The National Park Service

WILDLIFE RESPONSES TO MOTORIZED WINTER RECREATION IN YELLOWSTONE

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P.J. White and Troy Davis

Yellowstone Center for Resources

&

Dr. John Borkowski

Montana State University

in collaboration with

Dan Reinhart, Craig McClure, Patrick Perotti

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***Abstract*:** We monitored the behavioral responses of bison (*Bison bison*), elk (*Cervus elaphus*), and trumpeter swans (*Olor buccinator*) to motorized winter recreation by repeatedly surveying seven groomed or plowed road segments in Yellowstone National Park during December 2004 through March 2005. We sampled >2,100 interactions between vehicles and wildlife groups and used multinomial logits models to identify conditions leading to behavioral responses. Responses by these wildlife species to over-snow vehicles were relatively infrequent, short in duration, and of minor to moderate intensity, with >81% categorized as no apparent response or look/resume activities, 9% attention/alarm, 7% travel, and 3% flight or defense. Analyses of similar data collected during 1999-2004 indicated the likelihood of active responses by wildlife increased significantly if (1) wildlife were on or near roads, (2) more vehicles were in a group, (3) wildlife groups were smaller, (4) ungulates were in meadows instead of forest or geothermal habitats, (5) interaction times increased, (6) wildlife were traveling instead of resting, and (7) humans dismounted vehicles and/or approached wildlife. The likelihood of an active response by bison or elk decreased as cumulative visitation increased, suggesting that these ungulates habituated somewhat to motorized recreation. There was no evidence of population-level effects to ungulates from motorized winter use because estimates of abundance either increased or remained relatively stable during three decades of motorized recreation prior to wolf colonization in 1998. Thus, we suggest that the debate regarding the effects of motorized recreation on wildlife is largely a social issue as opposed to a wildlife management issue. The likelihood of active responses by wildlife can be diminished by (1) restricting travel to predictable routes and times, (2) reducing the number of vehicles in groups, (3) reducing the number and length of stops to observe wildlife, (4) stopping vehicles at distances >100 meters, and (5) preventing human activities away from vehicles. We recommend the following changes to winter use monitoring for wildlife during winter 2006: 1) reduce the scope of behavioral response monitoring to the west-central portion of the park; 2) use trail counters to monitor night-time use of roads by bison in the Firehole, Gibbon, and Madison drainages; 3) use model selection techniques to evaluate the strength of evidence in data for competing models regarding the effects of motorized winter recreation and road grooming on wildlife; and 4) use GPS data from bison radiocollared during 2004 and 2005 (rather than field crews) to predict bison trail systems based on environmental constraints that can be compared with the groomed road system to evaluate how grooming has affected bison movements.

INTRODUCTION

National parks protect some of our nation's most important natural resources and ecosystems that, in turn, attract millions of visitors annually for recreational activities. Thus, managers of these lands are essentially charged with conserving resources, while providing for their use and/or enjoyment by the people of the United States (e.g., National Park Service Organic Act of 1916; 16 USC 1, 2-4). Recreation may disrupt ecological processes by disturbing wildlife and resulting in altered inter-specific interactions, increased energetic costs, changes in behavior and fitness, and avoidance of otherwise suitable habitat (Boyle and Sampson 1985, Knight and Cole 1995). Thus, management policies for public lands must address the effects of recreation on wildlife and other resources to ensure that the integrity of the resources, and ecosystem processes on which they depend, are not harmed. The use of reliable science to obtain a thorough understanding of the resources, ecological processes, and human-related effects is an essential prerequisite for developing these policies (Parsons 2004).

The history of winter recreation in Yellowstone National Park illustrates the difficulty of balancing the trade-off between access and recreation-related effects. Snowmobiles were first used in Yellowstone during 1949, but regular use did not occur until the 1960s and 1970s (Yochim 1998). Private snowmobiles (1,000 total) entered the park for the first time in 1963-64 and park staff began grooming snow-covered roads in 1971 to facilitate the safe passage of over-snow vehicles (Aune 1981, Yochim 1998). Winter recreation and snowmobile use increased dramatically in the following decades and more than 140,000 riders per year entered Yellowstone during the early 1990s (Yochim 1998). Almost 1 million visitors entered Yellowstone on snowmobiles (87%) or snow coaches (13%) during 1992-2003 (National Park Service, U.S. Department of the Interior 2000). Not surprisingly, a conflict arose between protecting park resources and the desires of many visitors to view the park via snowmobile. Of particular concern are the effects of road grooming on bison distribution and movements and the effects of snowmobiling on the behavior, distribution, and energetics of wildlife (National Park Service, U.S. Department of the Interior 2000).

During the severe winter of 1997, more than 1,000 bison left the park and were killed to prevent the spread of brucellosis to livestock. Some of these bison left the park by traveling along roads groomed for over-snow use (National Park Service, U.S. Department of the Interior 2000). This event prompted several plaintiffs to file suit, alleging that the National Park Service failed to conduct adequate analyses under the National Environmental Policy Act, consult with the U.S. Fish and Wildlife Service on the effects of winter recreation on threatened and endangered species, and evaluate the effects of road grooming on wildlife and other resources (National Park Service, U.S. Department of the Interior 2000). A settlement was reached in which the park agreed to address these compliance issues and, in January 2001, a final rule was signed calling for the gradual phase out of all recreational snowmobile use by winter 2004 in favor of mass transit snow coaches (National Park Service, U.S. Department of the Interior 2001). However, this decision was never implemented owing to a series of lawsuits and court decisions (e.g., District of Columbia 2003, District of Wyoming 2004). These legal actions were prompted primarily by disagreements about the effects of recreation on wildlife and other resources. Also, there was a lack of rigorous empirical studies that the courts could use to evaluate the merits of conflicting claims (District of Columbia 2003). Road grooming and snowmobile use have continued at varying levels to present, in response to conflicting legal decisions and corresponding reactive changes in winter recreation regulations (National Park Service, U.S. Department of the Interior 2004).

Our research was designed to address one aspect of the controversy regarding motorized winter recreation in Yellowstone, the behavioral responses (i.e., energy expenditure) of wildlife to motorized winter recreation. Our specific objectives were to (1) quantify wildlife and human responses during motorized winter recreation, (2) identify conditions that increase the likelihood of behavioral responses, and (3) evaluate the potential effects of increased behavioral responses and energy expenditures by wildlife from motorized recreation on their survival and population dynamics. Based on our findings, we suggest management implications and recommendations for public lands with a dual mandate of sustaining wildlife resources and recreation.

METHODS

***Wildlife Responses to Motorized Winter* Recreation:** We examined the behavioral responses of bison, elk, and swans to motorized recreation to evaluate the following management objectives regarding human use and its potential adverse effects on wildlife during winter in Yellowstone National Park:

- Minimize the avoidance, displacement, or harassment of wildlife from noise, vehicles, or other human activities;
- Minimize vehicle-caused wildlife deaths or injuries;
- Minimize human conflicts with ungulate (e.g., bison, elk) movements on plowed roads;
- Minimize incidents of wildlife trapped by snow berms on plowed roads; and
- Minimize the facilitation of ungulate use of groomed roads.

We focused on these species because of their proximity and/or perceived sensitivity to motorized recreation activities during winter. During winter 2005, surveys along seven road segments were conducted at least twice a week (including weekends and holidays) by a pair of observers snowmobiling or driving ≤50 km/hr. The surveyed road segments and their endpoints were as follows ("C" denotes portion of road segment only open to snow coaches):

1. West Yellowstone to Madison	West entrance station	Madison junction
(C) Riverside Drive	Drive entrance	Drive exit
2. Madison to Old Faithful	Madison junction	Bridge south of Old Faithful
(C) Firehole Canyon Drive	Canyon Drive entry	Canyon Drive exit
(C) Freight Road	Madison-Old Faithful road	Freight Road parking lot
3. Madison to Norris	Madison junction	Norris junction
4. Norris to Mammoth	Norris junction	north end of Swan Lake flats
5. Mammoth to Lamar Valley	High bridge	Round Prairie/Pebble Creek
6. Canyon Village to Lake Butte	Lake Butte	Canyon junction
7. Fishing Bridge to West Thumb	Fishing Bridge	West Thumb

Similar surveys were conducted during winters 1999-2004, though the number and location of sampled road segments varied among years (Hardy 2001, Jaffe et al. 2002, Davis et al. 2004, White et al. 2004). Survey routes and times were chosen using a restricted randomization design (daylight hours only) to capture daily and weekly variation in wildlife and human activities. Observers traveled a given road segment until a wildlife group (i.e., $\leq$1 animal) was detected with the unaided eye. The observers stopped at a location where the group could be observed without disturbing the animals and observe approaching motorized winter vehicles. For each wildlife group, observers recorded group size, habitat, perpendicular distance to the road, and predominant wildlife activity exhibited by undisturbed wildlife groups.

Our sampling unit was an interaction between motorized vehicles (and associated humans) and an observed group of wildlife within 500 m of the road. This somewhat arbitrary definition of an “interaction zone” allowed assessment of the influence of distance from a disturbance on wildlife responses to human activities. During each interaction, observers recorded the type of vehicle (snowmobile, coach, wheeled), number of vehicles, most common human activity within the group, and duration of the interaction. Human responses were defined as: no visible reaction to wildlife (N); stopping to observe the animals (S); dismounting the snowmobile or exiting the snow coach (D); approaching wildlife (AP); or impeding and/or hastening wildlife by blocking wildlife movements, chasing animals, or forcing animals to move faster ahead of vehicles (IH). Observers also recorded wildlife response behaviors as: no visible reaction to vehicles or humans (N); look at vehicles or humans and then resume their behavior (LR); travel away from vehicles or humans (T); attention/alarm, including rising from bed or agitation (AA); flight (i.e., quick movement away; F); or defense (i.e., attack or charge; D). Once an interaction was completed, observers continued along the road segment to locate the next group of wildlife.

Observers of measured air temperature and categorized levels of precipitation, cloud cover, and visibility for each survey. We obtained daily measurements of snow water equivalent (SWE), which is an index of the mass of water contained in a column of snow, from four automated SNOTEL sites (http://www.wcc.nrcs.usda.gov/snotel/) to assess the effects of snow pack on wildlife behavior, distribution, and stress levels. The Madison Plateau (ID 11e31s) and Canyon (ID 10e03s) SNOTEL sites were located within Yellowstone National Park, while the West Yellowstone (ID 11e07s) and Northeast Entrance (ID 10d07s) sites were located near the park’s boundary. We summed daily measurements of snow water equivalent during 1 October through 31 April to obtain a cumulative value for each winter.

We obtained daily visitation statistics from the Visitor Services Office, which compiles data from entrance stations, Business Management Office operations, entrance studies, and visitor surveys. We did not quantify the number of park vehicles traveling through the study area when the park was closed to the public. We considered this traffic to be the baseline level of human activity. Deaths and injuries of wildlife during the winter use period were obtained from the Resource Management and Visitor Protection Office, biologists from the Yellowstone Center for Resources and other sources (e.g., Montana State University). We obtained counts and population estimates for central Yellowstone bison and elk during 1965-2005 from Garrott et al. (2003), Gates et al. (2005), and Yellowstone Center for Resources (unpublished data).

Potential model variables were partitioned into five groups of related quantitative or categorical variables: wildlife activity, wildlife-related variables, human activity, environmental variables, and traffic-related variables (Tables 1 and 2). The survey variable we modeled was the most common wildlife group response observed during an interaction. Because of the relatively low frequencies of travel (T), attention/alarm (AA), flight (F), and defense (D) responses for each wildlife species, we combined these four categories into a single "active" (AC) response category. Thus, we modeled three response categories (none (N), look/resume (LR), and active) corresponding to activities requiring an increasing amount of energy expenditure.

We fit multinomial logits regression models to the data because there were three response categories (N, LR, and AC). These models were similar to a logistic regression model because we modeled logits, which are functions of response probabilities given a set of covariate conditions, denoted $\mathbf{x} = (x_1, x_2,\ldots, x_p)$, for the p model variables (Stokes et al. 1996, Hosmer and Lemeshow 2000, Allison 2003). We computed maximum likelihood estimates and odds ratios for categorical and quantitative variables.

Two logits $L_i(\mathbf{x}) = \log [\pi_i(\mathbf{x})/ \pi_2(\mathbf{x})]$ ($i = 0, 1$) were modeled where $\pi_0(\mathbf{x})$, $\pi_1(\mathbf{x})$, and $\pi_2(\mathbf{x})$ were, respectively, the probabilities of an AC response, LR response, and N response given $\boldsymbol{x}$. We treated no wildlife response as the baseline response by selecting $\pi_2(\mathbf{x})$ to be in the denominator of each odds. The logit parameters were fit using the SAS CATMOD procedure (SAS Institute 1992). A maximum likelihood analysis of variance (ML ANOVA) was used in the modeling process, which began by fitting bison, elk, or swan models with all of the variables. Human response and winter variables were retained in all models because we were interested in the specific effects of human activities across winters. Likewise, we retained interaction time (duration) and the number of snowmobiles and snow coaches in all models. We used a conservative stepwise approach for model reduction (Hosmer and Lemeshow 2000). The variable having the largest p-value was removed if its p-value >0.1 and if the change in the likelihood ratio (LR) statistic was very small (i.e., the p-value for the LR test was >0.1). Once this reduction process terminated, we considered two-variable interactions for inclusion in the model using the same p-value and LR test criteria.

We produced a set of parameter estimates $b_{0i}, b_{1i},\ldots, b_{pi}$ (i=0,1) yielding the predicted logits for the final model: $\hat{L}_i(\mathbf{x}) = b_{0i} + b_{1i}x_1 + b_{2i}x_2 + b_{3i}x_3 + \ldots + b_{pi}x_p$ (i=0,1). For covariates $\mathbf{x}_1$ and $\mathbf{x}_2$, the estimated odds ratios

$$OR_1(\mathbf{x}_1, \mathbf{x}_2) = \frac{\hat{\pi}_0(\mathbf{x}_1)/\hat{\pi}_2(\mathbf{x}_1)}{\hat{\pi}_0(\mathbf{x}_2)/\hat{\pi}_2(\mathbf{x}_2)} \text{ and } OR_2(\mathbf{x}_1, \mathbf{x}_2) = \frac{\hat{\pi}_1(\mathbf{x}_1)/\hat{\pi}_2(\mathbf{x}_1)}{\hat{\pi}_1(\mathbf{x}_2)/\hat{\pi}_2(\mathbf{x}_2)}$$

were used for interpretation of results. For a quantitative variable, $\mathbf{x}_1$ and $\mathbf{x}_2$ were selected so that the odds ratio was calculated for a one unit of measurement increase by exponentiation of the parameter (i.e., e^{estimate}). We took the reciprocal (i.e., $1/e^{\text{estimate}}$) to get the odds ratio associated with a one-unit decrease. For a categorical variable, $\mathbf{x}_1$ and $\mathbf{x}_2$ were selected so that the odds ratio was calculated by exponentiation of the difference in estimates between the effect of interest and the baseline (i.e., $e^{\text{effect}-\text{baseline}}$; Borkowski 2005:10). The reciprocal (i.e., $1/e^{\text{effect}-\text{baseline}}$) provided the odds ratio for comparing a baseline to the effect (Borkowski 2005:14). $\hat{L}_1(\mathbf{x})$ and $\hat{L}_2(\mathbf{x})$, the predicted wildlife response probabilities $\hat{\pi}_0(\mathbf{x})$, $\hat{\pi}_1(\mathbf{x})$, and $\hat{\pi}_2(\mathbf{x})$ given $\mathbf{x}$ could be back-calculated.

Bison Trail Mapping**:** We designed a protocol to sample and map bison travel vectors (i.e., trail systems) in the west-central portion of the park to generate an independent dataset of bison travel networks that could be used to evaluate/validate these movement models. Our intent was to address the question of where bison have the highest propensity to travel in relation to variations in the landscape. These data could be used to predict the propensity for bison to travel in areas given the landscape attributes and evaluate if segments of groomed roads used frequently by bison during winter overlap with high landscape probabilities for bison to travel there anyway given the landscape attributes. In addition, the data could be used to validate and/or refine the predictions of conceptual models of bison movement through the park. If the models predict bison trail systems and movements accurately, then we could compare model predictions of bison movement based on environmental constraints with the existing groomed road system to evaluate how grooming has affected bison movements. Our basic predictions were as follows: 1) bison trails will generally run parallel with elevation contours (i.e., bison prefer not to travel up or down relatively steep slopes); 2) bison trails will occur at the lowest possible elevation in areas where the landscape is constrained; 3) bison prefer not to travel through forested areas; and 4) bison trails will connect meadow patches.

We conducted a pilot study to test the trail mapping protocol in the winter range for bison in the west-central portion of the park, including the Madison, Firehole, and Gibbon river drainages. The known winter range was defined based on rigorous ground and aerial surveys of bison distributions during 1997-2004. Our basic protocol was to snowshoe transects perpendicular to the elevation gradient (i.e., contour lines) along rivers within the winter range and record the locations and attributes of bison tracks intersecting each transect. Trail mapping occurred 2-3 days per week during February 16 through March 4, 2005, after most bison had migrated from the Hayden Valley to the Madison-Firehole area. We anticipated 2-3 people would be in the field sampling transects each day and that each person would sample at least 3 transects per day for bison tracks. Thus, we expected to sample >80 transects. In conjunction with this effort, personnel from Montana State University tracking wolves recorded the locations and attributes of bison tracks they opportunistically encountered in areas outside the high-use areas of the winter range.

Using Geographic Information Systems, biologists systematically located starting points for transects every 0.25 kilometers along the major rivers (Firehole, Gibbon, Madison) and other areas (e.g., Nez Perce Creek) within the winter range. Each starting point/transect was assigned a unique number and extended linearly from one side of the river in a perpendicular direction up the elevation gradient. Transects having adjacent starting points were sequentially alternated from one side of the river to the other. We stratified transects into stratum categories based on topographic relief (i.e., elevation gradient), habitat, and landscape openness/constraint (e.g., distance between steep elevation gradients). Specifically, transects were assigned to the following strata: 1) forested canyons with steep elevation gradients and tight landscape constraints; 2) open meadows with little change in elevation/slope; 3) primarily meadows with interspersed patches of forest in broad valleys with little change in elevation/slope or rolling hills; 4) primarily forest with interspersed meadows in broad valleys with little change in elevation/slope or rolling hills; and 5) primarily geothermal-influenced areas with meadows and interspersed patches of forest.

We randomly selected 100 transects from the set of starting points, with the restriction that each stratum contained at least 10% of the selected transects. Based on the order drawn, we assigned transects within each stratum across the sampling periods to account for temporal trends in the data analysis (i.e., sampled among strata each sampling period and throughout the winter). Time permitting, we allocated additional sampling effort to areas/strata where the number of intersected tracks along sampled transects was relatively low. Biologists snowshoed transects and recorded the locations and attributes of bison tracks intersecting each transect. When tracks were encountered, biologists ascertained the direction of travel, if possible, and categorized use (i.e., response variable) as follows: 1) single (i.e., single set of tracks through snow or mud with no other tracks within 50 meters along the transect; 2) diffuse (i.e., numerous sets of foraging tracks within 50 meters along the transect; tracks could be made by one or more animals); and 3) trail (i.e., multiple sets of tracks along a compacted, single-file path through mud or snow).

If use was categorized as single or trail, then the biologist measured the width of the outermost tracks (single use) or path/trench (trail) and used a Global Positioning System to record the location and general direction of the tracks for 50 meters in each direction from the intersection point (i.e., produce a line segment of the trail on GPS). If use was categorized as diffuse, then the biologist measured the distance along the transect over which the tracks occurred, rather than attempting to follow the tracks for 50 meters in each direction. The biologist then continued sampling the transect until more tracks were encountered. Sampling along a given transect ceased when one of the following situations occurred: 1) dangerous or impassable terrain was encountered (e.g., cliff face, geothermal crust area, avalanche conditions, herd of animals); 2) sampled ¼ km beyond known winter range; or 3) sampled 3 km along the transect. Biologists obtained a GPS location at the start and end point of each transect, as well as every 500 meters along transects.

Covariates that could be related to the presence/absence and category of use for bison tracks include: 1) slope (mean change over 200 meters); 2) habitat; 3) snow water equivalent; 4) elevation; 5) distance to river; 6) distance to forest edge; 7) distance to lowest elevation; 8) transect length; and 9) landscape open-ness/constraint (e.g., distance between steep elevation gradients. Many of these covariates will be highly variable along each transect and, therefore, cannot be adequately represented by a single measurement or estimate. These covariates could be estimated along each transect and at each intersection point with bison tracks using GIS coverages or model output (e.g., slope, snow water equivalent, distances), so that a measure of variability (e.g., range, minimum, maximum, standard deviation) could be calculated for each covariate. In addition, these covariates could be estimated at a random sample of locations throughout the bison range using GIS coverages or model output.

We anticipated this sampling design would result in transects from many strata (if not all strata) being sampled during the same day and transects located far apart being sampled within the same week. Hence, we would obtain a representative sample from the known bison range across time. Also, the dependence of observed covariates and responses among sampled transects would be minimized. We anticipated that many transects would intersect bison tracks at multiple places, especially in open meadows used as foraging patches. By measuring widths of trails and diffuse foraging areas, we obtained estimates of the proportion of each transect that was intersected by tracks (analogous to percent cover used in many studies). Also, we could create a weighted index or score for each transect by first assigning a use score to each set of intersected tracks based on its use category and then taking the sum of these use scores. Thus, each transect could have an associated index or score as a response variable, along with the transect covariates. These data could then be fit with a regression model or used in model selection techniques.

Unfortunately, only 37 transects were sampled during winter 2005 owing to logistical problems (i.e., shortage of housing and snowmobiles), inexperienced technicians, and poor snow conditions for mapping trails. Thus, during spring 2005 we collaborated with Montana State University and the Bison Ecology and Management Program to design a different analytical protocol based on GPS data collected from radiocollared bison during 2004 and 2005. Jason Bruggeman, a graduate student at Montana State University, will select consecutive GPS locations obtained 30 minutes apart and develop distributions of distances and turning angles between locations to define a threshold value for one or both of these parameters that indicates a significant movement bout. He will remove all locations for which the distance or angle between is below this threshold because these movements were likely related to foraging and not important for identifying key bison travel routes. Next, he will take each travel vector and sample for covariate attributes at points along the travel path. He will then create a random movement data set by randomly relocating the original travel vectors within the study area as per Bergman (2003). These random vectors will be sampled for the same covariates as the original travel paths. Using a habitat use/availability framework and a logistic regression analysis (response variable 1 or 0), he will be able to examine if bison movements are random and any important habitat and topographical features influencing bison choice of travel routes. The results of this analysis will be compared to a similar study and modeling exercise using a completely independent bison travel data set from ground distribution surveys conducted by Montana State University.

In addition, Jason Bruggeman will use the travel vectors to generate a GIS layer map and identify regions throughout the central bison herd's range with high and low probabilities of travel. He will then make comparisons between actual and expected bison travel behavior to provide a quantitative understanding of the role of topography and habitat in influencing bison travel routes. This GIS map will be compared to another map developed from the bison road travel database maintained by Montana State University to identify portions of the groomed road network that receive high and low bison use.

Bison Demography and Spatial Dynamics: In collaboration with the Yellowstone Center for Resources, Montana State University completed an inventory of existing data sets regarding population estimates, seasonal distribution patterns, spatial and temporal variation in activity budgets, and information on bison use of the road system in Yellowstone National Park. The quality and usefulness of each type of data was evaluated by two graduate students, who worked with Dr. Robert Garrott, several statisticians, and other faculty and park staff to establish the best possible analytical protocols for each database. These analytical protocols were summarized in two study plans designed to provide insights into the spatial and temporal patterns and drivers of bison population growth, movements, and use of the groomed road system. A study of the mechanisms influencing spatial dynamics of central Yellowstone bison was initiated by Jason Bruggeman, while a demographic analysis of the Yellowstone bison herds during 1901-2000 was initiated by Julie Fuller. Both graduate students should complete these analyses and produce scientific products within the next year. We are currently working with these students on journal manuscripts entitled "Temporal variability in bison winter use of a road and travel network in Yellowstone National Park" and "Bison demography in Yellowstone National Park, 1902-present."

***Nutritional Assays*:** Investigations with captive and free-ranging female elk have demonstrated that allantoin:creatinine ratios from urine deposited in snow can be used as an index of metabolizable energy intake (Garrott et al. 1996, Vagnoni et al. 1996). Pils et al. (1999) refined collection protocols and analytical techniques and presented results from the severe winter of 1997 for elk on the central and northern ranges of Yellowstone National Park, Wall Creek Wildlife Management Area (southwestern Montana), National Elk Refuge (Wyoming), and Hungry Horse Reservoir Area (northwestern Montana). During winter 2005, we collaborated with Montana State University and Montana Fish, Wildlife, and Parks to collect snow-urine samples from elk wintering on the central and northern ranges of Yellowstone National Park (including Dome Mountain outside the park), Gallatin Canyon, Blacktail Wildlife Management Area (Madison Valley, Montana), Sun Ranch (Madison Valley), and Wall Creek Wildlife Management Area (Madison Valley). Montana State University also collected snow-urine samples from bison in the Hayden Valley and Madison-Firehole areas.

Snow-urine samples collected during winter 2005 will be assayed for allantoin and creatinine this summer to enable temporal and spatial comparisons of the nutrition of wintering elk. Since the mid-1990s, biologists from Montana State University and Montana Fish, Wildlife, and Parks have collected snow-urine samples from elk wintering in the Gravelly-Snowcrest Range, Gallatin Canyon, Lower Madison, and/or west-central portion of Yellowstone National Park (Garrott et al. 1996, Pils et al. 1999, Hamlin and Ross 2002; unpublished data). Allantoin:creatinine ratios from these areas indicate that digestible dry matter intake and energy content of the winter diets for elk in these areas during recent drought years have been equal to or above that observed during the severe winter of 1997 (Hamlin 2005), when high winter-kill and migration of bison and elk out of the park were observed on the central and northern ranges of Yellowstone (Singer et al. 1989). Diet quality may have been slightly reduced in winter 2003, but was higher in all areas during winter 2004 compared to 1997. In fact, allantoin:creatinine ratios were higher during some of the recent drought years than for supplementally fed elk on the National Elk Refuge, Wyoming, during 1997 (Hamlin 2005). Perhaps mild winter conditions during the drought period have, to some extent, offset poorer nutritional conditions during summer.

RESULTS

Winter 2005: Snow pack during winter 2005 was 20% below average the historical average in the west-central portion of the park (Madison, West Yellowstone), 30% below average in the interior (Canyon), and 50% below average on the northern range (Northeast Entrance, Table 3). Ambient temperatures during surveys ranged from -15°F to 56°F in the Madison area, -10°F to 36°F in the Lake area, and -2°F to 54°F in the Mammoth area.

The public winter season was 89 days from December 15, 2004, through March 13, 2005, when all park grooming operations ceased. However, lack of snow accumulation precluded over-snow (OSV) traffic through the West Entrance Station prior to January 1, 2005, and after March 9, 2005. During these times, a mix of rubber-tracked snow coaches and commercial 4-wheel drive vehicles were allowed to enter the west gate and travel to Old Faithful. Plowing operations began at Mammoth Hot Springs on March 7, 2005, and progressed southward into the interior of the park. Monitoring of interactions between OSVs and wildlife began on December 9, 2004, six days prior to the scheduled opening for public use, and continued until March 25, 2005, approximately two weeks after roads closed to the public.

Total OSVs entering the park included 424 snowmobiles and 25 coaches through the East Entrance Station, 7,762 snowmobiles and 565 coaches through the South Entrance Station, and 10,229 snowmobiles and 970 coaches through the West Entrance Station (Appendix A). Data from the North Entrance Station were not available at the time of this report. The maximum number of snowmobiles and coaches entering the West Entrance Station on any given day was 302 mobiles and 25 coaches. The maximum daily number of snowmobiles and coaches entering the South Entrance Station was 146 mobiles and 16 coaches. The maximum daily number of snowmobiles and coaches entering the East Entrance Station was 27 mobiles and 2 coaches. Hardy (2001) reported that levels of stress hormones in central Yellowstone elk were higher after exposure to >7,500 cumulative vehicles entering the West Entrance Station. This threshold was reached on December 31st during both winters of her study (i.e., 1999, 2000), but progressively later in following winters (January 20, 2003; February 1, 2004; and February 22, 2005).

Observers conducted 262 surveys of road segments, totaling 7,600 kilometers, and recorded 3,785 groups of wildlife during these surveys (614 groups of elk, 1,920 groups of bison, 722 groups of swans, and 529 groups of other species such as bald eagles, coyotes, and wolves; Table 4, Appendix B). No groups of wildlife were observed during 6 surveys of road segments. Observers recorded 2,460 interactions between groups of wildlife and recreationists, including 1,006 groups of snowmobiles (41%), 431 groups of coaches (17%), 1,010 groups of wheeled vehicles (41%), and 13 groups of pedestrians (hikers, skiers, bicyclists; 1%). Seven hundred and sixty-two interactions between OSVs/humans and ungulates occurred when groups of bison or elk were off the roads, including 538 interactions involving snowmobiles and 224 involving snow coaches. Fifty-eight percent of the observed human responses (*n* = 1,276) towards groups of bison, elk, and swans were categorized as "no visible reaction to wildlife", 30% stopped to observe wildlife while remaining on their snowmobile or inside their coach, 4% dismounted (left their OSVs), 2% approached wildlife, and 6% impeded and/or hastened wildlife (Appendix C).

The predominant responses of most bison, elk, and swans to OSVs and wheeled vehicles were typically minor, with 66% (*n* = 1,416) categorized as no apparent response, 15% (*n* = 320) look/resume, 9% (*n* = 195) attention/alarm, 7% (*n* = 148) travel, 3% (*n* = 60) flight, and <1% (*n* = 2) defense (Borkowski 2005, Appendix D). Wildlife responses to motorized winter use differed somewhat across species, with the "no apparent response" and "look-and-resume" categories accounting for 91%, 70%, and 69% of the bison, elk, and swan observations (Borkowski 2005). The magnitude of the responses varied considerably among species, with the likelihood of observing an active response by bison and elk increasing as numbers of snowmobiles and snow coaches in a group increased, but not increasing for swans (Borkowski 2005). The estimated odds of observing an active response relative to no response by bison were 1.5 times greater for each additional snowmobile in the group (up to 4 snowmobiles) and 1.8 times greater for each additional snow coach (up to 3 coaches). Thus, under identical conditions, we would expect the odds of an active bison response (relative to the odds of no response) to be, on average, 2.2 times (i.e., 1.5^2) higher for a group of four snowmobiles than for a group of two snowmobiles. Likewise, the odds of observing an active response relative to no response by elk were 1.5 times greater for each additional snowmobile in the group and 4.7 times greater for each additional snow coach (Borkowski 2005).

Wildlife responses varied by species among commercially guided, administrative, and wheeled groups during winter 2005 (Borkowski 2005). For example, the estimated odds of observing an active response compared to no response by bison or elk were 2-3 times higher for administrative traffic than for non-administrative traffic. This finding appeared to be due to an increased tendency for administrative vehicles to stop more often in the vicinity of wildlife and to impede/hasten wildlife more frequently. At this time, however, we cannot satisfactorily explain why administrative traffic would stop more frequently, nor can we discount that this apparent result may be spurious owing to relatively small sample sizes.

Several other variables influenced the odds of a response by bison, elk, and/or swans to motorized use during winter 2005, including group size, distance to road, human activity, habitat, predominant wildlife activity, ambient temperature, interaction time, and precipitation (Borkowski 2005). For example, the estimated odds of observing an active response relative to no response by elk were 28 times higher for each additional minute of interaction time. The estimated odds of observing an active response relative to no response decreased as group size increased for bison and swans. The odds of an active response by bison, elk, and/or swans were not significantly influenced by the numbers of motorized vehicles entering the park during winter 2005 (Borkowski 2005).

No wildlife deaths owing to collisions with OSVs occurred during winter 2005. However, at least five elk, two coyotes, and one pronghorn died from collisions with wheeled vehicles. We observed wildlife on the plowed road from Mammoth to the Northeast Entrance Station on 55 occasions (36 bison groups, 18 coyote groups, and 1 elk group). Wildlife were not trapped by, or forced to jump over, snow berms along the sides of the road during any of these observations. Bison were observed on groomed roads during 261 of 1,920 observations, while elk were observed on groomed roads during 31 of 614 observations. Use of groomed roads occurred throughout the daylight survey hours, with no apparent peak time of road use. A total of 144 interaction events between ungulates (bison and elk) and OSVs were documented when animal groups were on the groomed roads, including 104 groups of snowmobiles and 40 groups of snow coaches. Seventeen percent of these snowmobile groups impeded or hastened wildlife movement. Sixty-two percent of these snow coach groups impeded or hastened wildlife movement. The estimated odds of an active response by bison relative to no response were 11 times greater when the bison group was on the road compared to off the road (Borkowski 2005).

We recorded numbers of animals and distances from roads for the nearest animal in 1,919 groups of bison, 614 groups of elk, and 722 groups of swans. Mean distances to the nearest animal in bison, elk, and swan groups from roads were 179, 148, and 86 meters, respectively. On average, swans were observed closer to roads because the road systems are typically located close to rivers. However, wildlife groups located closer to motorized winter use corridors exhibited increased responses to OSV traffic and associated human behaviors. Behavioral responses of wildlife decreased as distance from motorized winter use corridors increased. The estimated odds of observing no response relative to an active response by bison, elk, and swans were 1.2 times greater for each 10-meter increase in distance from the road. The estimated odds of observing an active response by bison more distant from the road increased as interaction time increased (Borkowski 2005).

***Winters 1999-2004*:** Peak snow water equivalent values (cm) for the Madison Plateau SNOTEL site were 86.1 in 1999, 50.5 in 2000, 61.0 in 2002, 56.6 in 2003, and 63.5 in 2004. Thus, snow pack was relatively high in 1999, but low during 2000-2004, compared to the 37-year average of 67.6 cm. The odds of observing a look/resume or active response relative to no response for bison and elk were 1.2-1.3 times more likely for a 1 cm increase in snow water equivalent.

The public OSV season lasted 89 days in 1999, 82 days in 2000, 82 days in 2002, 72 days in 2003, and 88 days in 2004. The mean and standard deviation (SD) of daily OSVs entering the West Entrance Station were 514 ± 208 in 1999, 486 ± 222 in 2000, 593 ± 269 in 2002, 320 ± 114 in 2003, and 178 ± 59 in 2004. Maximum daily numbers were 1,168 OSVs on December 28, 1998, 1,010 on February 19, 2000, 1,874 on December 30, 2001, 573 on February 30, 2003, and 330 on February 15, 2004. Peak visitation typically occurred on weekends and holidays, while fewer vehicles entered the park on weekdays. OSV counts during 1999, 2000, and 2002 exceeded the 1979 peak of 738 daily OSVs entering the West Entrance Station (Aune 1981) on 38 days. Cumulative OSVs entering the West Entrance Station totaled 45,785 in 1999, 40,298 in 2000, 46,855 in 2002, 23,073 in 2003, and 15,846 in 2004.

We observed >7,700 encounters between wildlife and OSVs in unguided groups (pre-2004), commercially guided groups of snowmobiles and snow coaches (2004 only), or administrative groups of park and concessionaire staff. The responses of OSVs and associated humans to observed wildlife groups were relatively minor. During 2003 and 2004, 59% of humans on OSVs that observed groups of bison or elk showed no visible reaction and did not stop, 22% stopped to observe wildlife but remaining on their snowmobile or inside their coach, 9% stopped and dismounted their OSVs, 5% approached the wildlife, and 5% impeded or hastened the movement of wildlife with the OSVs. For swans, 63% of humans showed no visible reaction and did not stop, 22% stopped, 9% dismounted, 6% approached, and <1% impeded or hastened wildlife. Snow coaches and snowmobiles accounted for 25% and 75% of these impede/hasten interactions.

There was a strong association between human behaviors and wildlife responses (Tables 5*a*, *b*). The odds of an active response by elk were 1-2 times greater when humans stopped their OSVs and 7-8 times greater when humans approached bison or elk (Table 6). For swans, the odds of an active response were 4-5 times greater when humans dismounted their OSVs and approached (Table 7). There was also a strong association between type and number of OSVs and wildlife responses (Tables 5*a*, *b*). The odds of an active response by bison and elk were 1-2 times greater when the vehicles were either snowmobiles or snow coaches compared to wheeled vehicles before and after grooming on the 3 road segments in the Firehole, Gibbon, and Madison drainages (Table 6). The odds of an active response by bison, elk, and swans were 1-2 times greater for each additional snowmobile in a group and 2 times greater for elk with an increase of one snow coach to a group (Table 8). The odds of an active response by elk also increased as interaction time increased (Table 8).

The odds of an active response by bison were 2 times greater when vehicles in a group were guided compared to unguided (i.e., unguided OSVs from winter 2003 or wheeled vehicles from either winter; Table 7). The relationship of guided and unguided groups on the elk group response differed between winters, with a reduction in the odds ratios for an active response by guided groups in 2003 compared to 2004 (Table 9). For swans, the effect of increasing numbers of snowmobiles differed based on whether the snowmobiles were guided or unguided, with a reduction in the odds ratios for an active response by guided compared to unguided groups (Table 10).

Wildlife responses to motorized winter vehicles and associated humans were typically minor during all winters. For bison, 83% of responses were categorized as no apparent response, 8% look/resume, 1% attention/alarm, 6% travel, 1% flight, and <1% defensive (Table 11). For elk, 50% of responses were categorized as no apparent response, 30% look/resume, 11% attention/alarm, 6% travel, 2% flight, and <1% defensive. For swans, 54% of responses were categorized as no apparent response, 21% look/resume, 10% attention/alarm, 14% travel, and 1% flight. For bison and elk, there were significant decreases in wildlife responses as group size and distance to the road increased. The odds of active responses by bison or elk decreased 18% for each additional animal in the group (Table 12). Also, the odds of observing no response relative to an active response by bison or elk were 2-3 times greater for each 100-m increase in distance of the nearest animal in the group to the road (Table 8). For swans, the odds of observing no response relative to an active response was 60 times greater for each 100-m increase in distance to the road (Table 8). There were significant interaction effects between winter and distance (Table 10 and 13), indicating the magnitude of the effect of distance to the road on the wildlife response varies among winters.

There was a strong association between wildlife response and habitat type (Table 5*a*, *b*). If a bison or elk group was on the road, then the odds of an active response were more than 11 times greater than if bison or elk were off-road in meadow habitat (Table 6). If bison or elk were in geothermal or forest habitats, however, then the odds of an active response were significantly lower than for groups in meadow habitat (Table 6). There was also a significant association between the predominant activity of wildlife prior to disturbance and their response. If bison, elk, or swans were traveling, then the odds of an active response were 3-10 times greater than if they were resting (Table 7). If the undisturbed activity was standing/feeding, however, then the odds of an active response by bison and swans were significantly lower than for resting (Table 7).

The odds of observing no response by bison or elk relative to an active response were 1.1 times more likely for each cumulative increase of 1,000 snowmobiles in visitation (Table 12). A significant interaction effect between winter and cumulative visitation was detected for both bison and elk (Table 13), indicating the impact of visitation on bison and elk group responses varied among winters. Interpretation of this interaction is difficult because visitation was highly variable across the five winters.

Aerial counts of central Yellowstone bison indicate that numbers increased from <500 to >3,000 during 1960-2004 (Gates et al. 2005). Likewise, counts and population estimates during 1965-2001 indicate that numbers of central Yellowstone elk fluctuated around a dynamic equilibrium of approximately 500-550 animals for at least three decades prior to the colonization of wolves in 1998 (Garrott et al. 2003). During the same period, the number of over-snow vehicle users increased from approximately 5,000 in the mid-1960s to >100,000 during the mid-1990s (Figure 1).

DISCUSSION

The frequency and intensity of responses by bison, elk, and swans to motorized winter use in Yellowstone were relatively minor and infrequent compared to several other studies of human disturbance. Fortin and Andruskiw (2003) reported that 3% of bison in Prince Albert National Park, Saskatchewan, Canada, reacted to human presence by approaching, 46% reacted by looking while remaining in place, and 51% reacted by fleeing the area. Bison were as likely to flee from a person on foot as a snowmobile and the probability of flight by groups that included bison less than a year old increased as the snowmobile approached, reaching 50% at 257 meters. Similarly, bison, mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*) at Antelope Island State Park, Utah, exhibited a 70% probability of flushing from on-trail hikers or mountain bikers when the animals were <100 meters from the trail (Taylor and Knight 2003).

The relatively infrequent and lower intensity responses to provocation by bison and elk in Yellowstone suggest there is a certain level of habituation to motorized winter use and the associated interactions with the humans. Habituation occurs when an animal learns to refrain from responding to repeated stimuli that are not biologically meaningful (Eibl-Eibesfeldt 1970). Wildlife may become conditioned to human activity when the activity is controlled, predictable, and not harmful to the animals (Schultz and Bailey 1978, Thompson and Henderson 1998), such as the daytime recreational traffic in central Yellowstone. Habituation by bison and elk to motorized winter use in Yellowstone may occur with available food as an incentive, in conjunction with frequent and predictable vehicular traffic patterns and the lack of direct negative impacts (e.g., no human hunting pressure; Hardy 2001).

Though large winter-to-winter variability in cumulative exposure to motorized winter use exists, bison and elk in Yellowstone have continued to utilize the same core winter ranges during the past three decades. The majority of OSVs travel in predictable ways, remaining confined to roads and typically without humans threatening or harassing elk and bison. Few people ventured far from roads, established trails, or areas of concentrated human activities (e.g., warming huts, geyser basin trails). These characteristics of winter recreation are likely to facilitate behavioral habituation by wintering bison and elk to motorized vehicle traffic (Hardy 2001). Hence, future winter recreational activities should be conducted in a predictable manner that allows animals to habituate to motorized vehicles and the associated human activities.

Despite this evidence of habituation, increased provocation of wildlife behavioral responses occurred if human activity was in close proximity to the wildlife group. Similar to Aune (1981), we found an increase in behavioral responses by ungulates to motorized use as the distance from groomed roads decreased. The closer bison, elk, and swans were to any type of human activity, including vehicular travel on roads, the more likely they were to behaviorally respond. Fortin and Andruskiw (2003) concluded the effects of humans on bison in Prince Albert National Park, Saskatchewan, Canada, could be minimized by keeping humans at least 260 m from herds and being discreet when near large herds containing young bison.

We did not conduct energetics modeling to evaluate the relative energy costs of wildlife interactions with OSVs in relation to their total daily energy expenditures because numerous assumptions are required and poorly defined parameter estimates could strongly affect model output (Beissinger and Westphal 1998). However, behavioral responses during each winter were consistently infrequent, short in duration, and of minor to moderate intensity. This finding suggests that animals exposed to OSVs typically do not incur a substantial energetic cost from such interactions, even if provocation is repeated several times during the day. Gross estimates of energy cost for an elk provoked by OSVs, based on the maximum observed distance moved by a provoked elk during 2004, represented an energy increment of approximately 1.5% of the total daily energy expenditure (27,030 kJ) for basal metabolism and activity of an undisturbed, adult female elk weighing 236 kg during winter (White et al. 2004). Accumulated energy costs of three such responses to provocations would average <5% of total daily energy expenditure. However, it is unlikely that this many travel or flight responses would occur for a given animal during a day. Such responses were only observed during <10% of interactions between elk groups and OSVs, and evidence suggests that animals habituate to increasing OSV traffic within and among days. Thus, it is unlikely that many elk incur moderate energy costs from human provocations.

Minor to moderate energy costs from disturbance should be easily compensated for and, most likely, not have significant demographic consequences (Reimers et al. 2003). Similar findings were reported for wild reindeer (*Rangifer tarandus*) in southern Norway responding to direct provocation by snowmobiles or skiers (Reimers et al. 2003), even though the mean flight distances of 660-970 m for reindeer were approximately 3-4 times greater than the maximum distance moved by elk after provocation during our winter monitoring. It is reasonable to expect that energetic costs of human disturbance would be minor if animals habituate to OSVs within and among winters, as appears to be the case for bison and elk in the most intensively used OSV corridors in Yellowstone.

The fundamental biological question regarding human winter use in Yellowstone is does winter recreation adversely affect the fitness and survival of bison and elk? Counts of central Yellowstone bison increased exponentially during 1965-2004 while motorized winter recreation also increased exponentially from 1,000 to >100,000 riders during the same period (Gates et al. 2005). Similarly, population estimates for central Yellowstone elk remained relatively stable during 1960-1998, prior to substantial colonization of the area by wolves (Garrott et al. 2003). These bison and elk winter in the same areas each year and coexisted with substantially increased motorized winter use without a decrease in abundance. Thus, any adverse effects of motorized winter use to ungulates have apparently been compensated for at the population level. Fortin and Andruskiw (2003) reached a similar conclusion for bison in Prince Albert National Park, Saskatchewan, Canada. They found no evidence that the frequency of disturbance imposed on bison by snowmobiles, trucks, or foot traffic had an important effect on resource use or bison density among meadows.

Based on these population-level results, we suggest that the debate regarding effects of human winter recreation on wildlife in Yellowstone is largely a social issue as opposed to a wildlife management issue. Effects of winter disturbances on ungulates from motorized and non-motorized uses more likely accrue at the individual animal level (e.g., temporary displacements and acute increases in heart rate or energy expenditures) than at the population scale. A general tolerance of wildlife to human activities is suggested because of the association between locations of large wintering ungulate herds and winter recreation. Habituation to human activities likely reduces the chance for chronic stress or abandonment of critical wintering habitats that could have significant effects at the population level, especially when these activities are relatively predictable.

RECOMMENDATIONS

Our findings suggest several aspects of human behavior associated with motorized winter use could be modified to reduce wildlife disturbance, including: 1) when possible, stop at distances >100 meters from groups of wildlife; 2) reduce the total number of motorized vehicles in groups that stop in the same area to observe wildlife; 3) reduce the total number of stops to observe wildlife and, during these stops, prevent human activities away from the vehicles; and 4) reduce interaction time because the likelihood of an active response by wildlife increases with increasing interaction times. Training is essential because recreationists often perceive it is acceptable to approach wildlife more closely than the tolerance levels indicated by empirical data and tend to blame others for stress to wildlife rather than hold themselves responsible (Taylor and Knight 2003). Because bison and elk behaviorally respond to recreationists that deviate from known, predictable routes, management measures that encourage visitors to remain on roads and established trails should reduce the incidence rates of wildlife disturbance.

Given the consistent findings of behavioral response studies to date, and the relatively low power to detect statistically significant changes in wildlife responses in the near future, we recommend focusing the behavioral sampling of wildlife responses to OSVs in the Firehole, Gibbon, and Madison drainages, while ceasing or reducing such monitoring throughout the remainder of the park. This approach will enable us to maintain continuity in behavioral sampling in the area of most intensive OSV use, while providing us to with more logistical flexibility to begin focusing other issues of importance. It will also reduce the significant fuel costs (~$6,000) associated with this monitoring during winter 2005. We also recommend the following changes in monitoring wildlife responses to motorized recreation during winter 2006: 1) use trail counters to monitor night-time use of roads by bison in the Firehole, Gibbon, and Madison drainages; 2) use model selection techniques to evaluate the strength of evidence in data for competing models regarding the effects of motorized winter recreation and road grooming on wildlife; and 3) use GPS data from bison radiocollared during 2004 and 2005 (rather than field crews) to predict bison trail systems based on environmental constraints and compare them with the existing groomed road system to evaluate how grooming has affected bison movements.

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Table 1. Variables used in multinomial logits regression models to evaluate the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 1999-2005. Type refers to categorical (C) or quantitative (Q) variables. An "X" indicates that the variable was initially included in models for the 5-winter study (1999-2004) and/or 2-winter study (2003-2004). The separate analyses for winter 2005 included the same variables as the 2-winter study.

Wildlife Behavior Variables	**Code**	**Type**	**Units**	**5-Winter Study**	**2-Winter Study**
Most common wildlife response	wresp	C		X	X
Predominant wildlife activity	actv	C			X
Number wildlife in group	sppnum	Q	10 animals	X	X
Distance of nearest animal to road	dist	Q	100 meters		X
Midpoint distance nearest animal to road	mdist	Q	100 meters	X	
Habitat types	hab	C		X	X
Winter	winter	C		X	X
Human Activity Variables	**Code**	**Type**	**Units**	**5-Winter Study**	**2-Winter Study**
Number of snowmobiles	sb	Q	1 snowmobile		X
Number of snow coaches	sc	Q	1 snow coach		X
Vehicle type	vtype	C		X	
Vehicle group type	gtype	C			X
Human / wildlife interaction time	intxn	Q	minutes		X
Most common human response	hresp	C		X	X
Weather Variables	**Code**	**Type**	**Units**	**5-Winter Study**	**2-Winter Study**
Snow water equivalent	swe	Q	cm index	X	X
Cumulative snow water equivalent	cumswe	Q	cm index	X	X
Temperature	temp	Q	degrees F		X
Cloud cover	ccover	C			X
Precipitation	prcp	C			X
Visibility	vsbl	C			X
Recreational Traffic Variables	**Code**	**Type**	**Units**	**5-Winter Study**	**2-Winter Study**
Daily west gate count	west	Q	100 vehicles	X	
Cumulative west gate count	cumwest	Q	1000 vehicles	X	
Daily west and south gate count	gate	Q	100 vehicles		X
Cumulative west and south gate count	cumgate	Q	1000 vehicles		X

Table 2. Categorical variables used in multinomial logits regression models to evaluate the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 1999-2005. An asterisk indicates the baseline category for that variable.

Variable	**Category**	**Explanation**
Undisturbed wildlife activity (actv)	T	Traveling
	S	Standing / Perching / Floating
	U	Unknown
	R*	Resting
Human response (hresp)	S	Stop and remain on OSV
	D	Dismount but remain near OSV
	AP	Approach wildlife
	IH	Impede / hasten wildlife (2-winter study only)
	N*	Did not stop
Vehicle group type (gtype)	A	Administrative traffic
	G*	Guided by a commercial operator
	N	Not guided
Off or On Road (onroad)	Off	All animals in group off road
	On*	Some animals in group on road
Winter (winter)	99	December 1998 to April 1999
	00	December 1999 to April 2000
	02	December 2001 to April 2002
	03	December 2002 to April 2003
	04	December 2003 to April 2004
Habitat (hab)	A	Aquatic
	F	Forest
	BF	Burned forest
	M*	Meadow
	TH	Thermal

Variable	**Category**	**Explanation**
Cloud cover (ccover)	0	Clear
	1	Up to 25%
	2	25-50%
	3	50-75%
	4*	75-100%
Precipitation (prcp)	0	None
	1	Light / Intermittent rain
	2	Constant rain
	3	Light snow
	4*	Heavy snow
Wildlife activity (actv)	U	Unknown
	R*	Resting
	S	Standing / Perching / Floating
	T	Traveling
Vehicle type (vtype)	W	Wheeled
	OSV*	Snowmobile / Coach
Visibility (vsbl)	1	Good
	2	Fair
	3*	Poor

Table 3. Snow-water equivalents (SWE) measured (centimeters) at four SNOTEL sites in or near Yellowstone National Park, Wyoming. Cumulative SWE was computed by summing daily values from October 1st through the end of each month.

SNOTEL Data	OCT	NOV	DEC	JAN	FEB	MAR	APR
West Yellowstone SNOTEL Site							
Average SWE per Month, 2005	0.5	2.9	6.4	15.6	18.7	20.8	16.8
Average SWE per Month, 1981-2004	0.32	3.11	10.0	16.8	22.7	27.8	21.1
2005 Percent of Average (1981-2004)	156	93	64	93	82	75	80
Maximum SWE per Month, 2005	2.0	4.3	9.4	17.5	19.8	24.4	25.7
Cumulative SWE, 2005	14.7	102.1	300.2	783.3	1307.1	1953.0	2455.9
Madison Plateau SNOTEL Site							
Average SWE per Month, 2005	2.3	9.4	17.2	32.3	37.7	42.0	51.5
Average SWE per Month, 1981-2004	1.5	8.4	21.3	33.5	44.3	55.6	60.8
2005 Percent of Average (1981-2004)	153	112	81	96	85	76	85
Maximum SWE per Month, 2005	8.9	11.9	22.4	35.8	39.9	48.8	54.1
Cumulative SWE, 2005	71.4	352.8	887.0	1888.2	2942.8	4245.4	5790.4
Canyon SNOTEL Site							
Average SWE per Month, 2005	0.8	4.0	7.2	14.3	17.5	20.6	22.5
Average SWE per Month, 1981-2004	0.6	4.4	11.3	18.5	24.7	31.0	32.2
2005 Percent of Average (1981-2004)	133	91	64	77	71	66	70
Maximum SWE per Month, 2005	3.6	5.3	9.1	16.0	19.1	23.4	24.6
Cumulative SWE, 2005	24.6	143.7	367.5	811.5	1300.7	1938.0	2614.2
Northeast Entrance SNOTEL Site							
Average SWE per Month, 2005	0.2	1.0	4.0	8.0	10.4	13.0	10.3
Average SWE per Month, 1981-2004	0.2	2.7	8.2	14.0	19.3	23.7	20.5
2005 Percent of Average (1981-2004)	100	37	49	57	54	55	50
Maximum SWE per Month, 2005	1.0	3.1	5.3	9.4	11.2	15.5	16.0
Cumulative SWE, 2005	5.1	36.3	159.8	406.7	696.7	1100.8	1408.4

Table 4. Summary of observed wildlife groups and interactions with motorized winter vehicles by kilometers (km) surveyed for each road segment during winter 2005, Yellowstone National Park, Wyoming, USA.

Road Segment	**Total Kilometers Surveyed**	**Wildlife Groups Observed**	**Groups Observed per Kilometer Surveyed**	**Interactions Observed**	**Interactions Observed per Kilometer Surveyed**
Madison to West Yellowstone (23 km)	1,375	1,265	0.92	951	0.69
Madison to Old Faithful (26 km)	1433	983	0.69	604	0.42
Mammoth to Norris (34 km)	686	100	0.15	54	0.08
Norris to Madison (23 km)	662	98	0.15	49	0.07
Mammoth to the Lamar Valley (60 km)	2,074	724	0.35	570	0.27
Fishing Bridge to West Thumb (34 km)	615	61	0.09	33	0.05
Canyon Village to Lake Butte (40 km)	755	554	0.73	199	0.26

Table 5*a*. Maximum likelihood analysis of variance for the 5-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 1999-2004.

		Bison	Bison	Elk	Elk
Model terms	df	χ^2	p-value	χ^2	p-value
intercept	2	56.14	<.0001	23.34	<.0001
hresp	6	127.12	<.0001	122.71	<.0001
vtype	2	25.60	<.0001	19.47	<.0001
winter	8	133.07	<.0001	55.58	<.0001
habitat	10	371.69	<.0001	98.59	<.0001
distance	2	79.37	<.0001	112.25	<.0001
sppnum	2	162.10	<.0001	55.52	<.0001
swe	2	23.19	<.0001	22.57	<.0001
cumwest	2	14.08	.0009	13.18	.0014
dist*winter	8	37.19	<.0001	26.37	.0009
cumwest*winter	8	61.04	<.0001	97.76	<.0001

Table 5*b*. Maximum likelihood analysis of variance for the 2-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 2003-2004.

		Bison	Bison	Elk	Elk	Swan	Swan
Terms	df	χ^2	p-value	χ^2	p-value	χ^2	p-value
intercept	2	0.21	.9023	5.09	.0786	25.13	<.0001
hresp	8	100.40	<.0001	32.13	<.0001	46.01	<.0001
sb	2	9.90	.0071	20.44	<.0001	6.83	.0329
sc	2	0.66	.7173	4.84	.0890	2.32	.3128
intxn	2	4.93	.0850	8.68	.0130	2.93	.2312
winter	2	103.36	<.0001	24.78	<.0001	1.48	.4767
gtype	4	46.27	<.0001	64.89	<.0001	17.00	.0019
habitat	6	123.45	<.0001	70.41	<.0001		
distance	2	48.57	<.0001	20.26	<.0001	18.51	<.0001
sppnum	2	28.11	<.0001	9.37	.0092		
cumgate	2	7.03	.0298	4.16	.1250		
actv	6	33.79	<.0001	24.29	.0005	14.30	.0264
rto	2	24.09	<.0001	8.79	.0123	13.05	.0015
ccover	8			19.66	.0117		
dist*winter	2	18.46	<.0001	7.91	.0192		
intxn*winter	2	18.79	.0009				
gtype*winter	4			27.18	<.0001		
coach*winter	2			6.69	.0352		
sb*rto	2			21.65	<.0001		
hresp*winter	6					24.95	.0003
sb*gtype	4					10.84	.0284

Table 6. Maximum likelihood estimates and odds ratios for the categorical variables in the 5-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 1999-2004.

			Bison				Elk			
Model term	Variable levels	Response levels	β	P		Odds ratio	β	p		Odds ratio
Habitat	A v M	AC v N	-.010	.9780		0.98	.213	.1443		1.53
		LR v N	.165	.5652		1.39	.513	<.0001	+	2.79
	BFv M	AC v N	-.486	.0739	-	0.38	.105	.4164		1.23
		LR v N	-.016	.5592		0.81	.390	.0004	+	2.18
	F v M	AC v N	-.440	.0113	-	0.41	.130	.3407		1.30
		LR v N	-.187	.1874		0.69	.054	.6880		1.11
	RDv M	AC v N	2.776	<.0001	+	257.5	1.225	<.0001	+	11.60
		LR v N	.973	<.0001	+	7.00	-.806	.0014	-	0.20
	TH v M	AC v N	-.693	<.0001	-	0.25	-1.056	<.0001	-	0.12
		LR v N	-.353	.0140	-	0.49	-.222	.1774		0.64
Vtype	W v OSV	AC v N	-.421	.0004	-	0.43	-.361	.0004	-	0.49
		LR v N	-.372	<.0001	-	0.48	-.302	.0002	-	0.55
Hresp	AP v N	AC v N	1.042	<.0001	+	8.03	.948	<.0001	+	6.66
		LR v N	.157	.4649		1.37	.256	.2775		1.67
	D v N	AC v N	.255	.1419		1.66	.162	.3611		1.38
		LR v N	.435	.0069	+	2.39	.033	.8349		1.07
	S v N	AC v N	-.079	.5068		0.85	.265	.0385	+	1.70
		LR v N	.213	.0660	+	1.53	.320	.0083	+	1.90
Winter	99 v 04	AC v N	-.308	.6646		0.54	-.835	.0954	-	0.19
		LR v N	-.316	.4869		0.53	-.486	.1495		0.38
	00 v 04	AC v N	-.729	.6088		0.23	.808	.1623		5.03
		LR v N	-.431	.5383		0.40	-.174	.6920		0.71
	02 v 04	AC v N	-2.070	<.0001	-	0.02	-1.954	<.0001	-	0.02
		LR v N	-1.488	<.0001	-	0.05	.016	.9515		1.03
	03 v 04	AC v N	2.682	<.0001	+	213.5	1.561	.0005	+	22.71
		LR v N	2.234	<.0001	+	87.25	.928	.0059	+	6.40

Table 7. Maximum likelihood estimates and odds ratios for the categorical variables in the 2-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 2003-2004.

			Bison				Elk				Swan			
Model term	Variable Levels		β	p		Odds ratio	β	p		Odds ratio	β	p		Odds ratio
habitat	A v M	AC v N	NA	NA		NA	.426	.0440	+	2.34	NA	NA		NA
		LR v N	NA	NA		NA	1.026	<.0001	+	7.78	NA	NA		NA
	BFv M	AC v N	-.240	.3633		0.62	-.183	.3215		0.69	NA	NA		NA
		LR v N	-.117	.5291		0.79	-.187	.3468		0.69	NA	NA		NA
	F v M	AC v N	-.161	.4590		0.72	.464	.0213	+	2.53	NA	NA		NA
		LR v N	.066	.6632		1.14	.386	.0709	+	2.16	NA	NA		NA
	RDv M	AC v N	2.138	<.0001		71.88	1.229	.0054	+	11.67	NA	NA		NA
		LR v N	.638	.0012	+	3.58	-.650	.3040		0.27	NA	NA		NA
	TH v M	AC v N	-.752	.0015	+	0.22	-1.041	.0011	-	0.12	NA	NA		NA
		LR v N	-.286	.0704	-	0.56	-.378	.1893		0.47	NA	NA		NA
hresp	IH v N	AC v N	1.797	<.0001	-	36.34	NA	NA		NA	NA	NA		NA
		LR v N	.465	.2715	+	2.53	NA	NA		NA	NA	NA		NA
	AP v N	AC v N	-.213	.5746		0.65	.662	.0075	+	3.75	.714	.0377	+	4.17
		LR v N	-.343	.3155		0.50	-.105	.6960		0.81	-.090	.8450		0.83
	D v N	AC v N	-.427	.1115		0.43	.238	.3380		1.61	.834	.0024	+	5.30
		LR v N	.109	.6378		1.24	.447	.0517	+	2.45	-.092	.8029		0.83
	S v N	AC v N	.035	.8549		1.07	-.026	.8847		0.95	-.100	.6567		0.82
		LR v N	.471	.0096	+	2.56	.008	.9620		1.02	.290	.2835		1.79
actv	U v R	AC v N	.530	.0134	+	2.88	.094	.6610		1.21	-.250	.3169		0.61
		LR v N	-.131	.4983		0.77	-.410	.0343	-	0.44	.192	.5057		1.47
	T v R	AC v N	.675	.0004	+	3.86	.892	.0287	+	5.95	1.150	.0109	+	9.98
		LR v N	.444	.0165	+	2.43	.601	.1052		3.33	.005	.9927		1.01
	S v R	AC v N	-.631	<.0001	-	0.28	-.104	.5762		0.81	-.392	.0541	-	0.46
		LR v N	-.029	.7987		0.94	-.293	.0710	-	0.56	.253	.2553		1.66
rto	No v Yes	AC v N	-.718	.0006	-	0.24	-.274	.3338		0.58	-1.147	.0003	-	0.10
		LR v N	-.769	<.0001	-	0.21	-.721	.0039	-	0.24	-.631	.0688	-	0.28
winter	03 v 04	AC v N	1.267	<.0001	+	12.61	1.104	<.0001	+	9.10	-.226	.3015		0.64
		LR v N	1.234	<.0001	+	11.79	.891	<.0001	+	5.94	-.239	.3526		0.62
gtype	A v N	AC v N	.486	.0094	+	2.64	4.550	<.0001	+	22.18	-.713	.0119	-	0.24
		LR v N	.585	<.0001	+	3.22	1.186	<.0001	+	10.73	-1.249	<.0001	-	0.08
	G v N	AC v N	.403	.0643	+	2.24	-.030	.9259		0.94	.119	.6895		1.27
		LR v N	.170	.3814		1.40	-.175	.4617		0.70	.529	.0827	+	2.88
cloud	0 v 4	AC v N					.166	.4425		1.39				
cover		LR v N					-.337	.1051		0.51				
	1 v 4	AC v N					.256	.1806		1.67				
		LR v N					.429	.0093	+	2.36				
	2 v 4	AC v N					.125	.6061		1.28				
		LR v N					.151	.5003		1.35				
	3 v 4	AC v N					-.585	.0044	-	0.31				
		LR v N					-.429	.0202	-	0.42				

Table 8. Maximum likelihood estimates and odds ratios for the quantitative variables in the 2-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 2003-2004.

		Bison				Elk				Swan			
Model Term	Response Levels	β	P		Odds ratio	β	p		Odds ratio	β	p		Odds Ratio
intercept	AC v N	-.102	.7743		0.90	-.260	.5837		0.77	2.680	<.0001	+	14.58
	LR v N	.075	.7976		1.08	.679	.0937	+	1.97	.088	.8918		1.09
dist	AC v N	-.418	.0028	-	0.66	-.646	.0001	-	0.52	-4.101	<.0001	-	0.02
	LR v N	-.638	<.0001	-	0.53	-.382	.0027	-	0.68	-2.176	.0184	-	0.11
intxn	AC v N	.002	.9337		1.00	.085	.0044	+	1.09	-.036	.3051		0.96
	LR v N	-.056	.0344	-	0.95	.069	.0180	+	1.07	.032	.3833		1.03
sb	AC v N	.048	.0175	+	1.05	.506	.0022	+	1.66	.166	.0682	+	1.18
	LR v N	.046	.0103	+	1.05	-.081	.6168		0.92	.249	.0091	+	1.28
sc	AC v N	.197	.5564		1.22	.880	.0278	+	2.41	.376	.2320		1.46
	LR v N	.219	.4948		1.24	.494	.1685		1.64	-.176	.6110		0.84
cumgate	AC v N	-.028	.0170	-	0.97	.022	.0747	+	1.02				
	LR v N	-.014	.1024		0.99	-.002	.8675		1.00				
sppnum	AC v N	-.196	.0002	-	0.82	.008	.8720		1.01				
	LR v N	-.194	<.0001	-	0.82	-.197	.0033	-	0.82				

Table 9. Maximum likelihood estimates and odds ratios for interactions involving winter and a categorical variable in the 2-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 2003-2004.

Animal Group	Winter levels	Response levels	Interaction	Categories	β	p		Odds ratio
Elk	03 v 04	AC v N	gtype	A v N	.393	.1200		1.48
		LR v N	*winter		.290	.1076		1.34
	03 v 04	AC v N		G v N	-1.444	<.0001	-	0.24
		LR v N			-.937	<.0001	-	0.39
Swan	03 v 04	AC v N	hresp	AP v N	.120	.7149		1.13
		LR v N	*winter		-.471	.2879		0.62
	03 v 04	AC v N		D v N	.199	.4605		1.22
		LR v N			.251	.4882		1.29
	04 v 04	AC v N		S v N	.531	.0192	+	1.70
		LR v N			.193	.4665		1.21

Table 10. Maximum likelihood estimates and odds ratios for interactions between categorical and quantitative variables in the 2-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 2003-2004.

Animal group	Interaction	Categories	Response levels	β	p		Odds ratio
Bison	dist*winter	03 v 04	AC v N	-.209	.0660	-	0.81
			LR v N	-.364	<.0001	-	0.70
Bison	intxn*gtype	A v n	AC v N	-.077	.0131	-	0.93
			LR v N	-.064	.0257	-	0.94
		G v N	AC v N	-.033	.3223		0.97
			LR v N	-.020	.5896		0.98
Elk	dist*winter	03 v 04	AC v N	-.384	.0060	-	0.68
			LR v N	-.083	.4920		0.92
Elk	coach*winter	03 v 04	AC v N	1.007	.0108	+	2.74
			LR v N	.450	.2018		1.57
Elk	sb*rto	No v Yes	AC v N	-.522	.0015	-	0.59
			LR v N	.077	.6306		1.08
Swan	sb*guide	A v N	AC v N	.311	.0758	+	1.37
			LR v N	.463	.0130	+	1.59
		G v N	AC v N	-.166	.0661	-	0.85
			LR v N	-.281	.0033	-	0.76

Table 11. Summary of interactions between wildlife groups and motorized winter vehicles and wildlife responses included in multinomial logits regression models for the 5-winter study (1999-2004) and/or 2-winter study (2003-2004) in Yellowstone National Park, Wyoming, USA.

	Five-winter Study					**Two-winter Study**	
Species	**1999**	**2000**	**2002**	**2003**	**2004**	**2003**	**2004**
Bison	577	514	1,864	1,556	1,471	1,642	1,532
Elk	347	222	798	547	765	567	805
Swan						327	385

Response Code	**Description of Wildlife Response**	**5-winter Frequency**		**2-winter Frequency**		
		Bison	**Elk**	**Bison**	**Elk**	**Swans**
N	No apparent wildlife response	4,994	1,352	2,565	631	382
LR	Look and resume activity	463	798	308	377	153
AC	Active response (T + A + F + D; see below)	525	529	301	364	177
	TOTAL	5,982	2,679	3,174	1,372	712
	Active Responses					
T	Travel away from vehicles and humans	350	160	163	100	100
A	Alarm, attention, or agitation	84	304	83	231	68
F	Flight	79	56	52	32	9
D	Defensive attack or charge	12	9	2	1	0

Table 12. Maximum likelihood estimates and odds ratios for quantitative variables in the 5-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA, 1999-2004.

		Bison				Elk			
Model Term	Response levels	β	p		Odds ratio	β	p		Odds ratio
intercept	AC v N	-4.637	<.0001	-	0.01	-2.831	<.0001	-	0.06
	LR v N	-2.999	<.0001	-	0.05	-1.776	.0004	-	0.17
cumwest	AC v N	-0.103	.0031	-	0.90	-0.089	.0084	-	0.91
	LR v N	-0.080	.0033	-	0.92	-0.090	.0007	-	0.91
sppnum	AC v N	-0.120	<.0001	-	0.89	-0.124	<.0001	-	0.88
	LR v N	-0.196	<.0001	-	0.82	-0.110	<.0001	-	0.90
swe	AC v N	0.247	.0003	+	1.28	0.268	<.0001	+	1.31
	LR v N	0.209	<.0001	+	1.23	0.216	<.0001	+	1.24
distance	AC v N	-0.594	.0089	-	0.55	-0.732	<.0001	-	0.48
	LR v N	-1.108	<.0001	-	0.33	-0.592	<.0001	-	0.55

Table 13. Maximum likelihood estimates and odds ratios for interactions involving categorical and quantitative variables in the 5-winter study evaluating the effects of motorized winter recreation on ungulates in Yellowstone National Park, Wyoming, USA 1999-2004.

			Bison				Elk			
Model Term	Variable levels	Response levels	β	p		Odds ratio	β	p		Odds ratio
dist	99 v 04	AC v N	-1.037	.1431		0.35	-.412	.1987		0.66
*winter		LR v N	-.882	.0084	-	0.41	-.132	.3308		0.88
	00 v 04	AC v N	.005	.9909		1.01	-.032	.9043		0.97
		LR v N	-.124	.6492		0.88	-.003	.9846		1.00
	02 v 04	AC v N	.438	.0535	+	1.55	.174	.2321		1.19
		LR v N	-.018	.9183		0.98	-.238	.0187	-	0.79
	03 v 04	AC v N	.056	.8165		1.06	-.158	.3356		0.85
		LR v N	.203	.1698		1.22	.140	.1918		1.15
cumwest	99 v 04	AC v N	-.028	.1470		0.97	-.060	<.0001	-	0.94
*winter		LR v N	.002	.8714		1.00	-.031	.0005	-	0.97
	00 v 04	AC v N	.063	.1098		1.07	.017	.3968		1.02
		LR v N	.072	.0010	+	1.07	.060	<.0001	+	1.06
	02 v 04	AC v N	.143	<.0001	+	1.15	.095	<.0001	+	1.10
		LR v N	.087	<.0001	+	1.09	.053	.0015	+	1.05
	03 v 04	AC v N	-.027	.1651		0.97	.089	<.0001	+	1.09
		LR v N	-.010	.4646		0.99	.062	<.0001	+	1.06

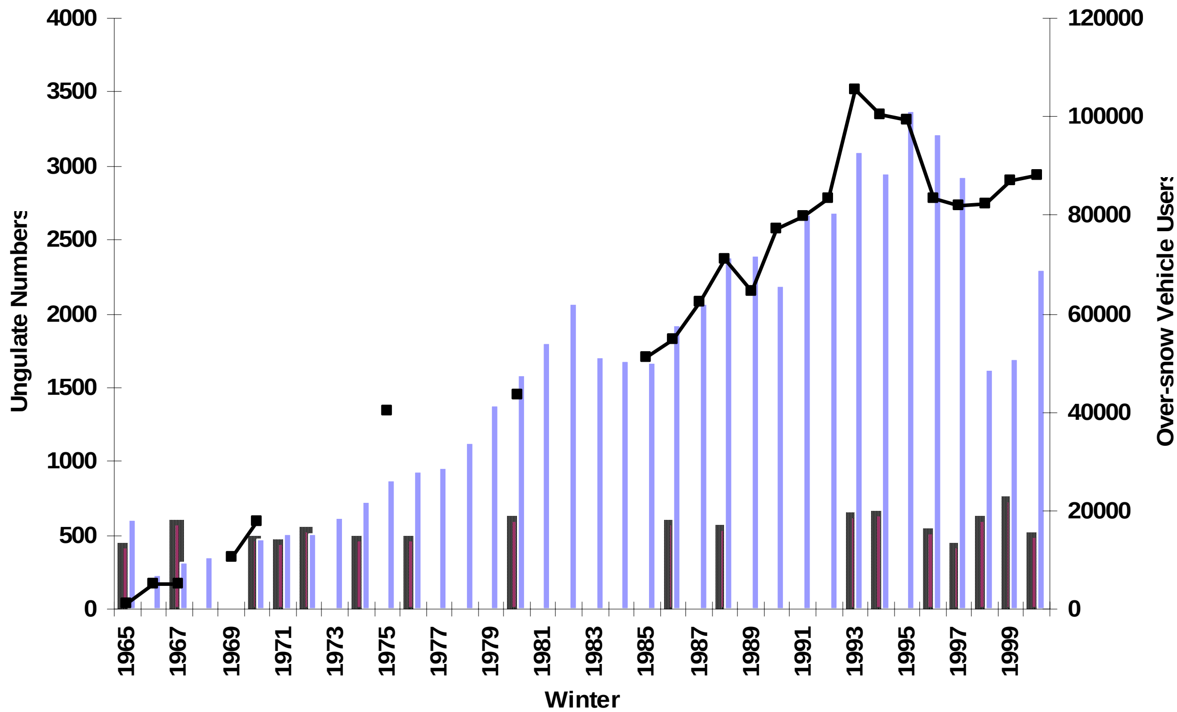
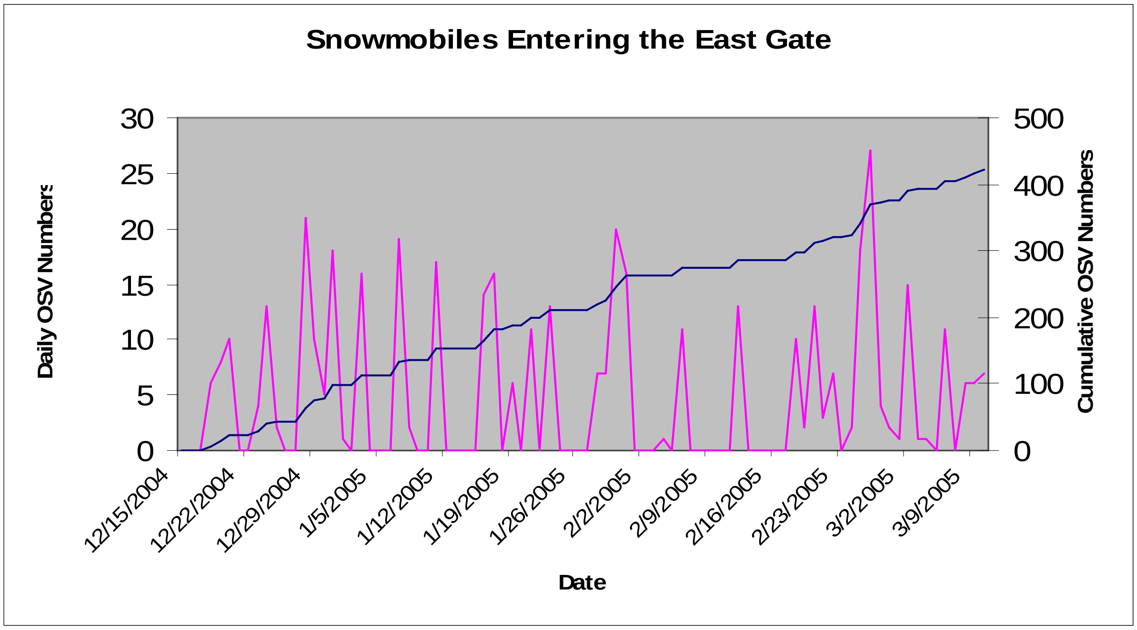
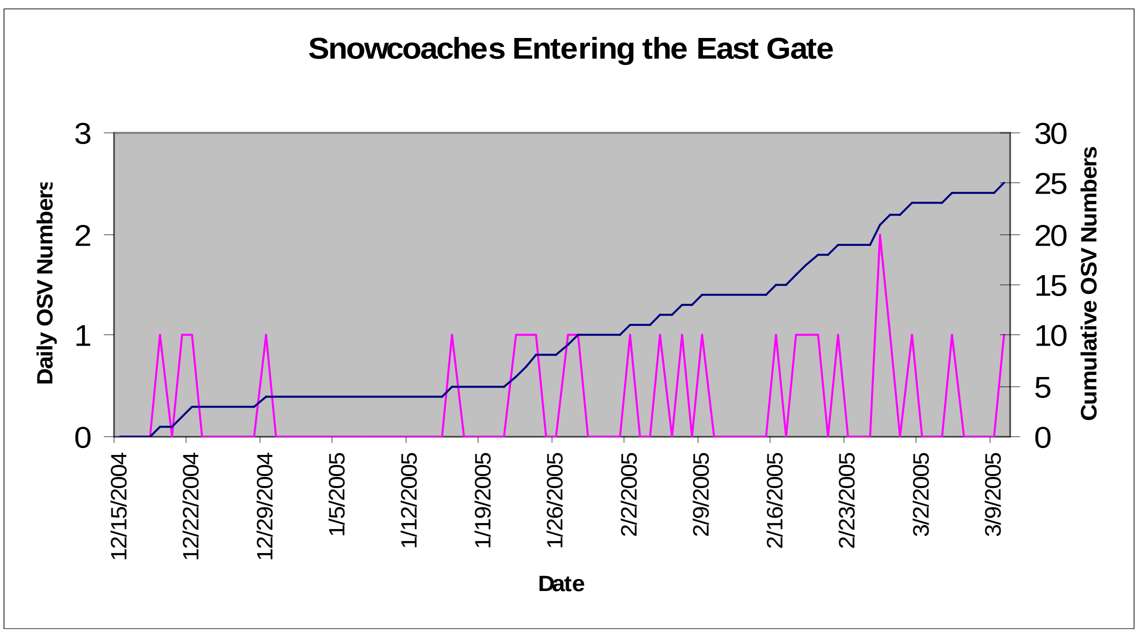


Figure 1. Over-snow vehicles users (squares with line), counts of central Yellowstone bison (solid columns), and population estimates of central Yellowstone elk (cross-hatched columns) in Yellowstone National Park during 1965-2000 (Garrott et al. 2003, Gates et al. 2005).

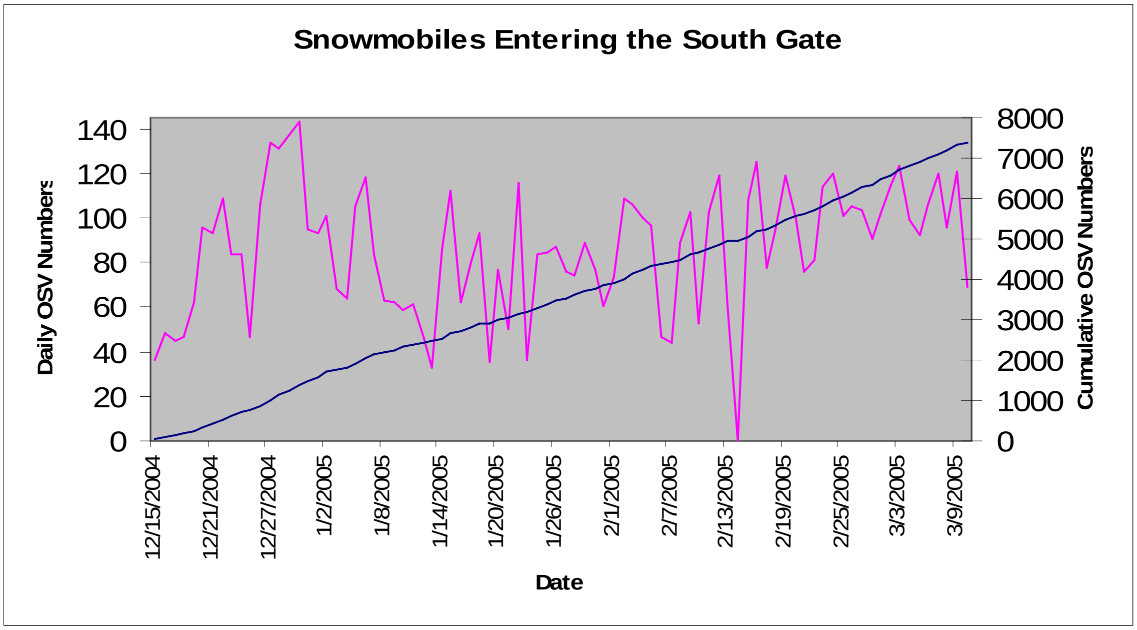
Appendix A. Daily and cumulative numbers of commercially guided snowmobiles, snow coaches entering various entrance stations of Yellowstone National Park during winter 2005. Daily totals are displayed on the left axis, while the cumulative total for the winter is displayed on the right axis. Note that the scales of the Y axes vary among figures.

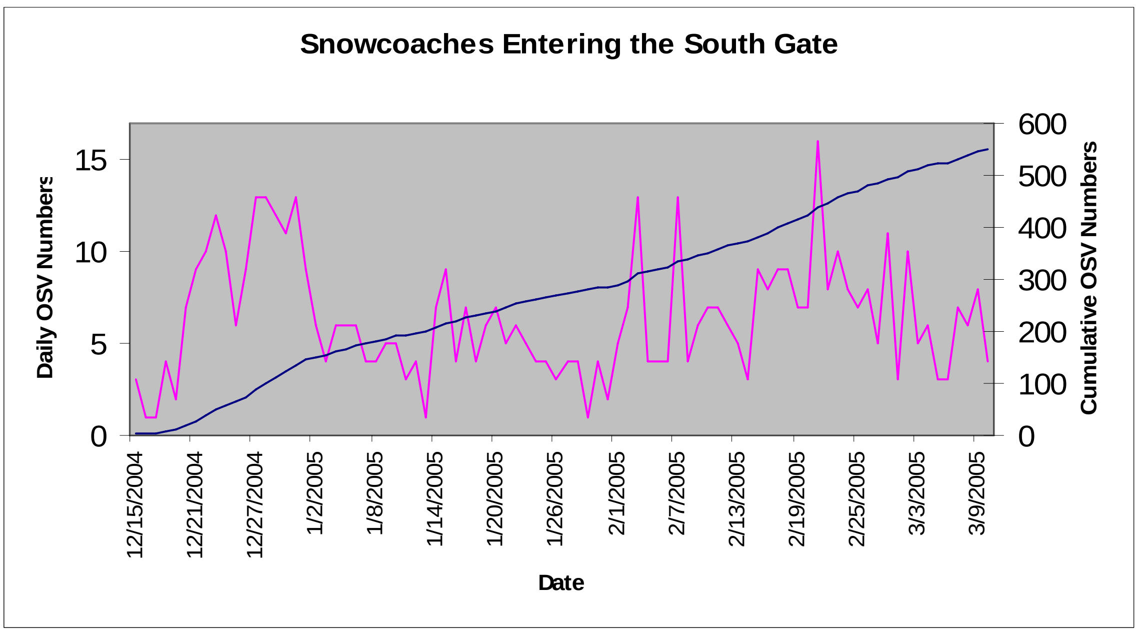
East Entrance Station



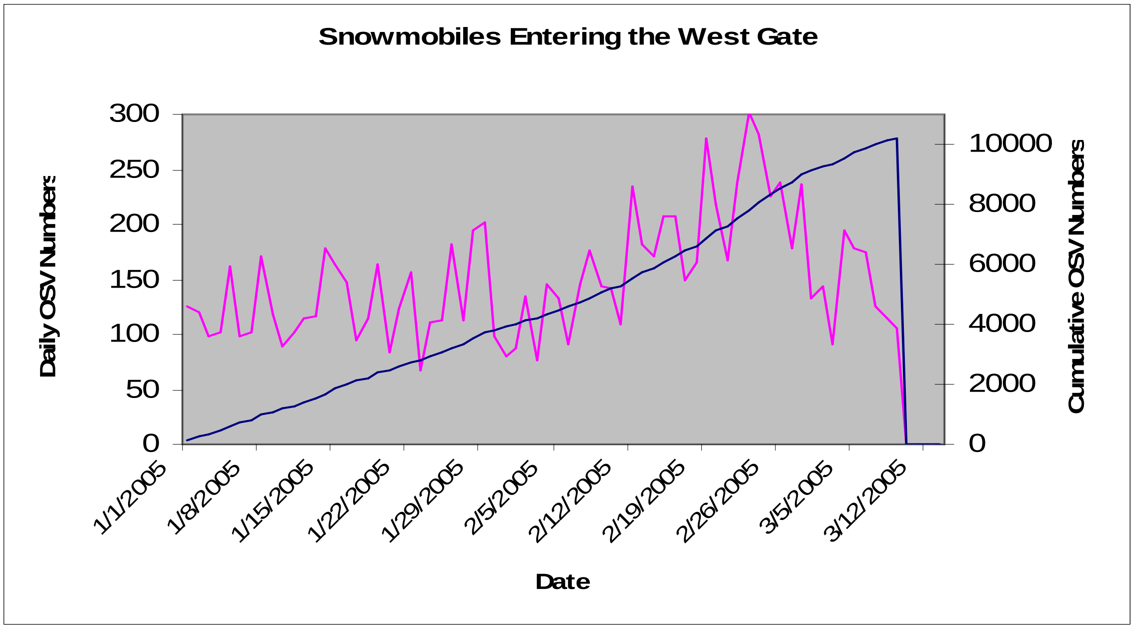


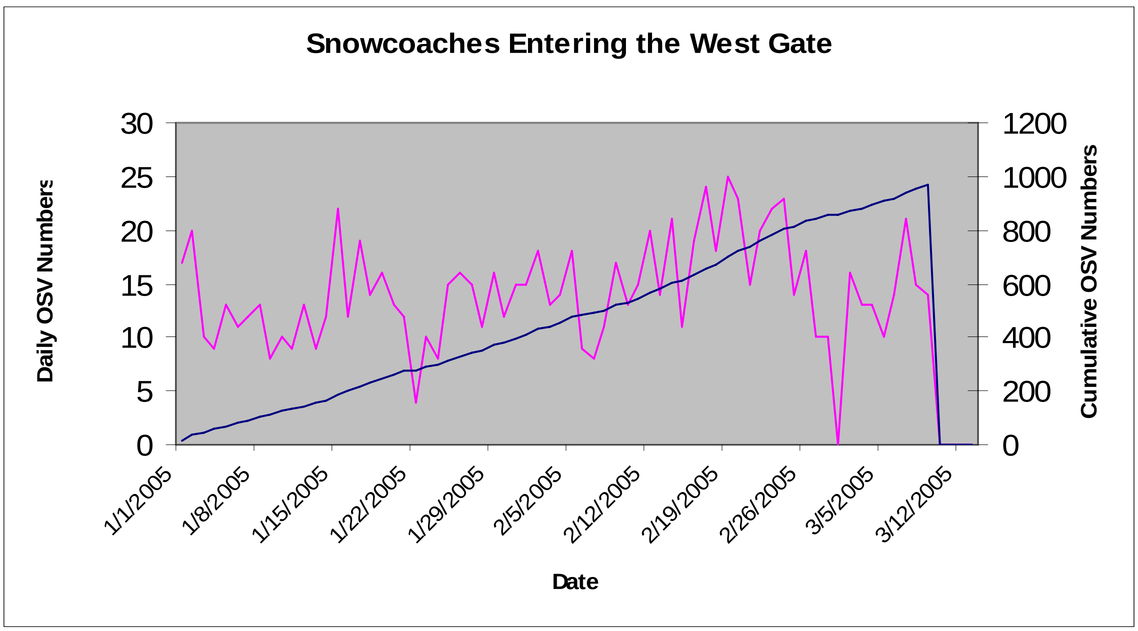
South Entrance Station





West Entrance Station





Appendix B. Summaries of observed wildlife groups and interactions by road segment and survey crew during December 6, 2005, through March 25, 2005, Yellowstone National Park, Wyoming. 'Pedestrian' indicates interactions with non-motorized humans (hiker, skiers, bicyclists, etc). Following the route name is the number of times the route was surveyed.

Madison to West Yellowstone (63)

Species	Groups Observed	Total Interactions	Interactions: Snowmobiles	Interactions: Snow coaches	Interactions: Wheeled vehicles	Interactions: Pedestrians
All Species	1265	951	495	235	220	1
Bison	252	178	82	42	54	0
Bald Eagle	144	84	42	29	13	0
Coyote	20	14	9	3	2	0
Elk	328	286	154	62	70	0
Great Blue Heron	11	1	0	0	1	0
Golden Eagle	9	6	2	2	2	0
Mule Deer	1	1	1	0	0	0
Moose	2	2	1	1	0	0
Muskrat	5	1	0	1	0	0
Otter	1	1	1	0	0	0
Pine Marten	1	1	1	0	0	0
Red-Tailed Hawk	1	0	0	0	0	0
Swan	490	376	202	95	78	1

Madison to Old Faithful road segment (53)

Species	Groups Observed	Total Interactions	Interactions: Snowmobiles	Interactions: Snow coaches	Interactions: Wheeled vehicles	Interactions: Pedestrians
All Species	983	604	289	152	152	11
Bison	695	425	191	119	106	9
Bald Eagle	56	15	5	7	3	0
Coyote	16	11	6	4	1	0
Elk	135	104	58	15	29	2
Great Blue Heron	1	0	0	0	0	0
Golden Eagle	3	1	0	0	1	0
Rough-Leg Hawk	2	0	0	0	0	0
Red-Tailed Hawk	1	1	0	0	1	0
Swan	74	47	29	7	11	0

Norris to Madison road segment (29)

Species	Groups Observed	Total Interactions	Interactions: Snowmobiles	Interactions: Snow coaches	Interactions: Wheeled vehicles	Interactions: Pedestrians
All Species	98	49	26	13	10	0
Bison	64	28	15	5	8	0
Bald Eagle	12	7	4	3	0	0
Coyote	6	4	3	0	1	0
Elk	9	7	4	2	1	0
Fox	1	0	0	0	0	0
Swan	6	3	0	3	0	0

Norris to Mammoth Hot Springs road segment (26)

Species	Groups Observed	Total Interactions	Interactions: Snowmobiles	Interactions: Snow coaches	Interactions: Wheeled vehicles	Interactions: Pedestrians
All Species	100	54	32	12	10	0
Bison	62	31	19	8	4	0
Bald Eagle	7	6	3	1	2	0
Coyote	11	8	4	1	3	0
Elk	5	1	1	0	0	0
Fox	3	3	2	0	1	0
Swan	11	5	3	2	0	0
Wolf	1	0	0	0	0	0

Mammoth to Lamar Valley road segment (33)

Species	Groups Observed	Total Interactions	Interactions: Snowmobiles	Interactions: Snow coaches	Interactions: Wheeled vehicles	Interactions: Pedestrians
All Species	724	570	0	0	570	0
Bison	461	369	0	0	369	0
Bald Eagle	13	10	0	0	10	0
Bighorn Sheep	6	4	0	0	4	0
Beaver	2	1	0	0	1	0
Coyote	79	68	0	0	68	0
Elk	137	97	0	0	97	0
Golden Eagle	8	7	0	0	7	0
Moose	1	1	0	0	1	0
Mule Deer	4	2	0	0	2	0
Otter	2	1	0	0	1	0
Ruffed Grouse	1	0	0	0	0	0
Wolf	10	10	0	0	10	0

Canyon to Lake Butte road segment (40)

Species	Groups Observed	Total Interactions	Interactions: Snowmobiles	Interactions: Snow coaches	Interactions: Wheeled vehicles	Interactions: Pedestrians
All Species	554	199	133	18	48	0
Bison	350	132	98	10	24	0
Bald Eagle	12	2	1	0	1	0
Coyote	53	19	11	1	7	0
Fox	2	2	2	0	0	0
Golden Eagle	1	0	0	0	0	0
Otter	3	2	1	1	0	0
Swan	133	42	20	6	16	0

Fishing Bridge to West Thumb road segment (19)

Species	Groups Observed	Total Interactions	Interactions: Snowmobiles	Interactions: Snow coaches	Interactions: Wheeled vehicles	Interactions: Pedestrians
All Species	61	33	31	1	0	1
Bison	36	22	20	1	0	1
Bald Eagle	1	0	0	0	0	0
Coyote	15	8	8	0	0	0
Otter	1	0	0	0	0	0
Swan	8	3	3	0	0	0

Summary of observed wildlife groups and interactions with motorized winter use by road segment:

Road Segment	Observations	% of Total Observations	Interactions	% of Total Interactions
Madison to West Yellowstone (23 km)	1265	33.42	951	38.66
Madison to Old Faithful (26 km)	983	25.97	604	24.55
Mammoth to Norris (34 km)	98	2.59	49	1.99
Norris to Madison (23 km)	100	2.64	54	2.20
Mammoth to the Lamar Valley (60 km)	724	19.13	570	23.17
Fishing Bridge to West Thumb (34 km)	61	1.61	33	1.34
Canyon Village to Lake Butte (40 km)	554	14.64	199	8.09

Summary of observed wildlife groups and interactions with motorized winter use by survey crew:

Area	Observations	% of Total Observations	Interactions	% of Total Interactions
Madison	2248	59.39	1555	63.21
Mammoth	922	24.36	673	27.36
Lake	615	16.25	232	9.43

Summary of the percentage of observed wildlife groups for which interactions with motorized winter use were documented by each survey crew:

Area	Observations	% of Observations that Documented Responses
Madison	2248	69.17
Mammoth	922	72.99
Lake	615	37.72

Appendix C. Comparisons of human behavior during interactions with wildlife during winter 2005, Yellowstone National Park, Wyoming. The human behavior is compared among commercially guided groups of snowmobiles and snow coaches, administrative groups of snowmobiles and snow coaches (i.e., researchers, park and concessionaire staff, contract workers), and wheeled vehicles.

Snow Coach User Responses to Wildlife in the Madison District (Madison to Old Faithful and Madison to West Yellowstone)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	42	56.76	3	100
Stop	20	27.03	0	0.00
Dismount	1	1.35	0	0.00
Approach	7	9.46	0	0.00
Impede-Hasten	4	5.41	0	0.00

Elk

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	94	59.87	3	75.00
Stop	31	19.75	0	0.00
Dismount	4	2.55	0	0.00
Approach	10	6.37	0	0.00
Impede-Hasten	18	11.46	1	25.00

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	62	63.92	5	100
Stop	26	26.80	0	0.00
Dismount	3	3.09	0	0.00
Approach	3	3.09	0	0.00
Impede-Hasten	3	3.09	0	0.00

Snow Coach User Responses to Wildlife in the Lake District (i.e., Canyon to Lake Butte and Fishing Bridge to West Thumb)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	8	100	3	100

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	1	16.67	0	0.00
Stop	5	83.33	0	0.00

Snow Coach User Responses to Wildlife in the Mammoth District (i.e., Mammoth to Norris and Norris to Madison)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	5	71.43	6	100
Stop	2	28.57	0	0.00

Elk

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	1	100	1	100

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	2	50.00	1	100
Stop	2	50.00	0	0.00

Snowmobile User Responses to Wildlife in the Madison District (i.e., Madison to West Yellowstone and Madison to Old Faithful)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	106	67.09	61	53.04
Stop	30	18.99	36	31.30
Dismount	14	8.86	8	6.96
Approach	2	1.27	0	0.00
Impede-Hasten	6	3.80	10	8.70

Elk

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	53	54.08	41	35.96
Stop	34	34.69	58	50.88
Dismount	4	4.08	3	2.63
Approach	3	3.06	0	0.00
Impede-Hasten	4	4.08	12	10.53

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	119	86.86	41	43.62
Stop	14	10.22	39	41.49
Dismount	3	2.19	1	1.06
Approach	1	0.73	0	0.00
Impede-Hasten	0	0.00	13	13.83

Snowmobile User Responses to Wildlife in the Lake District (i.e., Canyon to Lake Butte and Fishing Bridge to West Thumb)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	27	31.03	25	80.65
Stop	51	58.62	4	12.90
Dismount	7	8.05	2	6.45
Approach	0	0.00	0	0.00
Impede-Hasten	2	2.30	0	0.00

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	4	44.44	4	28.57
Stop	5	55.56	10	71.43

Snowmobile User Responses to Wildlife in the Mammoth District (i.e., Mammoth to Norris and Norris to Madison)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	10	62.50	11	61.11
Stop	5	31.25	6	33.33
Dismount	1	6.25	0	0.00
Approach	0	0.00	1	5.56

Elk

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	1	100.00	1	25.00
Stop	0	0.00	2	50.00
Dismount	0	0.00	1	25.00

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	0	0.00	3	100

Wheeled Vehicle User Responses to Wildlife in the Madison District (i.e., Madison to West Yellowstone and Madison to Old Faithful)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	32	56.14	83	80.58
Stop	13	22.81	11	10.68
Dismount	0	0.00	0	0.00
Approach	4	7.02	0	0.00
Impede-Hasten	8	14.04	9	8.74

Elk

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	12	33.33	25	39.68
Stop	18	50.00	32	50.79
Dismount	3	8.33	1	1.59
Approach	1	2.78	0	0.00
Impede-Hasten	2	5.56	5	7.94

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	17	68.00	37	57.81
Stop	4	16.00	20	31.25
Dismount	1	4.00	0	0.00
Approach	1	4.00	0	0.00
Impede-Hasten	2	8.00	7	10.94

Wheeled Vehicle User Responses to Wildlife in the Lake District (i.e., Canyon to Lake Butte and Fishing Bridge to West Thumb)

Bison

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	0	0.00	6	25.00
Stop	0	0.00	17	70.83
Impede-Hasten	0	0.00	1	4.17

Swans

Human Behavior	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	0	0.00	5	31.25
Stop	0	0.00	11	68.75

Wheeled Vehicle User Responses to Wildlife in the Mammoth District (i.e., Mammoth to Norris and Norris to Madison)

Bison

Human Behavior	Commercially Guided Groups		Unguided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion	No. Events	Proportion
None	5	31.25	255	77.51	30	83.33
Stop	6	37.50	46	13.98	2	5.56
Dismount	5	31.25	22	6.69	2	5.56
Approach	0	0.00	6	1.82	2	5.56

Elk

Human Behavior	Commercially Guided Groups		Unguided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion	No. Events	Proportion
None	3	75.00	8	61.54	59	72.84
Stop	0	0.00	4	30.77	12	14.81
Dismount	1	25.00	0	0.00	5	6.17
Approach	0	0.00	1	7.69	5	6.17

Appendix D. Comparison of wildlife (bison, elk, and swans) responses during interactions with commercially guided groups of snowmobiles and snow coaches, administrative groups of snowmobiles and snow coaches (i.e., park and concessionaire staff), and wheeled vehicles during winter 2005, Yellowstone National Park, Wyoming.

Wildlife Responses to Snowmobile Users in the Madison District (i.e., Madison to Old Faithful and Madison to West Yellowstone)

Bison

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	121	76.58	85	73.91
Look-Resume	11	6.96	16	13.91
Travel	10	6.33	7	6.09
Alarm-Attention	12	7.59	6	5.22
Flight	3	1.90	1	0.87
Defense	1	0.63	0	0

Elk

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	36	36.73	40	35.09
Look-Resume	27	27.55	24	21.05
Travel	8	8.16	8	7.02
Alarm-Attention	24	24.49	38	33.33
Flight	3	3.06	4	3.51

Swans

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	61	44.53	39	41.49
Look-Resume	34	24.82	10	10.64
Travel	15	10.95	19	20.21
Alarm-Attention	24	17.52	19	20.21
Flight	3	2.19	7	7.45

Wildlife Responses to Snowmobile Users in the Lake District (i.e., Canyon to Lake Butte, Fishing Bridge to West Thumb, West Thumb to South Entrance, and West Thumb to Old Faithful)

Bison

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	23	74.19	49	56.32
Look-Resume	7	22.58	27	31.03
T	1	3.23	5	5.75
AA	0	0	1	1.15
F	0	0	5	5.75

Swans

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	5	55.56	8	57.14
Look-Resume	4	44.44	4	28.57
Travel	0	0	2	14.29

Wildlife Responses to Snowmobile Users in the Mammoth District (i.e., Mammoth to Norris and Norris to Madison)

Bison

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	11	68.75	12	66.67
Look-Resume	3	18.75	5	27.78
Travel	2	12.50	1	5.56

Elk

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	1	100.00	3	75.00
Look-Resume	0	0	1	25.00

Wildlife Responses to Snow Coach Users in the Madison District (i.e., Madison to Old Faithful and Madison to West Yellowstone)

Bison

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	129	82.17	3	75.00
Look-Resume	7	4.46	0	0
Travel	8	5.10	1	25.00
Alarm-Attention	7	4.46	0	0
Flight	5	3.18	0	0
Defense	1	0.64	0	0

Elk

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	27	36.49	1	33.33
Look-Resume	16	21.62	1	33.33
Travel	5	6.76	1	33.33
Alarm-Attention	22	29.73	0	0
Flight	4	5.41	0	0

Swans

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	39	33.91	3	60.00
Look-Resume	23	20.00	1	20.00
Travel	8	6.96	0	0.00
Alarm-Attention	25	21.74	1	20.00
Flight	20	17.39	0	0.00

Wildlife Responses to Snow Coach Users in the Lake District (i.e., Canyon to Lake Butte, Fishing Bridge to West Thumb, West Thumb to South Entrance, and West Thumb to Old Faithful)

Bison

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	4	50.00	1	33.33
Look-Resume	3	37.50	1	33.33
Travel	1	12.50	0	0
Flight	0	0	1	33.33

Swans

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	3	50.00	0	0
Look-Resume	3	50.00	0	0

Wildlife Responses to Snow Coach Users in the Mammoth District (i.e., Mammoth to Norris and Norris to Madison)

Bison

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	6	85.71	5	83.33
Look-Resume	1	14.29	1	16.67

Elk

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	1	100.00	1	100.00

Swans

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	0	0	3	100.00

Wildlife Responses to Wheeled Vehicles in the Madison District (i.e., early winter and late spring use).

Bison

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	48	84.21	89	86.41
Look-Resume	2	3.51	6	5.83
Travel	5	8.77	4	3.88
Alarm-Attention	1	1.75	1	0.97
Flight	1	1.75	3	2.91

Elk

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	17	47.22	38	60.32
Look-Resume	9	25.00	10	15.87
Travel	0	0	4	6.35
Alarm-Attention	8	22.22	8	12.70
Flight	2	5.56	3	4.76

Swans

Wildlife Response	Commercially Guided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion
None	9	36.00	31	48.44
Look-Resume	10	40.00	14	21.88
Travel	3	12.00	11	17.19
Alarm-Attention	1	4.00	3	4.69
Flight	2	8.00	5	7.81

Wildlife Responses to Wheeled Vehicles in the Lake District (i.e., early winter administrative use).

Bison

Wildlife Response	Administrative Groups	
	No. Events	Proportion
None	19	79.17
Look-Resume	3	12.50
Travel	1	4.17
Flight	1	4.17

Swans

Wildlife Response	Administrative Groups	
	No. Events	Proportion
None	9	56.25
Look-Resume	5	31.25
Travel	2	12.50

Wildlife Responses to Wheeled Vehicles in the Mammoth District (i.e., early winter and late administrative spring use on interior roads and daily winter use on the plowed road from Mammoth to Cooke City).

Bison

Wildlife Response	Commercially Guided Groups		Unguided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion	No. Events	Proportion
None	16	100.00	31	86.11	304	92.40
Look-Resume	0	0	3	8.33	18	5.47
Travel	0	0	1	2.78	5	1.52
Alarm-Attention	0	0	0	0	1	0.30
Flight	0	0	1	2.78	1	0.30

Elk

Wildlife Response	Commercially Guided Groups		Unguided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion	No. Events	Proportion
None	3	75.00	8	61.54	71	87.65
Look-Resume	0	0	2	15.38	9	11.11
Travel	1	25.00	1	7.69	0	0
Flight	0	0	2	15.38	1	1.23

Swans

Wildlife Response	Commercially Guided Groups		Unguided Groups		Administrative Groups	
	No. Events	Proportion	No. Events	Proportion	No. Events	Proportion
None	2	50.00	1	100.00	0	0
Look-Resume	1	25.00	0	0	0	0
Travel	1	25.00	0	0	0	0