on transects during a given 5-day replicate. The chronological order of each off-road activity, in terms of which activity occurred during the first 5-day replicate in late April, versus the next 5-day replicate in early May, and so on, was randomly chosen.

Throughout the experiment, all human entry beyond the four off-road activities, including administrative use of roads, was prohibited to eliminate the confounding effects of other human activities with animal response to the off-road activities. Consequently, human activities such as timber harvest, road traffic, camping and hunting did not occur during the study because of their confounding effects.

Measuring Animal Responses

To monitor animal responses, 12 female mule deer and 12 female elk were radio-collared among a larger population of approximately 25 female deer and 100 female elk present in the Northeast Study Area in early April. Movements of these radio-collared animals were monitored with the ATS (Rowland et al. 1997). During periods of off-road activity, locations of each radio-collard deer or elk were generated at approximately 10-minute intervals. Locations of humans engaged in each off-road activity were generated at approximately 1-minute intervals, using GPS units carried by one of the persons in each group of hikers or riders of ATVs, horses or mountain bikes. Use of the automated telemetry system to track animal movements, combined with the use of GPS units to track human movements, provided real-time, unbiased estimates of the distances between each ungulate and group of humans.

Our method of estimating distances between ungulates and humans contrasts strongly with the use of direct observation, using rangefinders or other devices, to measure distances. Direct observation as a means of estimating distances between ungulates and humans is likely to be biased by the proportion of deer or elk whose reactions to human activities cannot be observed because such reactions are different than those of animals that can be observed. For example, some animals may run from human activity at distances beyond the view of observers, while other animals may react at close distances to, and in view of, observers. This bias in observed distances would result in underestimation of the true distance at which animals react to the human activity. In other cases, animals may flee from humans at close distances but not be viewed because such animals seek dense cover during flight; this bias would result in overestimation of distances. We avoided such biases with the use of our automated telemetry system and GPS units to continuously monitor the movements of ungulates and humans throughout our study.

We also located radio-collared animals during the 9-day periods of no human activity, or control period. Approximately two locations of each radio-collared animal were obtained every hour during control periods, to establish baseline information about areas of deer and elk use, habitat selection, movement rates, and flight responses in the absence of human activities. For this paper, we analyzed two types of animal reactions: (1) movement rate and (2) probability of flight response. We evaluated movement rate and probability of flight response because both can ultimately be used to estimate the energetic costs of animal reactions to off-road activities (see Conclusions and Interpretations).

Estimating Movement Rates

We defined movement rate as the speed of animal movement (yards moved per minute), estimated hourly, 24 hours per day, for a given species, treatment and control period. We calculated the speed of animal movement for each radio-collared deer or elk for each pair of successive locations; that is, the horizontal distance between two successive locations divided by the elapsed time between locations (Ager et al. 2003). Each measurement of animal speed for a given radio-collared animal was assigned to the time recorded for the first location of each pair of animal locations used in the calculation.

Only successive locations with consistent elapsed times were included in the calculation of movement rates to eliminate the bias of excessively short and long elapsed times. Short elapsed times (e. g., fewer than 5 minutes) between locations falsely inflate the movement rate because of random location errors in the ATS over such short time periods (Findholt et al. 1996, 2002). Long elapsed times (e .g., more than 35 minutes) between locations allow animals to move back and forth between the documented locations, thus biasing the estimate of movement rate downward (Ager et al. 2003).

To estimate overall patterns of movement rates for each species, rates calculated for each individual radio-collared animal were averaged among all animals, for mule deer and for elk, by hourly interval, for each off-road treatment and the paired control period that immediately followed that treatment. For this analysis, we minimized random variation by summarizing results across each 5-

day treatment and across each subsequent 9-day control. We did this after exploratory plots of data provided no evidence of change in movement rates of animals from day 1 through day 5 of each treatment period, or for day one through nine of each control period, as examined on an hourly basis. We then pooled hourly results for each species across the three replicates of each off-road activity, and across control periods, after finding no evidence of differences in like replicates across time, or in control periods across time.

Estimating Probabilities of a Flight Response

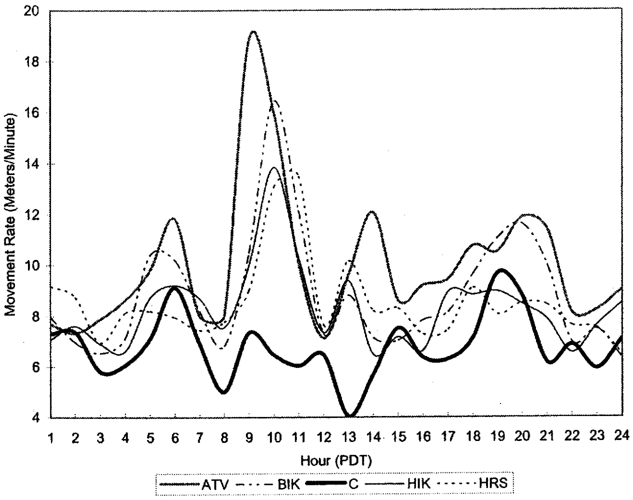
We used a stimulus response model to estimate the probability of a flight response by a deer or elk with changing distance between each animal and off-road activity. We defined a flight response as the speed of animal movement, or movement rate, that exceeded the 95th percentile of all deer or elk speeds calculated for each hour from data collected during the control periods. Specifically, a flight response was any animal movement for a given hour of day that exceeded the 95th percentile of all deer or elk speeds calculated for that same hour of day during the paired 9-day control period that immediately followed a given 5-day period of off-road activity. Thus by definition, when no stimulus was present (no human activity), a deer or elk would register a response (i. e., travel at speeds greater than the 95th percentile of all deer or elk speeds for that hour during the control period) 5 percent of the time. Probabilities of response were estimated using logistic regression within the generalized additive model framework (Hastie and Tibshirani 1990).

Each estimated probability of a flight response for a given radio-collared animal was linked to the estimated distance between that animal and each group of humans conducting an off-road activity, allowing an examination of how probabilities changed with distance between animals and humans. As with our analyses of movement rates, we pooled the probability data for each species across the three replicates of each off-road activity and across control periods. We pooled data after initial analyses showed that results for deer and elk were similar across the three replicates of each off-road activity and across all control periods.

Movement Rates of Elk

Movement rates of elk were substantially higher during periods of all four off-road activities, compared to periods of no human activity (Figure 2). Responses of elk to the morning and afternoon runs were clearly evident, with

Figure 2. Mean movement rate (speed, meters per minute) of elk, estimated hourly on a 24-hour basis, Pacific Daylight Time (PDT), during periods of no human activity (C) versus periods of ATV activity (ATV), hiking (HIK), mountain bike riding (BIK) and horseback riding (HRS), from April through October, 2002, in Northeast Study Area of Starkey.



the most pronounced increase in movement rates observed during the hours when each off-road activity occurred (Figure 2). For example, our morning pass on transects began between 0830 and 0930 Pacific Daylight Time (PDT), and highest movement rates for elk occurred in the hours immediately after, from 0900 to 1100, during all four activities (Figure 2). Moreover, lunch break for participants in the experiment occurred at or near noon, and movement rates for elk dipped to their lowest level at noon during all activities. Finally, we resumed each activity at 1230 to 1300 PDT, and movement rates for elk substantially increased immediately after (Figure 2).

Movement rates were substantially higher for elk during the morning pass, compared to the afternoon pass, for all four activities (Figure 2). Movement rates of elk during the afternoon pass, however, stayed well above the rates observed during the periods of no human activity (control period, Figure 2). Movement rates during the afternoon pass declined after 1500 PDT, when afternoon activities ended.

For the morning pass, movement rates of elk were highest during ATV riding, second-highest during mountain-bike riding and lowest during hiking and horseback riding (Figure 2). Movement rates of elk also stayed higher, over a longer period, during the afternoon ATV run, compared to rates during afternoon horseback riding, mountain-bike riding and hiking. Peak movement rates of elk during the morning pass were highest for ATV riding (21 yards per minute [19 m/min]), followed by mountain bike riding (17 yards per minute [16 m/min]) and horseback riding and hiking (both about 15 yards per minute [14 m/min]). For the afternoon run, movement rates of elk again were highest during ATV riding (13 yards per minute [12 m/min]), followed by horseback riding (about 11 yards per minute [10 m/min]) and hiking and mountain bike riding (about 10 yards per minute [9 m/min]).

By contrast, peak movement rates of elk during the control periods did not exceed 9 yards per minute (8 m/min). Moreover, peak movement rates during the control periods stayed below 8 yards per minute (7 m/min) during daylight hours of 0800 to 1500, the comparable period of each day when off-road treatments were implemented.

Interestingly, movement rates of elk also were higher than control periods at times encompassing sunrise and sunset for the days in which an off-road activity occurred, even though humans were not present at these times of day (Figure 2). These higher movement rates near sunrise and sunset suggest that elk were displaced from preferred security and foraging areas as a result of flight behavior during the daytime off-road activities. In particular, movement rates of elk at or near sunrise and sunset were higher during the 5-day treatments of mountain bike and ATV activity (Figure 2). This finding will be studied in detail in future analyses.

Flight Responses of Elk

The estimated probability of elk flight from a human disturbance was highly dependent on distance. When elk and humans were close to one another, the maximum probability of a flight response was approximately 0.65 during ATV, mountain bike and hiking activity, and 0.55 during horseback riding (Figure 3). Higher probabilities of flight response occurred during ATV and mountain bike activity, in contrast to lower probabilities observed during hiking and horseback riding (Table 1). Probability of a flight response declined most rapidly during hiking, with little effect when hikers were beyond 550 yards (500 m) from an elk. By contrast, higher probabilities of elk flight continued beyond 820 yards (750 m) from horseback riders and 1,640 yards (1,500 m) from mountain bike and ATV riders (Figure 3).

Movement Rates of Deer

In contrast to elk, mule deer showed less change in movement rates during the four off-road activities compared to the control periods (Figure 4).

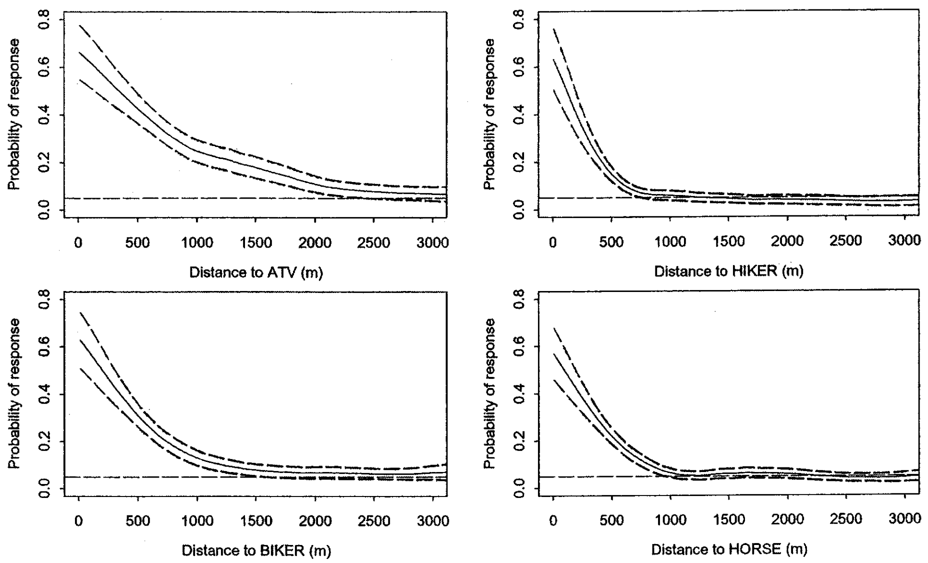


Figure 3. Estimated probability (solid line encompassed by dashed lines of the approximate 95 percent pointwise confidence interval) of a flight response by elk during 2002 in relation to distance (meters) from humans riding ATVs, mountain bikes, horses or hiking. A flight response is defined as an animal movement with a speed exceeding the 95th percentile of speeds observed during periods of no human activity (control period). The horizontal dashed line at the bottom of each graph is the probability of a flight response by elk during periods of no human activity, and this line represents the background, or the null condition, above which significant elk response to the off-road activities exists.

During the period of day from 0800 to1500 when off-road activities occurred, movement rates of deer during ATV riding were similar to rates during control periods. By contrast, daytime movement rates of deer were higher, compared to control periods, during mountain bike riding, horseback riding and hiking, especially in the morning (Figure 4).

Interestingly, the increased movement rates observed for elk near sunrise and sunset also were evident for mule deer. Movement rates at these times were particularly high during all four activities as well as during the control periods, suggesting that these times were peak foraging periods (Ager et al. 2003).

Flight Responses of Deer

Estimated probabilities of flight response for mule deer were similar among all four activities versus control periods (Table 1, Figure 5). These

Table 1. Estimated probabilities (and approximate 95 percent confidence limits) of a flight response by elk and mule deer as a function of distance between animals and humans riding all-terrain vehicles (ATV), mountain bikes (BIKE), horses (HORSE) or hiking (HIKE). On average there were 128 deer or elk locations obtained during a given day of each off-road activity (treatment periods). During periods of no human activity (control periods), the null probability of a flight response is 0.05. Thus, any values greater than 0.05 reflect an increased probability of a flight response in relation an off-road activity.

Distance[1]	ATV	Bike	Horse	Hike
109 yards (100 m)	0.62	0.58	0.50	0.52
from elk	(0.52–0.73)	(0.46–0.68)	(0.40–0.59)	(0.42–0.64)
545 yards (500 m)	0.43	0.31	0.22	0.15
from elk	(0.36–0.49)	(0.26–0.35)	(0.19–0.26)	(0.12–0.18)
1,090 yards (1,000 m)	0.25	0.13	0.07	0.06
from elk	(0.20–0.30)	(0.10–0.16)	(0.05–0.08)	(0.04–0.08)
All distances	0.19	0.14	0.11	0.08
from elk	(0.17–0.21)	(0.12–0.16)	(0.09–0.12)	(0.07–0.10)
109 yards (100 m)	0.06	0.08	0.11	0.10
from deer	(0.01–0.11)	(0.02–0.14)	(0.03–0.19)	(0.04–0.17)
545 yards (500 m)	0.05	0.07	0.05	0.04
from deer	(0.02–0.07)	(0.04–0.10)	(0.03–0.07)	(0.02–0.05)
1,090 yards (1,000 m)	0.03	0.06	0.04	0.04
from deer	(0.01–0.06)	(0.03–0.08)	(0.02–0.06)	(0.02–0.06)
All distances	0.03	0.05	0.04	0.04
from deer	(0.02–0.05)	(0.04–0.07)	(0.03–0.05)	(0.03–0.06)

[1] Distance between an animal and human during each off-road activity.

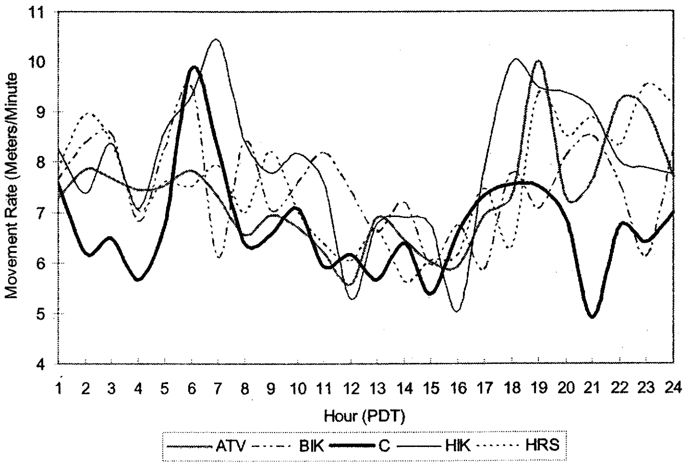


Figure 4. Mean movement rate (speed, meters/minute) of mule deer, estimated hourly on a 24-hour basis, Pacific Daylight Time (PDT), during periods of no human activity (C) versus periods of ATV activity (ATV), hiking (HIK), mountain bike riding (BIK) and horseback riding (HRS) during 2002 in the Northeast Study Area of Starkey.

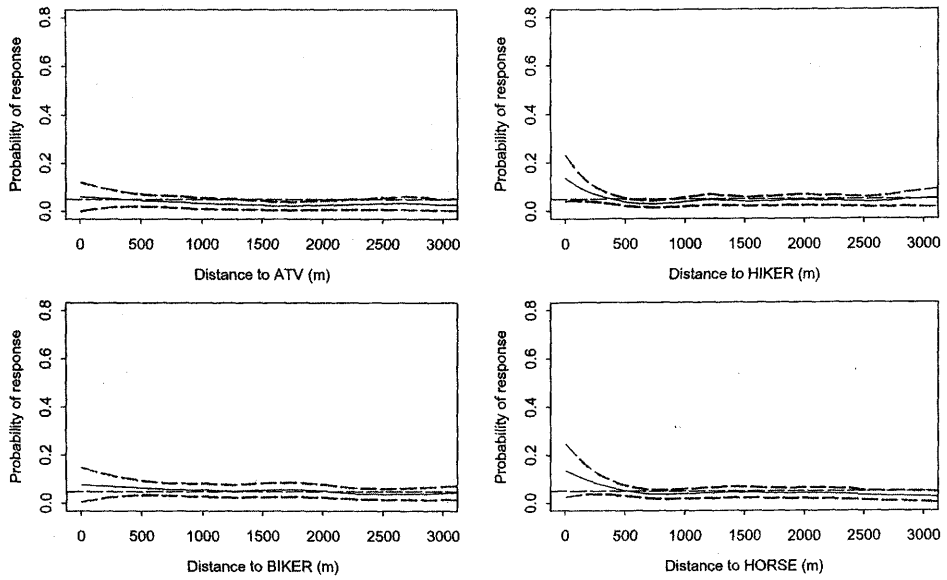


Figure 5. Estimated probability (solid line encompassed by dashed lines of the approximate 95 percent pointwise confidence interval) of a flight response by mule deer during 2002 in relation to distance (meters) from humans riding ATVs, mountain bikes, horses or hiking. A flight response is defined as an animal movement with a speed exceeding the 95th percentile of speeds observed during periods of no human activity (control period). The horizontal dashed line at the bottom of each graph is the probability of a flight response by deer during periods of no human activity, and this line represents the background, or null, condition, above which significant deer response to the off-road activities exists.

probabilities were nearly identical among all four activities and not significantly different than the null probability of 0.05 set for control periods, suggesting that deer were not exhibiting the same tendency for flight as shown by elk in relation to off-road activities (Table 1).

Conclusions and Interpretations

Elk

Movement rates and probabilities of flight response for elk were substantially higher during all four off-road activities, compared to control periods of no human activity. Consequently, off-road recreational activities like those evaluated in our study appear to have a substantial effect on elk behavior. The energetic costs associated with these treatments deserve further analysis to assess potential effects on elk survival. For example, if the additional energy required to flee from an off-road activity reduces the percent body fat of elk below 9 percent as animals enter the winter period, the probability of surviving the winter is reduced (Cook et al. 2004). Animal energy budgets also may be adversely affected by the loss of foraging opportunities while animals respond to off-road activities, both from increased movements and from displacement from foraging habitat. These potential effects will be evaluated as part of future analyses.

Our results from 2002 also show clear differences in elk responses to the four off-road activities. Elk reactions were more pronounced during ATV and mountain bike riding, and they were less so during horseback riding and hiking. Both movement rates and probabilities of flight responses were higher for ATV and mountain bike riding than for horseback riding and hiking.

Interestingly, the maximum probability of flight was approximately 0.65 for the treatments, meaning that, about 35 percent of the time, elk did not exhibit a flight response when close to an off-road activity. Most likely the response depends on local topography, cover and other factors that we have not yet analyzed as part of our flight response model. Future work will include terrain and vegetation measures as covariates in the probability models to examine whether these effects can be detected and quantified (see Taylor and Knight 2003b).

It is important to note that designing our study to maintain the same number of daily passes on transects among all four activities required the most effort for hiking and horseback riding, and the least effort for ATV riding. Specifically, to accomplish two runs per day required three groups of hikers or horseback riders (with each group hiking approximately 33 percent of transect length) but only one group of ATV riders. By contrast, accomplishing two runs per day required two groups of mountain bikers (with each group covering approximately 50 percent of transect length).

Our results for elk might have been different had we designed the study to test animal response to an equal number of groups, or equal density, of people engaged in the four off-road activities (i. e., the same number of groups of people engaged in each activity, regardless of the number of passes that could be accomplished), rather than testing for effects of equal saturation of the study area (i. e., two daily passes on transects for all four activities). In future analyses, we plan to explore the use of the amount of time spent by each off-road activity as a covariate and possibly weight the movement rates and probabilities of flight response by the inverse of time spent by each of the four off-road activities. This weighting would help account for differences in effort required among the four activities to achieve equal saturation of the study area.

Our results may also change if elk eventually become habituated to some or all of the off-road activities. We will evaluate this possibility in future analyses by formally testing for replicate and year effects under a random effects model, with repeated measures taken on radio-collared animals over time (Kirk 1982). Analyses to test for animal habituation to the off-road activities will be possible when all three years of data are collected.

Mule Deer

In contrast to elk, mule deer showed little measurable response to the off-road treatments. Movement rates increased slightly, however, during periods of all four-off road activities except ATV riding. Deer may well be responding to the treatments with fine-scale changes in habitat use, rather than substantial increases in movement rates and flight responses.

For example, it is possible that deer may respond to an off-road activity by seeking dense cover, rather than running from the activity. If mule deer are spending more time in dense cover, in reaction to any of the off-road activities, this could result in reduced foraging opportunities and a subsequent reduction in opportunities to put on fat reserves during summer that are needed for winter survival. Such potential responses will be evaluated as part of future analyses.

Utility of Response Variables

Taylor and Knight (2003b) defined a variety of terms for measuring animal responses to human activity. Neither movement rate nor probability of a flight response was defined, however, because these types of animal responses apparently have not been measured in past research. We measured these two responses to human activity because both variables can ultimately be used to estimate the energetic costs of animal reactions to human activities. For example, movement rate can be used as a background index of the rate of animal speed without human activities, versus periods of human activities, to estimate the additional energetic costs of increased movement, if any, in relation to human activities (Ager et al. 2003).

Similarly, the probability of a flight response indicates how likely an animal is to move at high speed in relation to its distance from a human. This probability indicates how likely an animal is to run from a human activity, and thereby disrupt the animal's activities related to energy acquisition (foraging) or energy conservation (resting). Any movement away from an area in relation to human activity has the potential to disrupt these foraging and resting patterns and, thereby, to cost energy (Johnson et al. 2004).

Future analyses will focus on the energetic costs, if any, to mule deer and elk from exposure to each off-road activity. Additional analyses also will include estimates of (1) the distance moved by an animal, given a flight response; (2) the time required for an animal that exhibits a flight response to return within a specified distance of the animal's location before the flight; (3) the change in space use by an animal, during or following periods of human activity, which may suggest or reflect an animal seeking greater refuge from the human activity, as compared to background, or null, use of space during periods of no human activity; and (4) the degree to which animals spend time in forage areas, gaining energy, versus time spent in nonforaging areas, during each off-road activity versus control periods.

Implications for Recreation Management

Laws and policies of public land management emphasize multiple resource uses. Management of timber, grazing, roads, minerals, and wilderness are examples of traditional uses on lands administered by the U. S. Department of Agriculture, Forest Service (Forest Service) and U. S. Department of Interior, Bureau of Land Management (BLM), the two largest federal landowners in the United States. Public land managers now face the additional challenge of serving a variety of off-road recreational uses that are increasing rapidly, and that can be difficult to accommodate on the same land area at the same time (Taylor and Knight 2003a).

New planning approaches are underway in the Forest Service to accommodate increasing off-road recreational demands while mitigating the negative effects on species like elk (U.S. Department of Agriculture Forest Service 2004). These approaches could consider two related concepts: (1) off-road use rates and (2) off-road recreational equivalents. We define off-road use rates as the number of passes per unit of time on a given linear route (primitive road or trail that we referred to as transects) traveled by an off-road activity. Our results show that one pass per day by any of the four off-road activities causes increased movement rates and flight responses by elk.

We define off-road recreational equivalents as the ratio of ATV riders, mountain bikers, horseback riders and hikers that results in approximately the same effect on a given resource, given the same off-road use rate. In the case of elk, movement rates and probabilities of flight were highest during ATV riding and lowest during horseback riding and hiking. These effects were a result of one group of ATV riders, two groups of mountain bikers and three groups of horseback riders or hikers required to complete one pass on the transects each morning or afternoon. Consequently, the stronger effects posed by ATV riding, combined with differences in the number of groups required of each activity to achieve one pass on the transects, suggest that recreational equivalents would exceed three groups of horseback riders or hikers to every one group of ATV riders, and exceed two groups of mountain bike riders to every group of ATV riders.

Although the formal methods of calculating the specific recreational equivalents could be a subject of lengthy debate, the idea that different levels of each off-road activity are required to approximate the same effect on a given resource is logical and defensible. Accordingly, off-road use rates and recreational equivalents could be tested as potential concepts in helping allocate recreational activities within and across watersheds on a given national forest or BLM field office. These concepts may be particularly relevant when derived from a combination of response variables or resource uses. For example, effects of each off-road activity on water quality, soil productivity, invasion of exotic plants and species sensitive to human activities could be considered in deriving use rates and recreational equivalents.

Such an approach would demand a substantial increase in research on effects of off-road activities. For management of elk, results from our study will be most useful when estimates of the energetic costs, if any, are derived for each of the four off-road activities in terms of use rates and recreational equivalents. Energetic costs to elk from one pass per day on a given linear route traveled by a given off-road activity could be estimated, and the equivalent energetic costs, given the same use rates, could be estimated among all off-road activities.

Although these details are not yet available, managers could begin to consider holistic management strategies for all off-road activities based on our current findings. Some watersheds might feature opportunities for ATV or mountain bike riding, for example, while other watersheds might focus on opportunities for horseback riding or hiking. Importantly, the watersheds identified for horseback riding or hiking could accommodate a substantially higher number of groups engaged in these off-road activities before realizing the same effects on elk as would be expected in watersheds where ATV or mountain bike riding are featured. This type of holistic management of different mixes of all off-road activities contrasts with management approaches that focus on a single off-road activity, without consideration of all off-road uses and their cumulative effects.

Other strategies for watershed planning might simply focus on restricting each recreational activity to specified trails or roads. In this case, our results suggest that the effectiveness of such a strategy would depend on how much area is affected by the network of trails or roads allowed for use. If the linear distance of trails or roads open to recreation is small, relative to the total area of the watershed, the effect on elk is likely to be minor or negligible. If the linear distance is large, relative to the size of the watershed, the negative effect on elk could increase substantially. The specific effects could be analyzed in the same manner as outlined for estimating effects of motorized road traffic on elk, as done with distance band models (Rowland et al. 2004).

Effective and defensible strategies to meet off-road recreation demands, while also mitigating negative resource effects, are likely to require a substantial increase in budgets of public land agencies for research, management and monitoring of these activities. Managers currently have little knowledge with which to develop effective strategies in partnership with the many public recreation users. Without such knowledge, the debate about off-road recreation is likely to intensify, with few scientifically based options for resolution in relation to mitigating potential negative effects on species like elk that are sensitive to human activities.

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