Ecological Applications, 13(4), 2003, pp. 951–963
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WILDLIFE RESPONSES TO RECREATION AND ASSOCIATED VISITOR PERCEPTIONS

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Abstract. Outdoor recreation has the potential to disturb wildlife, resulting in energetic costs, impacts to animals' behavior and fitness, and avoidance of otherwise suitable habitat. Mountain biking is emerging as a popular form of outdoor recreation, yet virtually nothing is known about whether wildlife responds differently to mountain biking vs. more traditional forms of recreation, such as hiking. In addition, there is a lack of information on the "area of influence" (within which wildlife may be displaced from otherwise suitable habitat due to human activities) of different forms of recreation. We examined the responses of bison (*Bison bison*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) to hikers and mountain bikers at Antelope Island State Park, Utah, by comparing alert distance, flight distance, and distance moved. Within a species, wildlife did not respond differently to mountain biking vs. hiking, but there was a negative relationship between wildlife body size and response. We determined the area of influence along trails and off-trail transects by examining each species' probability of flushing as perpendicular distance away from a trail increased. All three species exhibited a 70% probability of flushing from on-trail recreationists within 100 m from trails. Mule deer showed a 96% probability of flushing within 100 m of recreationists located off trails; their probability of flushing did not drop to 70% until perpendicular distance reached 390 m. We calculated the area around existing trails on Antelope Island that may be impacted by recreationists on those trails. Based on a 200-m "area of influence," 8.0 km (7%) of the island was potentially unsuitable for wildlife due to disturbance from recreation.

Few studies have examined how recreationists perceive their effects on wildlife, although this has implications for their behavior on public lands. We surveyed 640 backcountry trail users on Antelope Island to investigate their perceptions of the effects of recreation on wildlife. Approximately 50% of recreationists felt that recreation was not having a negative effect on wildlife. In general, survey respondents perceived that it was acceptable to approach wildlife more closely than our empirical data indicated wildlife would allow. Recreationists also tended to blame other user groups for stress to wildlife rather than holding themselves responsible.

The results of both the biological and human-dimensions aspects of our research have implications for the management of public lands where the continued coexistence of wildlife and recreation is a primary goal. Understanding wildlife responses to recreation and the "area of influence" of human activities may help managers judge whether wildlife populations are experiencing stress due to interactions with humans, and may aid in tailoring recreation plans to minimize long-term effects to wildlife from disturbance. Knowledge of recreationists' perceptions and beliefs regarding their effects on wildlife may also assist public lands managers in encouraging positive visitor behaviors around wildlife.

Key words: American bison; disturbance; flight distance; flush response; hiking; mountain biking; mule deer; outdoor recreation; pronghorn antelope; visitor perceptions.

INTRODUCTION

Millions of visitors annually are attracted to public lands to engage in recreational activities. Because outdoor recreation is the second leading cause for the decline of federally threatened and endangered species on public lands (Losos et al. 1995), and the fourth leading cause on all lands (Czech et al. 2000), natural resource managers are becoming increasingly concerned about impacts of recreation on wildlife (Knight and Gutzwiller 1995). Recent assessments have suggested that recreation may have pronounced effects on wildlife individuals, populations, and communities by affecting behavior and fitness and by altering interspecific interactions (e.g., Boyle and Samson 1985, Knight and Cole 1995*a*). To manage for coexistence between wildlife and recreationists, managers should be aware of the potential consequences of recreation for wildlife.

Manuscript received 25 April 2002; revised 20 November 2002; accepted 22 November 2002; final version received 7 January 2003. Corresponding Editor: R. S. Ostfeld.

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In addition, because natural resource managers must contend simultaneously with both ecological and social issues, integration of corresponding biological and social data on recreational impacts is necessary for informed decision making (Manfredo et al. 1995). Recreationists' perceptions regarding their effects on wildlife may influence their behavior on public lands. Knowledge of these perceptions can help managers encourage positive behaviors and increase visitor compliance with regulations (Purdy et al. 1987, Klein 1993).

Hiking and mountain biking are rapidly increasing in popularity as forms of outdoor recreation. Mountain biking in particular is one of the fastest-growing outdoor activities, with 43.3 million persons participating at least once in 2000 (USDA Forest Service and National Oceanic and Atmospheric Administration 2000). While researchers have examined the responses of wildlife to pedestrians, there is a lack of information on the responses of wildlife to mountain bikers. Despite this lack of knowledge, mountain biking is banned in all federal wilderness areas and on many other public lands, in part because it is assumed to be more disturbing for wildlife than hiking. Currently, it is not known whether wildlife respond differently to these activities.

Disturbance from recreation may have both immediate and long-term effects on wildlife. The immediate response of many animals to disturbance is a change in behavior, such as cessation of foraging, fleeing, or altering reproductive behavior (Knight and Cole 1991). Over time, energetic losses from flight, decreased foraging time, or increased stress levels come at the cost of energy resources needed for individuals' survival, growth, and reproduction (Geist 1978). In addition, the presence of humans in wildlife habitat may result in animals avoiding parts of their normal range (Hamr 1988, Gander and Ingold 1997). This loss of otherwise suitable habitat may be sufficient to reduce the carrying capacity of some public lands for wildlife (Light and Weaver 1973). The energetic cost for wildlife of responding to disturbance from recreation can also affect the carrying capacity of wildlife habitat (Stalmaster 1983). In some cases, wildlife may habituate to predictable disturbance from recreation, but in other cases they may not: mountain sheep (*Ovis canadensis*) and white-tailed deer (*Odocoileus hemionus*) did not habituate to pedestrians and snowmobiles, respectively (MacArthur et al. 1982, Moen et al. 1982).

The immediate behavioral responses of wildlife to recreation (e.g., flush response, alert and flight distances, distance moved) have conventionally been used to compare the degree of disturbance presented by different activities. The "area of influence" (Miller et al. 2001) may also be indicative of the relative impacts of recreational activities. Area of influence is defined as the area that parallels a trail or line of human movement within which wildlife will flush from a particular activity with a certain probability (Miller et al. 2001). Because most recreationists (except wildlife watchers and photographers) do not go out of their way to approach wildlife, the "area of influence" may provide a more meaningful estimate of disturbance than flight distances measured as a human directly approaches an animal. Wildlife avoidance of otherwise suitable habitat, therefore, can be assessed by the "area of influence" concept through examination of the probability of wildlife flushing within a certain distance of a trail.

The impetus for our research was the dearth of empirical studies that had examined wildlife responses to mountain biking, the lack of data regarding the area of influence of recreational activities, and the need for integration of ecological and social data on recreational impacts to wildlife. Our specific objectives were to (1) compare the behavioral responses of wildlife to hiking and mountain biking, (2) identify factors influencing wildlife response, (3) assess the area of influence around each activity, and (4) compare recreationists' perceptions of their effects on wildlife with corresponding empirical data. From our research, we suggest management and education implications for public lands where coexistence of wildlife and recreation is a primary goal.

STUDY AREA

Antelope Island is a 104-km^2 (11 330-ha) island located in the southeast corner of the Great Salt Lake (40°59′ N, 112°12′ W) and accessed by a causeway from Syracuse, Utah. A north–south ridge of mountains forms the backbone of the island and provides 600 m of relief from lake level to high point. The only sources of fresh water on the island are springs that emerge from the Lake Bonneville terrace level. Exotic annual grasses, primarily cheatgrass (*Bromus tectorum*) and threeawn (*Aristida* spp.), dominate the lower elevations of the island, the result of an altered fire regime and historic overgrazing by livestock (Wolfe et al. 1999). Some higher slopes exhibit a grassland–sagebrush (*Artemisia tridentata*) community, with small stands of juniper (*Juniperus osteosperma*) and bigtooth maple (*Acer grandidentatum*) occurring only in protected canyons (Wolfe et al. 1999). Portions of the eastern side of the island have been reseeded with perennial grasses or a grass–legume mixture (Wolfe et al. 1999). Between 1952 and 1972, maximum summer and minimum winter temperatures averaged 32.7°C and −6.2°C, respectively (Wolfe et al. 1999).

Approximately 650 American bison (*Bison bison*), 50 pronghorn antelope (*Antilocapra americana*), 225 mule deer, and 90 bighorn sheep inhabit Antelope Island (J. Sullivan, *personal communication*). The bison herd is managed to remain at 550–700 individuals (winter herd size) by an annual roundup and sale. The mule deer population naturally fluctuates. The pronghorn and bighorn populations were reintroduced to the island in 1993 and 1997, respectively, and continue to increase in size. Hunting is not currently allowed on Antelope Island.

Currently, the park attracts about 400 000 visitors annually (J. Sullivan, *personal communication*). Recreation occurs year-round, but is concentrated in the spring and early summer and temporally overlaps with the peak fawning/calving season for the island's large ungulates. A 40-km network of backcountry trails, located on the northern half of the island, is used exclusively by hikers, mountain bikers, and horseback riders. The southern half of the island is not accessible to the public except on rare occasions and by the discretion of the park management. Currently, there is interest in expanding the trail system and allowing visitors into the southern portion of the island.

METHODS

Behavioral responses to recreation

We examined the behavioral responses of bison, pronghorn antelope, and mule deer to hiking and mountain biking on Antelope Island from May through August 2000 and April through June 2001. Bighorn sheep were not studied after initial observations indicated that recreationists rarely encountered sheep near trails. Horseback trials were unsuccessful given the limitations of the study area and design. Trials involving all three species of wildlife were performed along designated recreation trails. Trials with mule deer only were also conducted along a randomly chosen, off-trail line of movement to assess the response of mule deer to persons hiking or biking off designated trails. Experimental hiking and biking trials were performed by two people; an assistant acted as the recreationist while a researcher (A. R. Taylor) collected data as a hidden observer. The recreationist moved at a typical pace for each activity, did not stop to look at the animals, and avoided talking during the trial. Necessary communication between observer and recreationist was conducted via handheld radios. We recorded the following responses when an animal or group of animals were observed within 500 m of the trail: (1) alert distance (the distance between the recreationist and the animals when they first became visibly alert to the recreationist), (2) flush response (whether or not the animals took flight in response to the recreationist's presence), (3) flight distance (the distance between the recreationist and the animals when they took flight from the recreationist), (4) distance moved (the distance traveled by the animals from their initial position until they stopped fleeing), and (5) perpendicular distance (the shortest straight-line distance between the trail and the initial position of the animals; Fig. 1). All distances were measured to the nearest meter with a Bushnell Yardage Pro 800 Compact laser rangefinder (Bushnell, Overland Park, Kansas, USA). We tracked animals that continued fleeing out of sight to estimate distance moved. For groups of animals, distances were measured to the first animal that exhibited a particular response. Animals were not approached directly and the recreationist did not leave the trail during a trial, thus her activity was performed tangentially to animals. Visual landscape cues were used to mark initial animal locations. Beanbags were dropped on the trail to mark wildlife responses during a trial so that distances could be measured after the trial was completed. This ensured that the recreationist's activity during a trial appeared continuous to the animals being sampled.

Trials were conducted from 0600 to 1200 and 1700 to 2100 daily to avoid stressing animals during the hottest part of the day, and to coincide with periods of higher animal activity. Starting locations for hiking and biking were randomly chosen to avoid traveling the trails in the same pattern each day. Because wildlife on Antelope Island are not marked, we could not avoid sampling individuals multiple times nor could we quantify the frequency of repeat sampling. Experimental trials were not performed on a section of trail more than once per day to reduce the chances of resampling the same individuals within a short period of time.

Disturbance context

Wildlife responses to recreationists are likely influenced by a suite of variables that may change with each situation (Steidl and Anthony 1996). An animal may choose to flush from a recreationist based on the size of the group with which it is foraging, or depending on its age or sex (Knight and Cole 1995*b*). We follow Steidl and Anthony's example in terming these variables the "disturbance context." We examined the influence of 13 different variables on the behavioral responses of bison, pronghorn, and mule deer (Table 1). The effects of these covariates on wildlife response were considered simultaneously in our analyses.

Visitor perceptions

To quantify recreationists' perceptions of their impacts on wildlife, we conducted an on-site survey during April through June 2001. Visitors were asked how close they felt was acceptable for recreationists to approach wildlife (corresponding to wildlife flight distance), how far they thought animals moved if they fled from recreationists (corresponding to distance moved), to what degree they believed wildlife were being affected by recreation, and which recreational user group they felt was most responsible for causing stress to wildlife. Visitors were also asked what management actions they would support on Antelope Island. We surveyed visitors from each of the island's three user groups (hikers, mountain bikers, and horseback riders), and did not survey individuals more than once.

Statistical analyses

The information-theoretic model selection approach synthesized by Burnham and Anderson (1998) was used to analyze the wildlife response data. To determine

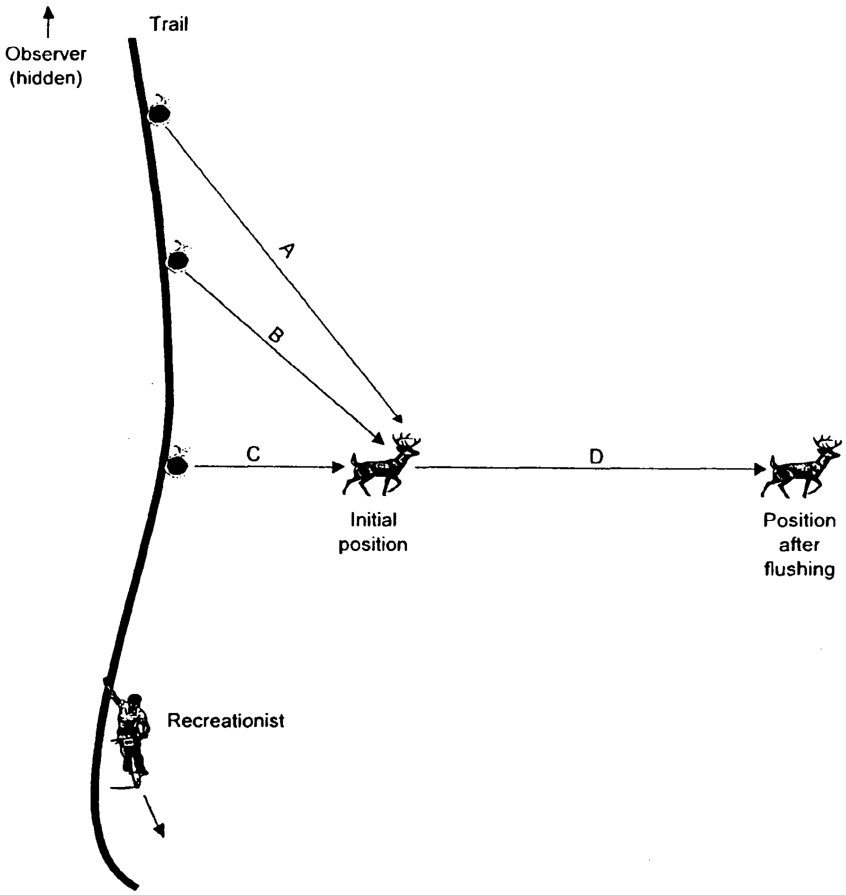

FIG. 1. Representation of response distances: A, alert distance; B, flight distance; C, perpendicular distance; D, distance moved. Markers on the trail represent beanbags dropped to mark response distance locations along trail. The observer remained hidden behind a rock, shrub, or topography during the trial. The mountain biker figure at the lower end of the trail represents the position of the recreationist after the trial has been completed.

the difference in wildlife response to hiking vs. mountain biking, a candidate set of 15 a priori multiple linear regression models was developed for each species/response distance combination (e.g., bison alert distance or mule deer flight distance; Appendix 1). These models included parameters for trial type (hiking or biking), trail position (on- or off-trail, mule deer only) and the variables comprising disturbance context (Table 1). Proc REG (SAS Institute 2001) was used to determine Akaike's Information Criterion (AIC) for each a priori model. The AIC values for each model were used to calculate AIC_c (a small-sample correction to AIC), $\Delta\mathrm{AIC}_c$ (the difference between the model with the lowest AIC_c and each subsequent model), model likelihood, and the Akaike weight (an indicator of the relative support for that model exhibited by the data; Appendix 1). The parameter estimates from each candidate set of models were model-averaged to arrive at a prediction of the mean distance of interest for each species/distance combination. The same set of models was used to determine wildlife responses to both hiking and biking. Therefore, the predicted mean distances for each activity differ only in the value of the trial type variable, the values of all other variables being held constant across the model set. To estimate model-selection uncertainty, the variance estimates of each model in the candidate set were model-averaged using the delta method (Seber 1982:7–9). The model-averaged estimates of precision (standard errors) are therefore unconditional on any one model but are conditional on the a priori set of models and on the data collected during this study. The response distances were $\log_e$ transformed to correct for non-normality.

To examine the relative importance of the factors influencing wildlife response (the disturbance context), Proc IML (SAS Institute 2001) was used to sum the Akaike weights for each variable over the subset of models that included that variable (Burnham and Anderson 1998:140–141). This procedure allowed us to quantify the weight of evidence for the importance of each variable, and avoids the fallacy of regarding as unimportant variables that are not included in the best

TABLE 1. Variables measured to examine influence of disturbance context on wildlife behavioral responses on Antelope Island, Utah, 2000–2001.

Variable name	Definition	Type	Species
Trail type	hiking or biking	categorical	B, MD, PH
Trail position	on or off designated trail	categorical	MD
Encounter distance	distance at which recreationist became visible to animals	continuous	B, MD, PH
Perpendicular distance	shortest distance between animals' initial position and trail	continuous	B, MD, PH
Encounter × perpendicular	interaction between encounter and perpendicular distances	continuous	B, MD, PH
Time of day	morning or evening	categorical	B, MD, PH
Location	north or south end of island	categorical	B, MD, PH
Time of day × location	interaction between time of day and side of island	categorical	B, MD, PH
Total group size	size of wildlife group including all sexes and ages	continuous	B, MD, PH
Adult males	number of adult males in group	continuous	B, MD, PH
Adult females	number of adult females in group	continuous	MD, PH
Subadults	number of animals older than calves but younger than adults	continuous	B
Young of year	number of individuals <1 year old	continuous	B, MD, PH
Recreationist position	position of the recreationist relative to the animals during a trial: downhill, level, or uphill from the group	categorical	MD, PH
Cover	amount of cover around animals' initial position: none, some, or total cover (refers to how well vegetation blocked researchers' view of animals)	categorical	MD

Note: Species codes: B, bison; MD, mule deer; and PH, pronghorn.

model from the model selection procedure (Anderson et al. 2001).

Logistic regression was used to determine the area of influence around persons on trails. A candidate set of nine a priori models was developed using perpendicular distance and the disturbance context variables to predict flush response (Appendix 2). The same nine candidate models were used for each species (bison, mule deer, and pronghorn). Program MARK (White and Burnham 1999) was used to select the best model from the candidate set based on each model's AIC$_c$ value. The parameter estimates from the best logistic regression model were used to calculate the mean probability of animals flushing as perpendicular distance increased.

Visitor responses to survey questions were analyzed using SPSS v.10.1 (SPSS 2000). Frequencies, cross-tabs procedures, and ANOVA were used to compare visitor perceptions to research data and to examine perceptions across the three user groups on the island.

RESULTS

Wildlife responses to hiking and mountain biking

We performed 98 trials to bison, 88 trials to pronghorn, 110 on-trail trials to mule deer, and 60 off-trail trials to mule deer. Hiking and mountain biking trials were evenly distributed among total trial numbers. Trials in which one or more measurements were not obtained were deleted from our analyses. Linear regression models indicated that there was little difference in alert distance, flight distance, or distance moved between hiking and biking for all three species, with the exception of mule deer flight distance (Fig. 2). Although statistical significance is not assessed with the information-theoretic approach, the large degree of overlap between the 95% confidence intervals for hiking and biking is indicative of a lack of biological difference between wildlife responses to these activities (Table 2; see Schenker and Gentleman [2001] for a discussion of using confidence interval overlap to assess statistical significance). R^2 values ranged between 0.16 and 0.80 for the best models in each set. Models predicting animal distances moved generally explained less variation in the response variable than models predicting alert or flight distances (Appendix 1). Mule deer responses were greater to off-trail trials than to on-trail trials for alert distance and distance moved (Fig. 2). We observed interspecific differences across all response distances: pronghorn exhibited the greatest response to both hiking and biking, whereas bison showed the smallest response, once response distances were averaged across the two activities (Table 2).

Disturbance context

The importance of the disturbance context variables and their direction of effect differed among species and response distances (Table 3). We considered a variable to be consequential if the importance value from Table 3 was >0.5, meaning that half or more of the total Akaike weight for the model set was represented by models that contained that variable. There was a positive relationship between encounter distance (i.e., the distance a recreationist first became visible to wildlife) and alert distance. Similarly, increasing alert distance generally increased flight distance. For bison and pronghorn, flight distance was positively related to distance moved. Perpendicular distance was a meaningful element of the disturbance context for all distances and in most species/distance combinations. In most cases, the larger the perpendicular distance between the trail and an animal, the greater the distance of the wildlife response. The position of the recreationist on the trail (whether below the animals, level with them, or above them) was important in determining deer alert distance, deer flight distance, and pronghorn distance moved (recreationist position was not measured for bison because they were almost always level with the recreationist). Animals responded most to recreationists above them and least to recreationists below them. Time of day (morning or evening) and wildlife group size were somewhat important in predicting response distances. Mule deer alert distance was greater in the evening, but bison flight distance and mule deer distance moved were greater in the morning. Larger group sizes tended to increase wildlife response distances. Group composition was relatively unimportant in predicting wildlife response except for deer flight distance and distance moved, which increased as the number of males in the group increased. Location on the island (north end, heavy trail use; south end, no public trails) did not influence wildlife response. Finally, for alert distance and distance moved, responses of deer to off-trail recreationists were greater than deer responses to on-trail recreationists.

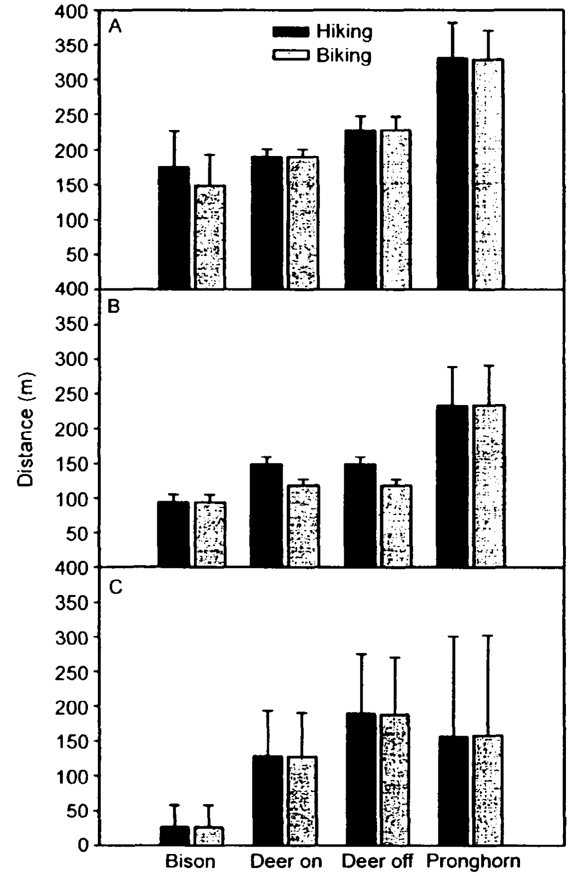

FIG. 2. Wildlife responses to hiking and mountain biking: (A) alert distance, (B) flight distance, (C) distance moved. "Deer on" indicates trials done on-trail to deer; "deer off" indicates trials done off-trail to deer. Bison and pronghorn trials were performed on-trail only. Error bars represent one standard error of the mean.

Area of influence

Of 98 trials to bison, 75 groups (77%) of animals flushed to the treatment. Forty-nine of 88 pronghorn groups (56%) flushed to the treatment. Of 110 on-trail trials to mule deer, 66 groups flushed (60%); 58 of 60 mule deer groups (97%) flushed to off-trail trials. Because the previous analysis (for response distances) indicated that there was little difference between hiking and mountain biking, and because the best logistic regression model did not include the variable "trial type," the data for hiking and mountain biking were combined for this analysis. The best logistic regression model included the variables species, perpendicular

TABLE 2. Means and 95% confidence intervals for alert distance, flight distance, and distance moved for bison, pronghorn, and mule deer on- and off-trail.

Response distance and species	*n*	Hiking		Biking		Combined	
		Mean	95% CI	Mean	95% CI	Mean	95% CI
Alert distance							
Bison	91	174.54	(99.10, 307.41)	148.91	(84.30, 263.04)	162.94	(92.37, 287.38)
Mule deer on trail	104	189.48	(168.56, 213.00)	189.51	(168.84, 212.71)	189.49	(168.66, 212.89)
Mule deer off trail	53	227.54	(192.27, 269.27)	227.57	(192.49, 269.04)	227.55	(192.35, 269.19)
Pronghorn	82	330.04	(243.14, 448.00)	327.74	(253.90, 423.07)	328.93	(247.98, 436.30)
Flight distance							
Bison	75	94.04	(75.14, 117.71)	94.06	(75.37, 117.39)	94.05	(75.24, 117.56)
Mule deer on trail	62	149.62	(131.45, 170.32)	118.45	(101.61, 138.08)	137.33	(119.20, 158.21)
Mule deer off trail	50	149.63	(131.54, 170.21)	118.45	(101.68, 138.00)	137.33	(119.30, 158.11)
Pronghorn	46	233.20	(147.46, 368.81)	233.93	(146.00, 374.80)	233.55	(147.12, 370.76)
Distance moved							
Bison	75	25.91	(3.90, 172.34)	26.00	(3.91, 172.95)	25.95	(3.90, 172.61)
Mule deer on trail	47	128.30	(50.41, 326.52)	127.31	(50.83, 318.84)	127.94	(50.52, 323.99)
Mule deer off trail	39	189.49	(81.03, 443.12)	188.02	(82.36, 429.26)	188.95	(81.48, 438.18)
Pronghorn	43	156.19	(33.41, 730.28)	157.82	(34.12, 730.02)	156.98	(33.75, 730.17)

Notes: Means are presented for hiking, mountain biking, and the mean of the two activities. Confidence intervals are based on the log-normal distribution so that no interval includes negative values for distances. All distances are in meters.

distance, trail position (on-trail or off-trail), and cover (none, some, and total; Appendix 2). On Antelope Island, cover typically referred to shrub (vegetation <3 m tall) density around the animals' initial position. In "no cover" trials, we had a full view of the wildlife at the onset of the trial. "Some cover" indicated that shrubs partially blocked our initial view of the animals. In "total cover" trials, our initial view was almost totally obscured. Wildlife flushing probabilities (Fig. 3) were graphed for a cover value of 0 (no cover), which was most often observed for wildlife in our study. As the value of the cover variable increased (to some cover and total cover), flushing probability decreased for a given perpendicular distance. Two other models had ΔAIC_c values <2, indicating that there was substantial support in the data for these models (Burnham and Anderson 1998; Appendix 2). The second best model was identical to the best model but lacked the cover variable, and is approximated by using a cover value of 0 in the best model. The third best model contained the variable "young of the year" instead of cover. The young of the year variable applied to bison only; larger numbers of calves tended to increase the probability of bison flushing at a given perpendicular distance.

As perpendicular distance increased, the probability of animals taking flight from a recreationist decreased (Fig. 3). There were no interspecific differences in flush response and therefore probability of flushing. This contrasts with the results of the previous analysis, in which response distances differed between the three species. At 100 m from a trail, bison, mule deer, and pronghorn showed approximately a 70% probability of taking flight from a person on that trail (Fig. 3). For mule deer, the area of influence around off-trail trials was much greater than that for on-trail trials. At 100 m from the line of movement of an off-trail trial, mule deer showed a 96% probability of flushing; that probability did not drop to 70% until the perpendicular distance increased to 390 m.

Visitor perceptions

We distributed 205 surveys to hikers, 230 to mountain bikers, and 205 to horseback riders on Antelope Island. Generally, recreationists failed to perceive that they were having as great an effect on wildlife as our biological data indicated. To compare measured flight distance with visitor perceptions of how close wildlife will allow humans to approach, we asked the question "How close do you feel it is acceptable for recreationists to approach wildlife?" The question was phrased in this way because it is difficult for people to estimate actual wildlife flight distances. User groups did not differ in their view of how close recreationists should approach wildlife (hikers, $F_{2,409} = 0.506$, $P = 0.945$; mountain bikers, $F_{2,396} = 0.027$, $P = 0.974$; horseback riders, $F_{2,401} = 1.877$, $P = 0.154$), but their combined perceptions differed greatly from actual wildlife flight distances (Fig. 4). Most recreationists felt that it was acceptable to approach wildlife at a much closer distance (mean acceptable distance to approach = 59.0 m) than wildlife in our experimental trials would typically allow a human to approach (mean flight distance of all species = 150.6 m).

Visitor perceptions of distance moved by wildlife were not substantially different from actual distances moved by wildlife during experimental trials. Recreationists thought bison were less likely to run long distances during flight than either mule deer or pronghorn; this perception was supported by our biological data. Forty percent of visitors surveyed believed that bison moved between 30.5 and 91.4 m in response to recreationists; this perception corresponds to the mean distance moved by bison (26.0 m) in our study. Seventy-eight percent of recreationists surveyed believed that deer and pronghorn move either more than 91.4 m or out of sight in response to recreationists; these perceptions correspond fairly well to the mean distance moved by deer and pronghorn in our study.

Of all visitors surveyed, 46%, 53%, and 54%, respectively, felt that bison, deer, and pronghorn were being negatively affected by recreation on Antelope Island. Fewer horseback riders than hikers or mountain bikers believed that recreation was having a negative effect on wildlife (Fig. 5). Generally, recreationists held members of other user groups responsible for stress or negative impacts to wildlife rather than holding members of their own recreational user group responsible (Fig. 6). These differences were significant overall ($\chi^2 = 47.349$, df $= 4$, $P < 0.001$). Survey respondents showed much support for penalizing recreationists who chased or intentionally stressed wildlife, and moderate support for closing trails to recreation in the spring (during fawning/calving season for wildlife) and for establishing minimum approach distances to wildlife. Visitors expressed little support for allowing only one type of recreational use on island trails, having fewer trails on the island, for requiring visitors to watch an educational video about the effects of recreation on wildlife, and for allowing recreation only on the north (developed) end of the island.

DISCUSSION

Wildlife responses to hiking and mountain biking

Our results indicate that there is little difference in wildlife response to hikers vs. mountain bikers. Certain qualities of each activity may have affected wildlife responses. While both activities involve humans traveling by non-motorized means on or off designated trails, hikers retain their human form while mountain bikers appear unlike humans because they are on a bicycle. Typically, pedestrians induce a more intense wildlife response than do motorized vehicles, perhaps because animals react most to the human form (Richens and Lavigne 1978, Eckstein et al. 1979, MacArthur et al. 1982, Freddy et al. 1986). However, mountain bikers

TABLE 3. Importance values (as calculated by summing Akaike weights across all possible models) and direction of effects (where substantial) of disturbance context variables.

				Disturbance context variables			
Response distance	Species	Trial type	Trial position	Encounter distance	Perpendicular distance	Time of day	Location
Alert distance	B	**0.63**, +	NA	**1.00**, +	**0.59**, +	0.34	0.31
	MD	0.30	**0.93**, −	**1.00**, +	**1.00**, +	**0.73**, +	0.30
	PH	0.24	NA	**1.00**, +	**1.00**, +	NA	0.32
Flight distance	B	0.26	NA	0.29	**0.88**, +	**0.55**, −	0.33
	MD	**0.94**, +	**0.53**, −	**0.53**, +	**1.00**, +	0.43	0.47
	PH	0.25	NA	0.22	**0.65**, +	0.44	NA
Distance moved	B	0.25	NA	0.25	0.25	0.32	0.32
	MD	0.25	**0.71**, −	0.24	0.27	**0.67**, −	0.35
	PH	0.30	NA	0.28	0.35	NA	**0.64**, +

Notes: Importance values >0.5 were considered consequential and are in bold type. A "+" indicates a positive relationship between the variable and the response distance measured; a "−" indicates a negative relationship between the same. NA denotes variables that were not considered for that species/distance combination. Species abbreviations: B = bison, MD = mule deer, and PH = pronghorn.

travel at a higher speed and are less apt to be talking than hikers, which may cause mountain biking to be less predictable for wildlife. The lack of difference in wildlife responses to hiking vs. biking may be attributable to a balance between the disturbing attributes of each activity.

Our finding that there was little difference between mountain biking and hiking contrasts with the results of a recent study on the responses of bighorn sheep to hikers, mountain bikers, and vehicles. In this case, the researchers found that sheep exhibited a greater probability of flushing, longer distances moved, and longer response durations when disturbed by hikers compared to mountain bikers or vehicles (Papouchis et al. 2001). The difference in findings between these studies, however, may be attributable to a difference in methodology. Papouchis et al. compared the responses of sheep approached directly and off-trail by hikers with those of sheep approached tangentially on a road or trail by mountain bikers and vehicles. Generally, wildlife exhibit a stronger response to humans that approach them directly and to humans located off designated trails (MacArthur et al. 1982, Moen et al. 1982, Knight and Cole 1995*a*, Miller et al. 2001). Therefore, the differences in sheep response to hiking and mountain biking seen in Papouchis et al.'s study may be as much attributed to the different approach methods and trial positions as to the different forms of recreation.

We also found that for alert distance, flight distance, and distance moved, a gradient of response existed among the three species studied on Antelope Island. Bison exhibited the shortest response distances and pronghorn the longest distances. The differences in response may be attributable to the specific characteristics of each species. The bison are rounded up annually and therefore may be more tolerant of human disturbance than the other species studied. Bison also have poorer eyesight than either mule deer or pronghorn, and tend to stand their ground when facing a predator rather than taking flight (Hirth 2000). Both white-tailed deer (*Odocoileus virginianus*) and mule deer typically use surrounding cover to avoid detection by a predator (Hirth 2000). Mule deer in our study were often observed to flee only to the nearest cover before stopping, and were more often observed in some cover when a trial was initiated. Because increasing cover generally decreased wildlife response, mule deer in cover could be expected to show a lesser response than animals in the open. Pronghorn as a species typically inhabit open, arid regions, in which their best defense against predators is early detection, rapid flight, and fleeing long distances. In addition, our study was conducted during the summer months on Antelope Island, when wildlife would be more likely to experience heat stress during exertion. Pronghorn exhibit several cooling mechanisms that would enable them to dissipate heat generated during flight better than either mule deer or bison (Vaughn 1986:462). The trend of decreasing response with increasing body size seen in our study merits further investigation. If supported by future studies, this pattern may provide a way to assess the relative response of different species to recreation, and allow managers to establish buffers that protect the most sensitive species from disturbance.

Our study did not attempt to address differences in wildlife response that might be caused by variations in recreationist behaviors, such as group size (of humans), silent vs. talking recreationists, people who stop their activity to look at wildlife, or visitors accompanied by dogs. It is expected that these factors would change wildlife response distances and the likelihood of animals flushing from recreationists, and should be taken into consideration when estimating levels of disturbance to wildlife from recreation at specific sites (Knight and Cole 1995*b*).

Disturbance context

Of the variables comprising disturbance context, encounter distance and perpendicular distance were ex-

TABLE 3. Extended.

Disturbance context variables						
Group size	Adult M	Adult F	Subadults	Young of year	Position	Cover
0.25	0.25	NA	0.25	0.24	NA	NA
0.65, +	0.36	0.39	NA	NA	**0.67**. +	0.32
0.26	0.42	0.27	NA	NA	0.29	NA
0.85, +	0.36	NA	0.24	0.28	NA	NA
0.44	**0.79**, +	0.41	NA	NA	**0.51**, +	0.42
0.57, +	0.21	0.48	NA	NA	0.25	NA
0.27	0.23	NA	0.31	0.50	NA	NA
NA	**0.94**. +	0.36	NA	NA	0.24	**0.62**. −
0.63. +	0.30	0.46	NA	NA	**0.85**, +	NA

tremely important in predicting wildlife response. Encounter distance (the distance at which a recreationist first became visible to animals) influenced alert distance for all three species because it established the upper limit at which wildlife could respond. Encounter distance was also an important variable in shaping the flush responses of bald eagles to river recreationists in Alaska (Steidl and Anthony 1996). In both studies, response distance (alert distance in our study, flight distance in Steidl and Anthony's) increased as encounter distance increased. Because our study took place in an open grassland environment with few visual obstructions, encounter distances were typically long because wildlife could see recreationists at great distances. Animals that encounter recreationists at great distances may be more affected by recreational activities than animals with limited encounter distances, as when vegetation shields recreationists from wildlife (Stalmaster and Newman 1978). The results of our study are most applicable for parks and natural areas with an open environment rather than a wooded community type.

Perpendicular distance (the shortest distance between wildlife and a recreationist on a trail) played a role in determining alert and flight distances in all three species. Interestingly, as perpendicular distance decreased, alert and flight distances decreased, indicating that animals close to the trail became alert and consequently fled at shorter distances than animals located far from the trail. Recarte et al. (1998) believed that fallow deer (*Dama dama*) perceived their linear transects (analogous to trails in this study) as predictable sources of disturbance and took flight in relation to the minimum distance to which an observer could approach. In our study, typical perpendicular distances

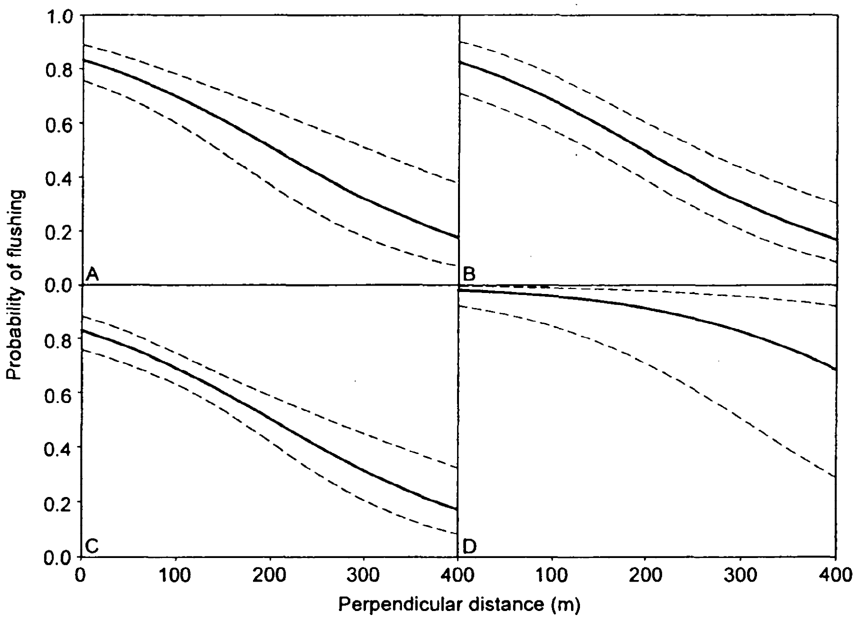

FIG. 3. Probability of wildlife flushing with increasing perpendicular distance: (A) bison, (B) pronghorn, (C) deer on-trail, (D) deer off-trail. Dashed lines indicate 95% confidence limits on probability.

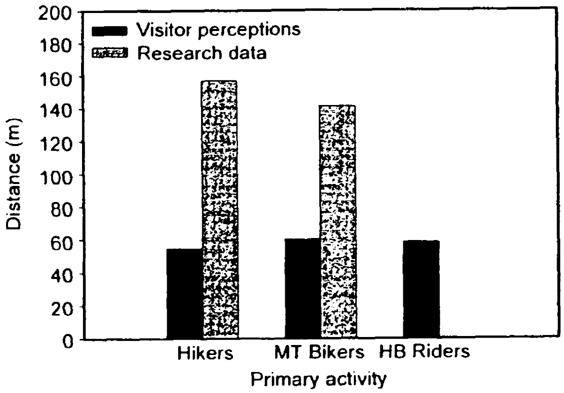

FIG. 4. Visitor perceptions of acceptable approach distance vs. wildlife flight distance. How close survey respondents believed it is acceptable for different user groups to approach wildlife contrasted with wildlife flight distances (from empirical data averaged across bison, deer on- and off-trail, and pronghorn). Research data on wildlife flight distances to equestrians (HB riders) were not collected in this study.

ranged between 50 m and 200 m, and few groups of animals were observed very close to trails. It is possible that these animals were those most habituated to trail-based recreation, and therefore showed little response when less habituated animals would already have fled (Whittaker and Knight 1999, Miller et al. 2001).

Time of day (morning or evening), animal group size and composition, and the position of the recreationist relative to the group also influenced wildlife response distances. Flight distances in bison, deer, and pronghorn were greater during morning trials than during evening trials, indicating a greater tolerance of recreationists during the evening (after 1700 hours [i.e., 5:00 P.M.]). This was previously found to be true in moose (*Alces alces*), elk (*Cervus elephus*), and mule deer (Altmann 1958), and may be related to the importance of evening as a feeding period during the heat of a continental summer.

Generally, the larger the group size of wildlife, the greater their response distances were. This finding contrasts with a previous study in which larger groups took flight less frequently than smaller groups (Recarte et al. 1998), but may be due to the tendency of gregarious animals to follow the lead of certain individuals in the group (Knight and Cole 1995*a*). For example, one animal beginning to flush often appeared to cue other group members to flush as well. In addition, one member of a group often continued to run after others had stopped, which occasionally spurred the stopped animals to begin running again. It is possible that larger groups have a greater chance of containing a particularly wary animal that will flush at large distances from a disturbance, thereby encouraging less wary animals to take flight at greater distances than they otherwise would.

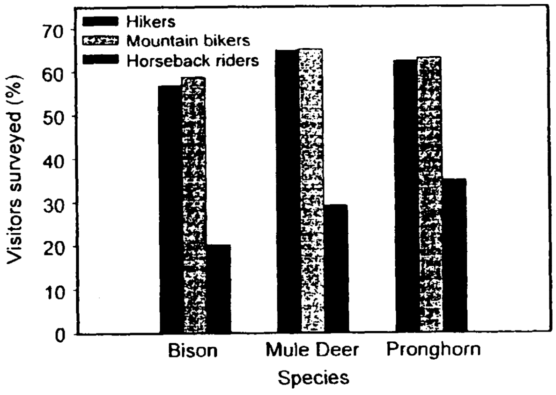

FIG. 5. Visitor perceptions of recreation effects. Values are the percentage of survey respondents in each user group who believed that bison, pronghorn, and mule deer may be negatively affected by recreation.

The presence of adult males reduced alert distance in pronghorn (similar to Hamr [1988] and Recarte et al. [1998]), but increased flight distance and distance moved in mule deer. Male deer often appeared more vigilant and wary than female deer on Antelope Island. Finally, a recreationist located above wildlife elicited a stronger response than a recreationist located level with or below wildlife. Due to the topography of Antelope Island, humans approaching animals from below are generally closer to the water, and therefore further from the interior of the island and typical escape terrain.

In many cases, it is difficult to make generalizations regarding the importance of external variables to wildlife response because studies are conducted with a variety of methods (A. Taylor and R. Knight, *unpublished manuscript*). For example, some researchers approach wildlife directly while others approach tangentially;

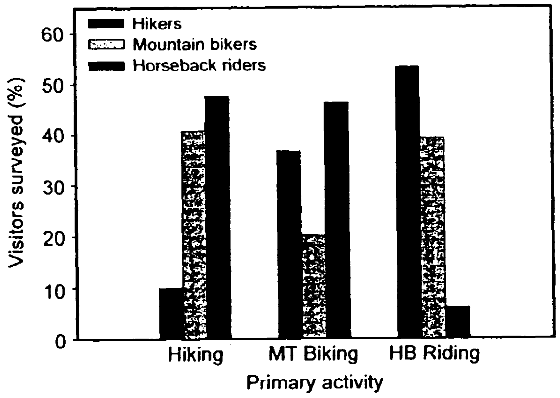

FIG. 6. Visitor perceptions of user group responsibility. Values are the percentages of survey respondents within each primary activity (user group) holding either hikers, mountain bikers, or horseback riders most responsible for stress to wildlife.

data collected using these different approach methods should not be compared.

Area of influence

The area of influence around a recreationist on a trail did not differ between mountain biking and hiking. This may mean that wildlife do not differentiate between hikers and bikers, but are instead reacting to the presence of a moving human on a trail, regardless of the person's activity. However, the area of influence differed considerably between on-trail and off-trail trials. This may reflect the spatial and temporal predictability of on-trail versus off-trail activities. Previous studies have indicated that animals react most to spatially unpredictable activities (Schultz and Bailey 1978, MacArthur et al. 1982, Hamr 1988, Miller et al. 2001). On-trail recreation may appear more predictable to wildlife because it occurs frequently and along a particular line of movement, and animals may habituate to this type of activity (Knight and Cole 1995*a*, Whittaker and Knight 1999).

Bison, mule deer, and pronghorn exhibited a 70% probability of flushing within 100 m of a trail. Increasing cover (from none to some to total cover) decreased the probability of wildlife flushing to recreationists. Therefore, although the area of influence of recreational activity is smaller on-trail than off-trail, it is still likely that animals will take flight from on-trail recreation, particularly if they are encountered in the open. Inherent in the flushing response is the potential for decreased energy acquisition and increased energy expenditure, and the possibility of animals avoiding suitable habitat due to recreational pressure. Thus, even on-trail recreation may have negative energetic consequences for wildlife and could result in displacement from otherwise suitable habitat (Miller et al. 2001). If wildlife on Antelope Island are able to habituate to human activity, the effects of recreation on animal populations may decrease over time. However, there is little evidence at this time to suggest that habituation may be occurring. The pronghorn on Antelope Island did not habituate to largely predictable recreational use over a three-year period following the opening of trails on the island, and in fact used areas that were significantly farther from trails than they had prior to the start of recreational use on the island (Fairbanks and Tullous 2002).

Visitor perceptions

Approximately 50% of visitors surveyed on Antelope Island did not believe that recreation was having a negative impact on wildlife. Our finding corresponds to the general public impression that recreation is benign and does not affect wildlife (Flather and Cordell 1995). In addition, visitor perceptions of wildlife flight distance differed remarkably from our research data. This was also the case in the only other study where wildlife responses to recreation and the perceptions of recreationists regarding those responses have been simultaneously measured (Stalmaster and Kaiser 1998). If visitors believe that they can approach wildlife more closely than animals will actually allow, then recreationists will disturb wildlife in a majority of encounters. Because flushing from recreational activity may come at the cost of energy needed for normal survival, growth, and reproduction (Geist 1978), and because it may cause animals to avoid otherwise suitable habitat (Hamr 1988, Gander and Ingold 1997, Miller et al. 2001), it is important that recreationists understand that their activities can flush wildlife and may make suitable habitat unavailable. By understanding and altering recreationists' perceptions with regard to their impacts on wildlife, public lands managers can influence visitor behavior and reduce the potential negative effects of recreation for wildlife.

There was little support among respondents for many of the management actions suggested on our survey. This may be because recreationists generally do not believe that they have an impact on wildlife, or because they believe that other user groups are more responsible for disturbing wildlife. In northwestern Washington, river recreationists also showed little support for restrictions on recreation, ostensibly because they did not understand that bald eagles were affected by recreation (Stalmaster and Kaiser 1998). Additional research integrating ecological and social data on recreational impacts is needed to fully examine the link between visitor perceptions, recreationist behavior, and public support for management actions that may reduce the impacts of recreation to wildlife.

RECOMMENDATIONS

Management

We found no biological justification for managing mountain biking any differently than hiking, if management decisions were to be based only on wildlife responses to each activity. However, because bikers travel faster than hikers, they may cover more ground in a given time period than hikers, thus having the opportunity to disturb more wildlife per unit time. Addressing the potential for mountain bikers to have a greater effect than hikers on wildlife will require knowledge of the typical distance traveled by bikers vs. hikers and their relative proportions among visitors to public lands. Importantly, because wildlife reacted most strongly to recreationists off trails, visitors should stay on designated trails to reduce disturbance to wildlife. Based on a 200-m area of influence around recreational trails (i.e., wildlife exhibit a 70% probability of flushing within 100 m on either side of the trail), 8.0 km^2 of 113.3 km^2 (7%) of Antelope Island may be potentially unsuitable for diurnal wildlife use due to disturbance from recreation. A decrease in suitable habitat may reduce the carrying capacity of public lands for wildlife (Light and Weaver 1973). This may be of particular concern where "islands" of public lands are surrounded by urban or suburban development, because wildlife in these areas may not be able to extend their home ranges to include less disturbed habitat (Miller et al. 2001). If management objectives include minimizing disturbance to wildlife habitat, new trails should follow existing edges and avoid water and forage resources, wildlife travel corridors, and escape terrain.

In addition, managers should investigate and consider visitor perceptions when planning management actions to separate wildlife and recreation, because visitors are more likely to comply with regulations when they understand how wildlife will benefit (Purdy et al. 1987). For example, survey respondents on Antelope Island tended to support the placement of minimum approach distances (buffer zones) around wildlife and tended to oppose the idea of fewer trails on the island.

The area of influence concept may provide a valuable measurement of potential habitat avoidance due to disturbance, and an estimate of the overall influence of recreational trails on wildlife habitat. Flight distance may be used as an assessment of the tolerance zone that an animal places between itself and a potential danger or disturbance (Altmann 1974). Flight distance has also been shown to be the best behavioral indicator of stress in wildlife (Stemp 1983). Therefore, we recommend that buffer zones or minimum approach distances (based on wildlife flight distances) be used to discourage recreationists from approaching wildlife too closely and causing them to flee. However, if such buffer zones are used for trail-based activities, data on wildlife flight distances should be collected by approaching animals tangentially rather than directly, so that the appropriate distance is used to determine the buffers.

Finally, the responses of wildlife to horseback riders need to be investigated. Horseback riding is another common use of non-motorized recreational trails, yet no study has addressed the comparative effects of equestrians on wildlife. Horseback riders in our survey tended to believe that they had the least impact on wildlife of any user group, and they were generally less supportive of management actions to protect wildlife. It is unclear whether these perceptions have a biological basis.

Education

We recommend that visitor education programs focus on informing recreationists about their potential effects on wildlife. Recreationists tend to believe that their activities are benign because they are dispersed over large areas (Flather and Cordell 1995). However, the majority of recent assessments suggest that recreation can affect wildlife individuals, populations, and communities. Recreationists need to be aware of wildlife responses such as flight distances and increased stress levels, the possibility for reduced carrying capacity of public lands, and the fact that each additional user may have a small yet cumulative impact on the environment.

ACKNOWLEDGMENTS

We thank the staff of Antelope Island State Park (G. Taylor, J. Sullivan, and S. Bates) for funding and logistical support of this project. T. Smith (previous Park Manager) deserves much credit for initiating the study. The Nature Conservancy of Utah and the Graduate School at Colorado State University also provided funding. Special thanks are due B. Pettitt, B. Parker, and especially B. Taylor for assistance with data collection. J. Vaske assisted with survey design and analysis, and P. Lukacs and G. White with the biological analysis. J. Savidge, J. Vaske, and J. Bradford provided invaluable insights on earlier drafts of the manuscript, and we are grateful for the helpful criticisms of R. S. Ostfeld and two anonymous reviewers. Finally, we also thank all of the researchers who have previously examined wildlife responses to human activities; your work has made ours possible.

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APPENDIX A

Tables showing values used in linear regression models to compare responses of wildlife to hiking and mountain biking are available in ESA's Electronic Data Archive: *Ecological Archives* A013-014-A1.

APPENDIX B

A table showing values used in logistic regression models to compare responses of wildlife to hiking and mountain biking is available in ESA's Electronic Data Archive: *Ecological Archives* A013-014-A2.

Published on Wildlands CPR (http://www.wildlandscpr.org)
By Adam Switalski, Road-RIPorter Issue: Fall Equinox 2003, Volume 8 #3

September 8, 2003

Where Have All the Songbirds Gone? Roads, Fragmentation, and the Decline of Neotropical Migratory Songbirds

There are approximately 250 species of neotropical migratory birds, most of which are songbirds. They breed in North American forests during our summer and spend winters in Central and South America in search of insects, nectar, and fruits. These songbirds play a major role in maintaining the health and stability of forested ecosystems by dispersing seeds, pollinating flowers, and consuming massive amounts of insects that if unchecked could lead to defoliating outbreaks. They are also enjoyed by millions of people.

Although songbirds are arguably the most watched and beloved of wildlife, they have experienced a significant decline in recent years (Terborgh 1989, 1992; Finch 1991; Hagan and Johnson 1992). This decline is concerning because bird populations are indicators of ecological integrity and are highly sensitive to adverse environmental change (Maurer 1993). This article reviews two important factors ¤ roads and habitat fragmentation ¤ in the decline of neotropical migratory songbirds.

Why are neotropical migratory songbirds declining?

Songbirds require large amounts of continuous forested habitat for survival and successful reproduction in both their wintering grounds in Central and South America and their summer breeding grounds in North America (Robbins 1979; Whitcomb et al.1981; Robbins et al. 1989) Although much of the birdsø tropical habitat has been degraded, studies suggest that conversion of large tracts of North American forest is the leading cause of their decline (Terborgh 1989; B"hning-Gaese 1993). Much of North Americaøs forested area has been logged, converted to agriculture or suburban landscapes, and left inhospitable for songbirds.

More subtle causes of habitat loss include the construction of roads and power lines. These linear barriers also have been correlated with a decline in neotropical migrant songbirds (Berkey 1993; Boren et al. 1999; Ortega and Capen 2002). Whether by forest conversion or the construction of roads and power lines, fragmentation subdivides habitat into smaller and smaller parcels. The result is an increase of edge habitat, or the boundary between intact forest and surrounding impacted areas. Small forests with large amounts of edge habitat are a hostile landscape for nesting neotropical migratory songbirds. In these areas, songbirds face two great threats: 1) the loss of eggs and nestlings to predators and, 2) parasitism by cowbirds.

Nest Predation

Nest predation is thought to be a leading cause of declines in neotropical migratory songbirds

(Wilcove 1985; AndrTn and Angelstam 1988; Yahner and Scott 1988). Forest edges comprise ideal habitat for many predators that would not typically invade a forest ecosystem, and many opportunistic predators concentrate their feeding efforts along these edges. When roads, power lines, or pipelines are constructed through forests, small mammalian predators such as raccoons, opossums, skunks, and feral cats use these linear avenues to access songbird breeding grounds and prey upon their eggs and young. Additionally, egg-eating birds such as American crows or blue jays also focus their hunting along forest edges.

Brood Parasitism

The Brown-headed Cowbird (Molothrus ater) also thrives along forest edges and may pose an even greater hazard to songbirds than that posed by predation (Brittingham and Temple 1983; Temple and Cary 1988). Cowbirds are an obligate brood parasite, which means they lay their eggs in the nests of other birds and rely on the host parents to rear their young. This can greatly reduce the reproductive success of parasitized songbirds because the host parents dedicate much of their time feeding the fast-growing cowbird nestling while neglecting their own young.

Cowbirds are native to the northern Great Plains and evolved in close association with bison; they expanded their range as European settlement brought domestic cows and grain throughout North America. Songbirds did not evolve with cowbirds and have only recently been exposed to nest parasitism. With hundreds of millions of cowbirds now living throughout the summer breeding range of songbirds, they will continue to be a great threat.

Other Factors

In addition to fragmentation and edge effects, roads and other linear barriers contribute to the decline of songbirds in others ways. Songbirds are very sensitive to noise and will avoid roads with a large volume of traffic (Reijnen et al. 1995, 1996). With millions of miles of roads in North America, this renders ineffective a huge amount of potential summer breeding habitat. Songbirds also can be attracted to less-traveled roads for gravel to aide in digestion, for insects and worms on roadsides, and to take dust baths (Noss 1995). This can lead to collisions between birds and vehicles (e.g. Novelli et al. 1988). It is estimated that a million vertebrates are victims of road kill every day in the United States; many of these are songbirds. Additionally, worms contaminated by road pollution can be fatal to the birds that feed upon them (Noss 1995).

Conclusions and Solutions

Neotropical migratory songbirds are beloved and provide priceless ecosystem services, however, a severe decline of songbirds has been documented. Many causes for this decline have been identified. Edges created from roads, forestry, agriculture, and suburbanization have resulted in a number of ecological changes for songbirds, including greater susceptibility to nest predation and brood parasitism. Habitat fragmentation has created a population sink in many of the areas where songbirds once thrived.

To reverse songbirdsø decline, it will be necessary to preserve critical summer breeding habitats and, where possible, protect and restore large tracts of intact forest. Conservation efforts should be focused on a regional scale because small nature preserves alone will not be sufficient to preserve songbirds (Askins 1995). Maurer and Heywood (1993) recommend decreasing timber harvest on remaining tracts of extensive forest on public lands. In urban areas, Hennings and Edge (2003) suggest increasing forest canopy and reducing street density within a 100-meter radius of streams. Successfully protecting and restoring large continuous forest tracts, reducing forest edges, and improving urban/suburban habitats should help slow songbirdsø decline.

--- *Adam Switalski is the Science Program Coordinator for Wildlands CPR.*

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ent: Sunday, January 31, 2010 7:12 PM
o: Tornek, Terry; Bogaard, Bill; Gordo, Victor; Madison, Steve; Haderlein, Steve; Robinson, Jonathan (ITSD); McAustin, Margaret; McIntyre, Jacqueline; Holden, Chris
Cc: Fuentes, Theresa; Laveaga, Rosa; Jomsky, Mark; Craig Sherman; gaboon@sbcglobal.net; Mary E Barrie; Hugh Bowles; Beck, Michael; Marietta
Subject: Public Comments on Agenda Item #6 for 2/1/10 City Council (3)

Attachments: EcoEffects of Linear Developments Wildlands CPR.docx; Effects of Horses Ikeda.docx; Human Activites on Wildlife.pdf

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From Spirit of the Sage Council for Agenda Item #6, for submission to the City Council - Public Comment on 2/1/10 , or thereafter. The comment letter is includes 15 attachments that will follow in groups of 3 in 5 emails. This is group 3.

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Thank you

Leeona Klippstein, Executive Director
Spirit of the Sage Council
(626) 676-4116

Published on Wildlands CPR (http://www.wildlandscpr.org)
By Sharon Mader, Road-RIPorter Issue: Autumn Equinox 2006, Volume 11 #3

July 17, 2006

Comparing the Ecological Effects of Linear Developments on Terrestrial Mammals

Roads and the human activities associated with them have profound impacts on wildlife. Roads, however, are not the only human intrusion that cuts through natural landscapes. Many other linear barriers mar the natural landscape, including trails, electrical power lines, oil and gas pipelines, and railways. According to Lyon et al. (1985), the linear development itself typically does not cause a disturbance response; it's the human presence on it that causes problems, therefore the level of use must be assessed and evaluated. Foreman (1995) determined that some linear features could be positive and some negative in terms of wildlife impacts: they can provide habitat, serve as conduits for travel or seriously impact wildlife by becoming barriers or sinks that negatively affect wildlife travel and mortality.

How do linear developments affect wildlife?

There have been a significant number of comprehensive studies conducted to assess the impacts of paved roads, but much less has been written about the impacts of dirt roads and trails on wildlife. There are even fewer studies that directly compare the diverse species-specific impacts that emerge along this spectrum of linear features. Jalkotzy et al. (1997) described possible wildlife disturbances within distinct categories to help assess potential impacts within the spectrum of linear barriers. These categories are as follows:

1. Individual Disruption

This refers to wildlife disruption that occurs in the immediate vicinity of a linear feature. Although all linear developments can cause problems, roads probably have the greatest impact on wildlife populations (Foreman et al. 2003). Larger-ranging, more sensitive species are most affected by roads in sometimes not so obvious ways. Wolves, for example, are sensitive to road activity near their natal dens and these disturbances can cause wolves to move pups to less-disturbed areas (Chapman 1977).

The effects of trails on wildlife can have similar negative impacts. In general, smaller linear barriers tend to be less disruptive because they usually have narrower rights-of-way, more curvilinearity and less intense human use (Foreman 1995). Large carnivores tend to be quite sensitive to human presence on trails. Both grizzly bears and black bears avoided trails and tended to maintain an average distance of 274m from trails. Avoidance distances by bears increased to 883m of trails in areas that were more heavily used (Kasworm 1990). Mountain lions were found to adopt a greater degree of nocturnal feeding behavior in order to avoid humans on trails (Jalkotzy et al. 1997).

2. Social Disruption

This is considered any change to the social structure of a population that results from a linear barrier. Changes can include displacement into habitat areas already occupied by other animals of the same species, changes in group structure, or mortality in different age classes as a result of the linear feature (Foreman 1997). Again, these impacts vary significantly for different species and can therefore be difficult to quantify in terms of general impacts on wildlife when comparing and contrasting roads and trails.

3. Habitat Avoidance

When wildlife avoid habitat because of linear barriers or the activities associated with them, habitat can be lost or not used to its full potential (Jalkotzy et al. 1997). Elk tend to avoid habitat close to roads, particularly in areas where they are hunted (Czech 1991). In northwest Montana, grizzlies avoided habitats within 274 m of trails (Kasworm 1990). Mace (1996) found that grizzly bears in the Swan Mountains of Montana appeared to move away from trails during spring, summer, and autumn. They concluded that grizzly bears had become negatively conditioned to human activities and avoided what would otherwise have been valuable habitat. In general, the impacts of trails depend on the types of activities and frequency of use (e.g., hiking, snowmobiling, biking). Studies revealed a broad variation among species in their response to human presence and specific recreational activities on trails.

4. Habitat Disruption or Enhancement

Linear developments can disrupt habitat by introducing exotic plants, and pollutants like dust, salt and vehicle emissions (Foreman 1995). Habitat can also be altered when vegetation is removed for road construction or when new plants or grasses are planted in highway right-of-ways. Whether these human activities disrupt or enhance a particular habitat can usually be linked to the width of the linear feature. The effects of habitat disruption on wildlife are probably small when compared with the effects of habitat avoidance (Jalkotzy et al. 1997).

5. Direct or Indirect Mortality

Direct mortality is a result of the road itself (e.g. wildlife-vehicle collisions or powerline collisions/electrocutions), while indirect mortality can result when roads or trails provide greater access for hunting, trapping, and poaching. A report compiled by Hellmund Associates cited research where aggressive bird species were observed following trails and displacing other sensitive species, resulting in increased predation on songbirds and other neotropical birds. Changes to the area surrounding a trail can have impacts that extend for hundreds to thousands of feet and are referred to as the trail distance effect (Hellmund Associates 1998).

6. Population effects

These are defined as wildlife populations suffering losses as a direct result of linear developments. Roads and vehicles can have a tremendous negative impact on terrestrial vertebrates, but seem to have less impact on overall population size (Foreman and Alexander 1998). There are many information gaps that make it difficult to assess the impacts of roads, but there is growing evidence that linear developments can affect the distribution, movements, and overall populations of wildlife species (Jakotzy et al. 1997). For example, there is concern that development within the petroleum and forest industries has impacted woodland caribou populations (James et al. 2000).

Also, studies found that desert bighorn sheep fail to utilize 20-35% of suitable habitat in

Canyonlands National Park, Utah, as a result of human activity and this habitat avoidance has resulted in a decreased population (Papouchis et al. 2001). Another potential impact is the displacement of wildlife to areas with greater risk of predation (Papouchis et al. 2001). The presence of humans on trails and roads can also lead to increased stress on wildlife populations and disrupt wildlife behavior (Vohman 2002).

How do we measure the cumulative impacts of linear features?

Cumulative effects of roads, trails, and other linear barriers on wildlife should be measured through a cumulative effects assessment (CEA) and utilize geographic information systems (GIS). Fairbanks and Tullouse (2002) urged managers to incorporate research findings on wildlife into GIS mapping to help assess the impacts of proposed linear developments. The three main ways to measure the cumulative impacts of linear features are: 1) measure road densities, 2) assess road/trail design, and 3) conduct an ecological evaluation prior to development (Hellmund Associates 1998).

Existing systems for evaluating road/trail impacts on a landscape level

After reviewing existing literature to identify a viable system for comparatively evaluating and weighting the impacts of roads and trails, I discovered three systems (two of which have specific evaluative measures). The first included in the Arc Wildlife Services study presented a model developed by Weaver (1986) for assessing impacts on large carnivores or other sensitive species that tend to avoid linear developments. The second system provides a set of assessment tools to evaluate impacts on small mammals (Joslin et al. 1999). The third provides a weighted system based on flight distances to compare and contrast reactions of wildlife to a variety of trail uses (Hellmund Associates 1998). It would be ideal to have a system that includes all elements, species and factors in one, however, since species' needs and reactions to linear development are often dramatically different, it may be more appropriate to use a series of weighted systems in order to best represent the big picture impacts of a proposed road or trail.

It seems safe to infer from the research that the larger and more significant the linear feature and the greater the density of developments within area, the greater the impacts on wildlife. It is also evident from the research that the cumulative effects of all linear intrusions (roads, trails, seismic lines, power lines, rail lines) should be considered collectively to truly grasp the overall effects on the diverse species that inhabit any given ecosystem.

Only when we consider the overall density of roads and trails, taking into account the zones of avoidance for multiple species, will we glimpse the ecological impacts of our choices. Perhaps by doing so in a meaningful way, decision-makers will choose to limit new linear features or realign human travel routes in a way that will provide meaningful ecological benefits to wildlife populations.

—Sharon Mader has been a life-long environmental activist and is currently an Environmental Studies graduate student at the University of Montana.

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The Role of Horses in the Introduction and Spread of Noxious Weeds

Robin Ikeda, Biology Professor, Chaffey College
May 2001

On 17 May 2001, I was asked by Larry Henderson, Bill Alexander, and the North Etiwanda Preserve District Board to provide the Board with research justifying the commonly held position that horses should be permanently excluded from the North Etiwanda Habitat Preserve, primarily because they act as a potent agent of dispersal of invasive plant species. As an epistemological point, allow me to redefine the assignment. For the purposes of research, it is only appropriate for me to approach the question from a neutral position. Had there been evidence refuting my original position, I'd be compelled to report it here, and to alter that position. I found no such evidence. I also became curious about other impacts of horses. What I found is summarized below.

There are two means by which vertebrates transport and disperse seeds: externally, in their integuments (epizoochory) and internally, in their guts (endozoochory). Horses are effective dispersal agents in both regards.

I. Epizoochory (External)

- Horses commonly carry seeds of burr clover, horehound, wild oats, and star thistle, among other weeds, in their fur and tails (Muhlenback, 1979; Jordan, 2000; Schiffman, 1997 Reichard, 1997).
- (See Sorenson, 1986 for a review of mechanisms of seed dispersal by adhesion.)

II. Endozoochory (Internal)

- Among the many noxious weed species reportedly dispersed by horses and other livestock are Erodium, Bromus, Avena (oats), Brassica, and Circium (Schiffman, 1997).
- Crop contamination by weeds has evidently been responsible for many of the initial introductions (Baker, 1986; Mack, 1981).
- Seeds may be brought into new habitats with straw used for pack animals (Kruger, et.al., 1986).
- Seeds of a great many species (Muhlenback, 1979 sites 75 species in one train car load) of noxious weeds are commonly present in livestock feed, such as hay. These constitute not only the dietary grains of horses, such as alfalfa, oats, and corn, but seeds of the species which invaded the feed crops. The literature on this is huge. Muhlenback, 1979 cites some of the vast European literature on the subject (e.g., Meyer, 1931). See also Beach, 1909; Courtney, 1973; and Kruger, et.al., 1986.
- Surprisingly, weed seeds are even present in certified weed-free hay (Zamora and Olivarez, 1994).
- Some weed seeds also survive the grinding process to remain viable in alfalfa pellets (Zamora and Olivarez, 1994; Cash, et.al., 1998). Weed seedlings emerged from eleven percent of the pellet samples studied by Cash's group. The proportion can be reduced to diminishingly small figures by the use of tiny screens to eliminate intact seeds after grinding (Cash, et.al., 1998). Evidently, feed manufacturers presently take no such precautions. I doubt that they'd be effective in local feed anyway, since mustard is a contaminant, and its seeds are impossibly tiny.
- Seeds of a great many species, including those of noxious weeds, are capable of surviving the trip through the mammalian gut, and are deposited alive, with a supply of fertilizer, after a few days or weeks (Baker, 1986; Thill, et.al., 1986). There is a large literature on the subject of seed viability in the dung of range and dairy cattle; Janzen, 1984 provides a helpful review. There is a fledgling literature about seed viability and dispersal in horse dung (Janzen, 1981; Janzen, 1984; Benninger, 1989). Given that an average head of cattle is estimated to deposit 300,000 seeds a day (Schiffman, 1994), a large proportion of which are weedy and viable, and that horse guts are inordinately more seed-friendly places than are those of cattle, it is safe to speculate that a great many of the seeds ingested by horses are dispersed by their dung. Study on the topic is clearly needed (Cash, et.al., 1998).
- There are a number of studies correlating the presence of horses with the introduction of weeds.
  1. The abundance and diversity of weed species is higher close to trails (Benninger-Truax, et.al., 1992).
  2. The above pattern disappears, and alien species are abundant off trail in areas which had been used to pasture horses (Tysler and Worley, 1992).
  3. The presence of invaders common to hay alfalfa fields and feed correlates with use of the affected areas by horses (Jordan, unpublished data. In Jordan, 2000).
  4. The presence and abundance of invaders correlates with troop training activities during WWI and WWII. Muhlenback (1979) references some of the European literature describing this pattern.
  5. The presence, abundance, and diversity of invaders correlates positively with the presence of grazing livestock (Aschmann, 1991; Groves, 1989; Lidicker, 1989; Wagner, 1989).

Assessing the Effects of Human Activities on Wildlife

Robert J. Steidl and Brian F. Powell

HUMAN ACTIVITIES THAT AFFECT WILDLIFE AND THEIR HABITATS are pervasive and increasing. Effects of these activities are manifested at all ecological scales, from short-term changes in the behavior of an individual animal through local extirpations and global extinctions (Pimm et al. 1995; Chapin et al. 2000). Consequently, understanding the effects of humans on wildlife and wildlife populations, as well as devising strategies to ameliorate these effects, is an increasing challenge for resource managers. Given the conflicting mandate to both encourage human use and to protect sensitive natural resources in national parks, developing reliable strategies for assessing and monitoring the effects of human activities on natural resources is essential to ensuring appropriate stewardship of these resources.

Given the breadth of relevant human activities, the diversity of wildlife species potentially affected, and the multitude of ways they may be affected, scientists and resource managers planning to assess the effects of human activities on wildlife must be careful to state their study objectives explicitly. In all cases, these objectives should specify the human activity of interest; the timing, intensity (frequency, duration) and spatial extent of the activity; the focal wildlife species of interest; and the range of ways that species might respond to the activity—that is, the objectives should define the "disturbance context" in which the human–wildlife interaction occurs (Steidl and Anthony 2000). Given well-defined objectives and a clear disturbance context, a measure that gauges the response of the wildlife species of interest to the human activity must be selected carefully.

In this paper, we provide a general classification for the ways in which human activities can affect wildlife, distinguish among general types of relevant studies based on different objectives, and identify appropriate measures for gauging wildlife response for different types of studies. Our goal is to provide a conceptual framework to guide studying and monitoring human–wildlife interactions, specifically those deriving from non-consumptive recreational activities.

Classifying human activities

Virtually all human activities can affect wildlife populations either positively or negatively. Those activities that are likely to have adverse effects can be divided into those that function primarily by altering the physical environment in a relatively permanent way and those that cause changes to an animal's behavior. Activities that alter the physical environment change the amount or the suitability of habitat for a species. Widespread and large-scale examples include activities that directly alter the structure and composition of the landscape, such agriculture, forestry, livestock grazing, and unregulated off-road vehicle use. In general, these are land use or land management practices that change the trajectory of ecological succession, including altering the dominant plant communities and the abiotic features of a site. The ecological effects of these activities on vertebrates are readily apparent and have been relatively well studied (e.g., Blair 1996; Spies et al. 1996; Lichstein et al. 2002).

Perhaps less obvious in their ecological impacts are those non-consumptive human activities that do not appreciably alter the physical environment but nonetheless can affect wildlife adversely. Examples include recreational activities such as hiking, wildlife viewing, and boating—all common activities for visitors in parks. As recreational use increases in wilderness and other protected areas, sensitive wildlife species may be increasingly affected by these activities (Steidl and Anthony 2000). The magnitude of effects of recreational activities on wildlife is influenced by many factors, including the type, duration, frequency, magnitude, location, and timing of the disturbance, as well as the particular species of interest. Although effects of these activities are typically of short duration, cumulatively they can effect wildlife populations adversely in both the short- and long-term (Burger 1981; Henson and Grant 1991; Fernandez and Azkona 1993; Holmes et al. 1994; Steidl and Anthony 1996, 2000; Swarthout and Steidl 2001, 2003; Mann et al. 2002; Johnson et al. 2005). Observed effects include increased energetic stresses (Bélanger and Bédard 1990), changes in activity budgets (Steidl and Anthony 2000; Mann et al. 2002; Swarthout and Steidl 2001, 2003), displacement from preferred environments (McGarigal et al. 1991), and reduced productivity through abandonment and decreased survival of young (Tremblay and Ellison 1979; White and Thurow 1985).

Although there are human activities that cause physical changes to park environments, such as construction of building and roads, or vegetation destruction resulting from overuse of particular areas, most wildlife-related impacts away from these areas likely result from short-term recreational pursuits of visitors. We focus the remainder of our discussion on these types of activities.

Types of studies

Given the wide range of potential information needs and study objectives, we distinguish between two fundamentally different kinds of studies: research and monitoring. These can be classified primarily based on their different objectives and secondarily based on different durations. *Research studies* include an objective related to answering specific questions and are usually of relatively short duration (1–3 years). An example would be a study conceived to assess the distance at which a population of birds flushes in response to a particular visitor activity, such as hiking or mountain biking (e.g., Swarthout and Steidl 2001). The goal for this type of study might be to reliably establish the distance at which birds flush in response to the activity so that the activity can be restricted in particular areas to reduce disturbance frequency and minimize adverse effects. In contrast, *monitoring studies* involve quantifying changes in characteristics of resources over time, are usually not driven by particular questions, and are always intended to be undertaken over long-time periods (Steidl 2001). The goal for monitoring studies is almost always related to quantifying changes in characteristics of resources over time. A third kind of study, which we only mention here, is a hybrid between research and monitoring studies. *Impact assessment studies* are designed to measure the effects of a planned activity or action within the context of a previously established monitoring program. These are often large-scale studies where the fundamental approach is to establish a monitoring program based on a series of sampling sites, a subset of which is eventually subject to being affected by the impact. The effect of the impact is estimated by comparing how sites subject to the impact change relative to control or reference sites over time (Green 1979). The application of these studies is useful to natural resource managers interested in assessing the effects of management actions, such as opening or closing particular trails or other facilities, especially when replication of the impact is impossible.

All types of studies benefit from careful application of the basic tools of research design, which include randomization, replication, reduction of error, incorporation of adequate controls, and understanding how the scope of inference for any study is dictated in part by the way study units are selected (Ramsey and Shafer 2001).

Research studies. Specific resource management questions about human-wildlife interactions are best answered through well-designed research studies, either experimental or observational. Questions that can be answered experimentally, which always involves some type of manipulation by the investigators, are more powerful than observational studies because they provide strong evidence of a causal link between the activity and the response measure. Observational studies cannot establish cause-and-effect inferences because of the potential for confounding by additional factors that may have influenced the response measure. Observational studies, therefore, provide only correlative inferences, yet can offer strong evidence when designed carefully. There is a vast literature on conceiving and designing effective research studies on wildlife populations (e.g., Morrison et al. 2001).

Monitoring. Ecological monitoring studies almost always focus on quantifying changes in characteristics of resources over time. Consequently, monitoring studies are correlative and can therefore quantify patterns and associations but cannot establish causal links between changes in the resource of interest and changes in levels of human activity or other environmental characteristics. For example, if we observe a decline in abundance of a species in an area over time concurrent with an increase in a particular type of human activity, we cannot claim that the increase in human activity caused the decrease in abundance. Despite their limited inference relative to randomized experiments, monitoring studies can still provide information that is valuable for understanding and reducing human-wildlife conflicts (Burger et al. 2004) especially when designed as part of an integrated monitoring program that encompasses a range of biotic and abiotic resources. Specifically, by measuring other environmental characteristics that are thought to affect changes in the wildlife response measure of interest (e.g., vegetation structure, food resources, rainfall), the ability to detect temporal and spatial changes in the resource is increased and the likelihood that the observed change was driven by a confounding variable is reduced. Lastly, the information provided by monitoring studies can be increased if they are designed to be comparative—that is, designed to contrast wildlife responses in areas of concern or impact with those in control or reference areas (e.g., Romero and Wikelski 2002).

Monitoring visitor impacts on wildlife is different than most observational studies because changes in parameters of interest are designed to be measured for long time periods, usually spanning multiple generations. Therefore, well-designed monitoring programs should provide sufficient temporal and spatial coverage as well as the flexibility to address a range of potential impacts, the nature and extent of which may be unknown when the program is being designed.

Choosing an appropriate wildlife response measure

Understanding both the short- and long-term consequences of interactions between humans and wildlife requires that a response measure be chosen that reflects the temporal and spatial scales appropriate to the human activity being assessed (Table 1). Many attempts to understand the effects of human activities on wildlife have focused on measures that are most appropriate for long-term assessment (i.e., 5–10 years or more) such as abundance (e.g., Mathisen 1968; Fraser et al. 1985; Westmoreland and Best 1985), reproductive success (e.g., Fernandez-Juricic 2000), and species diversity (e.g., Francl and Schnell 2002). Although these are clearly important measures, they are not appropriate for assessing all types of human activities because changes in behavior and space use are often overlooked, both of which can have long-term consequences for populations (Holthuijzen 1989; Anthony et al. 1995; Gill et al. 2001). Changes in behavior are consequential because they can ultimately affect reproductive success, survival, and habitat occupancy, which in turn can reduce population viability, especially for rare, threatened, or endangered species. Response measures that include aspects of behavior, such as activity budgets or space use, are most appropriate for short-duration human activities such as hiking.

As a general guideline, wildlife response measures should reflect the temporal and spatial scales of the human activity of interest, including the type of activity, its daily and seasonal timing, duration, and frequency, especially during initial investigations. The choice of the species or population to study is also critical, because species vary widely in their responses to human activities as do different populations of the

Table 1. Potential response measures for assessing effects of human activity on wildlife and wildlife populations.

Appropriate study period	Measure
Short-term	Physiological responses — heart rate, stress hormones Behavior and activity budgets Space and habitat-use
Long-term	Reproductive success and productivity Survival or mortality rates Abundance or density Distribution or occupancy rates Species richness Species diversity

same species, which can depend on their previous exposure to the human activity of interest. Assuming the choice of species and populations has been made or was mandated by legislation, the response measure should match the disturbance context, which is defined, in part, by the time scale of the human activity of interest. For most research studies, short-term responses seem most appropriate, whereas for most monitoring studies, long-term responses seem most appropriate (Table 1).

Effects of human activities on bald eagles *(Haliaeetus leucocephalus)* have been relatively well studied, so we'll use this species to illustrate the importance of choosing appropriate response measures. Many research studies have used reproductive success as the response measure and have reported no relationship between the level of human activity and reproductive success (e.g., Mathisen 1968; Fraser et al. 1985). In some cases, these negative results may reflect two fundamental problems: a disconnection between the scale of human activity being studied and the response measured (a short-term study and a long-term response measure) and a likely potential problem assessing impacts that have been in place for years.

With regard to the disconnection between the scale of the human activity and the response measure, the nesting season for bald eagles is long (>120 days), so short-term activities are unlikely to effect reproduction unless the activity is very intense. In most studies where bald eagles were disturbed by researchers approaching nests, the activities were of short duration (usually less than an hour) relative to the nesting period (Grier 1969; Fraser et al. 1985). Once a pair has made the decision to breed and has invested energy into producing offspring, they are more difficult to displace with such short-duration impacts relative to a pair that has not yet nested or to individuals that are not breeding (Trivers 1974). This investment may explain why some species abandon nesting sites the year after, rather than the year of, a short but intense disturbance near the nest (Platt 1977).

Populations that have long been exposed to a particular human activity may have already responded to the activity or may have become habituated. Because many studies are initiated well after the human activity was established, a conclusion of "no effect" may be misleading because consequential effects may have already occurred. For example, changes in distribution of bald eagle territories away from a new source of human activity did not occur until several years after the activity was established (Gerrard et al. 1992). If the eagles that are most sensitive to human activities abandon their nests after the level of human activity exceeds some threshold level but before a study is initiated, the chances of observing any residual effects would be low. These "time lags" may obscure changes in site occupancy unless viewed on longer time scales (Wiens 1986). And although the conclusion of no effect is likely appropriate for the specific locations where these data were collected, applying management recommendations to other areas based on information gleaned from these kinds of biased samples could have adverse consequences. Without thinking carefully about the contextual issue of previous exposure, activities affecting wildlife may be classified incorrectly or inappropriate management recommendations made.

Planning monitoring studies that include human–wildlife issues

Monitoring studies that include an objective to assess changes in wildlife populations in response to changes in visitor activities will need to quantify human activities carefully. Sampling should be designed to capture the amount, types, and intensity of the human activity as well as how the activity varies spatially and temporally (Gregoire and Buhyoff 1999; Watson et al. 2000). Carefully quantifying these elements will increase the ability to relate trends in the resource with changes in levels and types of human activity. As we mentioned previously, monitoring changes in wildlife populations is more efficient when integrated into a broader program that includes measuring additional biotic and abiotic parameters, especially those that might be directly affected by human activities of particular interest.

There are a number of tools for designing studies that can be used to increase the success of a monitoring program while balancing the interrelationships and trade-offs among sampling effort, cost, and the overall ability of the program to detect trends in resources (e.g., www.pwrc.usgs.gov/monmanual/). In general, sampling designs that include elements to reduce sampling variability, such as stratified or cluster sampling, tend to be more efficient than those that do not account for heterogeneity of the response measure across the study area (Thompson 2002). Power analysis can guide some of the more challenging design questions, such as how many samples are necessary to meet study objectives, how large a trend is likely to be detected with a given amount of sampling effort, and what the probability of detecting a particular trend that is considered biologically meaningful might be (Gerrodette 1987; Steidl and Thomas 2001).

Monitoring changes in natural resources requires a detailed statement of goals and a careful choice of parameters to measure. To link monitoring to management, a threshold in the response measure should be identified such that when the threshold is reached, managers are alerted that resource levels have reached an unacceptable level and some sort of action needs to be taken. A tight integration between monitoring and management is critical, as monitoring programs often fail because they were established without involvement of managers (Noon 2003). Those programs that are linked clearly to management objectives and are designed to provide regular updates on the status and trends of natural resources and human activities will be most useful and therefore will have the highest chances of persisting over the long term.

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Jomsky, Mark

From: Leeona Klippstein [leeona@earthlink.net]
Sent: Sunday, January 31, 2010 7:25 PM
To: Tornek, Terry; Bogaard, Bill; Gordo, Victor; Madison, Steve; Haderlein, Steve; Robinson, Jonathan (ITSD); McAustin, Margaret; McIntyre, Jacqueline; Holden, Chris
Cc: Fuentes, Theresa; Laveaga, Rosa; Jomsky, Mark; Craig Sherman; gaboon@sbcglobal.net; Mary E Barrie; Hugh Bowles; Beck, Michael; Marietta
Subject: Public Comment on Agenda Item #6 for 2/1/10 City Council (4)

Attachments: The Impacts of Mountain Biking on Wildlife and People.docx; EcoEffectsOfRoads Wildlands CPR.docx; Effects of Roads on Wetlands Wildlands CPR.docx

The Impacts of EcoEffectsOfRoaEffects of Roads
Mountain Biking..ds Wildlands CP..on Wetlands W...

From Spirit of the Sage Council for Agenda Item #6, for submission to the City Council - Public Comment on 2/1/10 , or thereafter. The comment letter is includes 15 attachments that will follow in groups of 3 in 5 emails. This is group 4.

If you are unable to retrieve the attachments, please contact me to resend.

Thank you

Leeona Klippstein, Executive Director
Spirit of the Sage Council
(626) 676-4116

The Impacts of Mountain Biking on Wildlife and People -- A Review of the Literature

Michael J. Vandeman, Ph.D.
July 3, 2004

"Every recreationist -- whether hiker, biker, horsepacker, or posey sniffer -- should not begin by asking, 'What's best for ME?' but rather 'What's best for the bears?'" Tom Butler

"Will we keep some parts of the American landscape natural and wild and free -- or must every acre be easily accessible to people and their toys? … Mountain bikes' impacts on the land are large and getting worse. … The aggressive push of mountain bike organizations to build ever-growing webs of trails poses serious problems of habitat fragmentation, increased erosion, and wildlife conflicts.

As interest in extreme riding continues to grow, as trail networks burgeon, and as new technology makes it possible for ever-more mountain bicyclists to participate, even the most remote wild landscapes may become trammeled -- and trampled -- by knobby tires. … The destruction of wilderness and the fragmentation of habitats and ecosystems is death by a thousand cuts. Will introduction of mountain bikes -- and their penetration farther into wilderness -- promote additional fragmentation and human conflicts with the natural world? Yes." Brian O'Donnell and Michael Carroll

"Some things are obvious: mountain bikes do more damage to the land than hikers. To think otherwise ignores the story told by the ground. Although I have never ridden a mountain bike, I am very familiar with their impacts. For the last seven years I have regularly run three to six miles several times a week on a network of trails in the Sandia Mountain foothills two blocks from my home. … These trails receive use from walkers, runners, and mountain bikers; they are closed to motorized vehicles.

Because I'm clumsy, I keep my eyes on the trail in front of me. I run or walk in all seasons, in all kinds of weather. I have watched the growing erosion on these trails from mountain bike use. The basic difference between feet and tires is that tire tracks are continuous and foot tracks are discontinuous. Water finds that narrow, continuous tire tracks are a rill in which to flow. Also, because many mountain bikers are after thrills and speed, their tires cut into the ground. Slamming on the brakes after zooming downhill, sliding around sharp corners, and digging in to go uphill: I see the results of this behavior weekly. …

I regularly see mountain bikers cutting off cross-country, even on steep slopes, for more of a challenge. They seem blind and deaf to the damage they cause. Admittedly, backpackers and horsepackers can cause damage to wilderness trails. But this is a poor argument to suggest that we add another source of damage to those trails." Dave Foreman

"Studies show that bike impacts are similar to those of other non-motorized trail users." Jim Hasenauer (professor of rhetoric and member of the board of directors of the International Mountain Bicyclists Association)

Introduction:

I first became interested in the problem of mountain biking in 1994. I had been studying the impacts of the presence of humans on wildlife, and had come to the conclusion that there needs to be habitat that is entirely off-limits to humans, in order that wildlife that is sensitive to the presence of humans can survive (see Vandeman, 2000). But what is the best way to minimize the presence of people? Restricting human access is repugnant, and difficult and expensive to accomplish. It occurred to me that the best way to reduce the presence and impacts of humans is to restrict the technologies that they are allowed to utilize in nature: e.g. prohibit bicycles and other vehicles (and perhaps even domesticated animals, when used as vehicles).

Having been a transportation activist for eight years (working on stopping highway construction), and having a favorable view of my fellow bicyclists as environmentalists, I turned to them to help me campaign to keep bicycles out of natural areas. Was I ever surprised! I discovered that many bicyclists (e.g. many mountain bikers) aren't environmentalists at all, but are simply people who like to bicycle -- in the case of mountain bikers, many of them just use nature, as a kind of playground or outdoor gymnasium! (Of course, there are also hikers, equestrians, and other recreationists who fall into this category.) To my suggestion to keep bikes off of trails in order to protect wildlife, they reacted with hostility! (There is a degree of balkanization among activists, where some transportation activists ignore the needs of wildlife, and some wildlife activists eschew bikes and public transit.)

In 1994 I attended a public hearing held by the East Bay Municipal Utility (water) District to decide whether to allow bikes on their watershed lands. Mountain bikers were there asking for bike access, and the Sierra Club was there to retain the right to hike, while keeping out the bicycles. I said that I had no interest in using the watershed, but that I wanted to ensure that the wildlife are protected -- hence, I asked that bikes not be allowed. Afterward, the EBMUD Board of Directors took a field trip to Marin County, the birthplace of mountain biking, to see the effects of mountain biking there. While they were hiking along a narrow trail, a mountain biker came racing by, swearing at them for not getting out of his way fast enough. That helped them decide to ban bikes. Today bikes are still restricted to paved roads, and EBMUD is still one of the public agencies most protective of wildlife.

It is obvious that mountain biking is harmful to some wildlife and people. No one, even mountain bikers, tries to deny that. Bikes create V-shaped ruts in trails, throw dirt to the outside on turns, crush small plants and animals on and under the trail, facilitate increased levels of human access into wildlife habitat, and drive other trail users (many of whom are seeking the tranquility and primitiveness of natural surroundings) out of the parks. Because land managers were starting to ban bikes from trails, the mountain bikers decided to try to shift the battlefield to science, and try to convince people that mountain biking is no more harmful than hiking. But there are two problems with this approach: (1) it's not true, and (2) it's irrelevant.

I will examine (1) in a moment. But first, let's look at relevance: whether or not hiking (or All Terrain Vehicles or urban sprawl or anything else) is harmful really has no bearing on whether mountain biking is harmful: they are independent questions. Such a comparison would only be relevant if one were committed to allowing only one activity or the other, and wanted to know which is more harmful. In reality, hiking is always allowed, and the question is whether to add mountain biking as a permitted activity. In that case, the only relevant question is: Is mountain biking harmful? Of course, it is. However, since many people seem interested in the outcome of the comparison, I will examine the research and try to answer it.

The mountain bikers' other line of research aims to prove that mountain bikers are just like hikers, implying that they should have the same privileges as hikers. (Of course, they already have the same privileges! The exact same rules apply to both groups: both are allowed to hike everywhere, and neither is allowed to bring a bike where they aren't allowed.) Using surveys, they have tried to show that mountain bikers are really environmentalists, lovers of nature, and deep ecologists. Of course, surveys are notoriously unreliable: statements of belief don't easily translate into behavior. I'm going to ignore this research, since I am (and the wildlife are) more interested in actual impacts, not intentions.

The International Mountain Biking Association (IMBA) has done me the favor of collecting all the research they could find that seemed favorable to mountain biking. Gary Sprung (2004) summarized it in his carefully worded essay, "Natural Resource

Impacts of Mountain Biking". Gary says "the empirical studies thus far do not support the notion that bikes cause more natural resource impact". I will show that this is not true; in fact, those studies, if their data are interpreted properly, show the exact opposite: that mountain biking has much greater impact than hiking! Gary says that we should make "make rational, non-arbitrary, less political decisions regarding which groups are allowed on particular routes". This is disingenuous. Mountain bikers (but not bikes) are already allowed on every trail.

Impacts on Soil (Erosion):

Gary says "No scientific studies show that mountain bikers cause more wear to trails than other users". He cites Wilson and Seney (1994) and claims that "hooves and feet erode more than wheels. … Wilson and Seney found no statistically significant difference between measured bicycling and hiking effects". He quotes the study: "Horses and hikers (hooves and feet) made more sediment available than wheels (motorcycles and off-road bicycles) on prewetted trails" (p.74).

This study is frequently cited by mountain bikers as proof that mountain biking doesn't cause more impact than hiking. But it has a number of defects that call its conclusions into question. The authors used a "rainfall simulator" to measure "sediment made available" by the various treatments. They "[collected] surface runoff and sediment yield produced by the simulated rainstorms at the downslope end of each plot", which they claim "correlates with erosion" (they don't say what the correlation coefficient is). This doesn't seem like a good measure of erosion. For example, if a large rock were dislodged, the very weak "simulated rainfall" wouldn't be capable of transporting it into the collecting tray; only very fine particles would be collected. In fact, they admit that the simulator's "small size … meant that the kinetic energy of the simulated rainfall events was roughly one-third that of natural rainstorms". Another reason to suspect that the measurements aren't valid is that "none of the relationships between water runoff and soil texture, slope, antecedent soil moisture, trail roughness, and soil resistance was statistically significant".

Another problem with the study is that the hikers and mountain bikers used trails that were significantly different, prior to the experiment!: "The results from Part A of Table 4 suggest that the trails used for the five treatment types were not similar in terms of their sediment yield behavior prior to the treatments. Trail plots used for hikers were statistically different from one of the other groups (off-road bicycles) at the .05 level" (p.84). This makes it even less likely that the hiker-mountain biker comparison is valid.

The authors also ignored the relative distances that various trail users typically travel (for example, bikers generally travel several times as far as hikers, multiplying their impacts accordingly) and the additional impacts due to the mountain bike bringing new people to the trails that otherwise would not have been there (the same omission is true of all other studies, except Wisdom et al (2004)). They do say "Trail use in the last ten years has seen a dramatic increase in off-road bicycles" (p.86), but they don't incorporate this fact into their comparison. In addition, there is no recognition of different styles of riding and their effect on erosion. We don't know if the mountain bikers rode in representative fashion, or, more likely, rode more gently, with less skidding, acceleration, braking, and turning. There was also no recognition that soil displaced sideways (rather than downhill) also constitutes erosion damage. It seems likely that they underestimated the true impacts of mountain biking. I don't think that these results are reliable. (Note that the study was partially funded by IMBA.)

Gary next cited Chiu (Luke.Chiu@utas.edu.au) and Kriwoken (L.K.Kriwoken@utas.edu.au), claiming that there was "no significant difference between hiking and biking trail wear". It is apparent he and the authors misstated the implications of the study. If we assume, as they claim, that bikers and hikers have the same impact <u>per mile</u> (which is what they measured), then it follows that mountain bikers have several times the impact of hikers, since they generally travel several times as far. (I haven't found any published statistics, but I have informally collected 72 mountain bikers' ride announcements, which advertise rides of a minimum of 8 miles, an average of 27 miles, and a maximum of 112 miles.)

Besides ignoring distance travelled, there were a number of other defects in the study. The biking that was compared with hiking was apparently not typical mountain biking. It was apparently slower than normal and included no skidding. Bikers who skidded (a normal occurrence) were not compared with hikers. Their erosion impacts were much greater than those of any hikers (judging from the study's graph labelled "Figure 3"). Bikers' impacts under wet conditions were also greater than those of the hikers, which probably would have been statistically significant, if the numbers (of data points) had been greater.

One useful result was that the bikers tended to create a V-shaped groove, whereas the hikers' impact was spread more evenly across the trail. They admit that this "could act as a water channel and increase erosion" (p.356). They also surveyed trail users: "34% of riders listed excitement/risk as a main reason for visiting [the park]. This, combined with the 57% of 'other users' who visit for relaxation, sets up a potential for goal interference, in that a rider aiming for an exciting/risky experience has the potential to interfere with a walker aiming to have a relaxing experience." (p.357) This would also tend to indicate that many bikers travel faster than those in this study, since they are seeking "excitement" and "risk".

Impacts on Plants:

Gary says "No scientific studies indicate that bicycling causes more degradation of plants than hiking. Trails are places primarily devoid of vegetation, so for trail use in the center of existing paths, impacts to vegetation are not a concern." However this is a concern for plants that try to establish themselves in the trail, and for roots that cross the trail and end up being killed or damaged.

He cites Thurston and Reader (2001), claiming that "hiking and bicycling trample vegetation at equal rates … the impacts of biking and hiking measured here were not significantly different". Actually, that is not true. Although overall impacts weren't significantly different, "soil exposure [was] greater on biking 500 pass lanes than hiking 500 pass lanes" (p.404). In other words, after 500 passes, mountain biking began to show significantly greater impacts. Thus their conclusion, "the impacts of biking and hiking measured here were not significantly different" (p.405) is unwarranted.

The authors said "Bikers traveled at a moderate speed, usually allowing bicycles to roll down lanes without pedaling where the slope would allow." Thus it would appear that the mountain biking that they measured is not representative: it was unusually slow and didn't include much opportunity for braking, accelerating, or turning, where greater impacts would be expected to occur.

The authors also said "Some hikers feel that bikers should be excluded from existing trails" (p.397). Of course, this is not true. Hikers are only asking that bikes be excluded, not bikers. On page 407 they admit the "possibility … that mountain bikers simply contribute further to the overuse of trails". In other words, allowing bikes on trails allows trail use to increase over what it would be if bikes weren't allowed. This is probably true, and deserves to be recognized and researched.

They found that "One year following treatments, neither vegetation loss nor species loss was significantly greater on treated lanes than on control lanes" (p.406). They conclude that the recreation impacts are "short-term", and experience "rapid recovery". This is unjustified. Killing plants and destroying seeds modifies the gene pool, and introduces human-caused loss of genetic diversity, and evolution. Dead plants and lost genetic diversity do not "recover" (see Vandeman, 2001).

However, the greatest defect of the study and its interpretation is that is that it doesn't consider the distance that bikers travel. Even if we accepted their conclusions that impacts per mile are the same, it would follow that mountain bikers have several times the impact of hikers, since they are easily able to, and do, travel several times as far as hikers. Try walking 25 or 50 or 100 miles in a day!

Impacts on Animals:

Gary cites Taylor and Knight (1993), claiming that "hiking and biking cause [the] same impact to large mammals on Utah island". First, as noted by Wisdom et al (2004), this study lacked a control group, and hence can't infer causation. Second, the authors made the same mistake that all other researchers made: they ignored the different distances that hikers and bikers travel. I also wonder how realistic it was to have all recreationists continue past the animals without stopping to look at them. (All of those researchers also failed to implement blind measurement and analysis: the researchers were aware, as they were measuring, which treatment they were testing. Only Wisdom et al were able to carry out their measurements (electronically) without any people even being present.)

This is a very informative paper. The authors "examined the responses of bison …, mule deer …, and pronghorn antelope … to hikers and mountain bikers … by comparing alert distance, flight distance, and distance moved" (p.951). They noted, significantly, that "Outdoor recreation has the potential to disturb wildlife, resulting in energetic costs, impacts to animals' behavior and fitness, and avoidance of otherwise suitable habitat. … outdoor recreation is the second leading cause for the decline of federally threatened and endangered species on public lands" (p.951). They also noted that "Mountain biking in particular is one of the fastest-growing outdoor activities, with 43.3 million persons participating at least once in 2000" (p.952). However, they didn't draw on this fact when they concluded "We found no biological justification for managing mountain biking any differently than hiking" (p.961).

The authors also surveyed the recreationists, and found that they "failed to perceive that they were having as great an effect on wildlife as our biological data indicated. Most recreationists felt that it was acceptable to approach wildlife at a much closer distance (mean acceptable distance to approach = 59.0 m) than wildlife in our experimental trials would typically allow a human to approach (mean flight distance of all species = 150.6 m). … Of all visitors surveyed, 46%, 53%, and 54%, respectively, felt that bison, deer, and pronghorn were being negatively affected by recreation on Antelope Island. … Visitors expressed little support for allowing only one type of recreational use on island trails, having fewer trails on the island, for requiring visitors to watch an educational video about the effects of recreation on wildlife, and for allowing recreation only on the north (developed) end of the island" (p.957). (Gary Sprung omitted this information from his summary.)

They noted that the wildlife might habituate to the presence of humans, but that exactly the opposite happened with the pronghorn: they "in fact used areas that were significantly farther from trails than they had prior to the start of recreational use on the island" (p.961). They also noted: "Because flushing from recreational activity may come at the cost of energy needed for normal survival, growth, and reproduction …, and because it may cause animals to avoid otherwise suitable habitat …, it is important that recreationists understand that their activities can flush wildlife and may make suitable habitat unavailable" (p.961). I think that the wealth of such information provided by the authors makes this paper especially valuable.

They concluded "Our results indicate that there is little difference in wildlife response to hikers vs. mountain bikers" (p.957). I was present when Ms. Taylor presented her findings at the Society for Conservation Biology meeting at the University of Kent, in Canterbury, England, in July, 2002. I pointed out to her that she wasn't justified in concluding, as she did, that "hiking and mountain biking have the same impacts", since she only measured impacts per incident. Since bikers are able, and typically do, travel several times as far as hikers, a more proper conclusion would be that bikers have several times as much impact on wildlife as hikers. That is why I am so disappointed to find her later concluding in this 2003 paper, "We found no biological justification for managing mountain biking any differently than hiking" (p.961). If mountain bikers can travel even twice as far as hikers, and disturb twice as many animals, I would think that that is biologically significant! It isn't much help that she goes on to admit that "because bikers travel faster than hikers, they may cover more ground in a given time period than hikers, thus having the opportunity to disturb more wildlife per unit time" (p.961). She has still drawn an unjustified conclusion, and it is certain to be frequently quoted (out of context) by mountain bikers, as they try to lobby for more trail access.

I also wonder about the accuracy of their measurements of distance. Distance is notoriously difficult to measure accurately, especially when animals and recreationists may be hidden from view ("Due to the inherent errors in triangulating in the steep canyon country, only ground visual locations were used in the analysis" p.577). Bias may also have been introduced by the fact that researchers knew, as they were measuring, which treatment they were measuring.

Sprung next cited Papouchis et al (2001), claiming that "Hikers have [the] greatest impact on bighorn sheep [in Canyonlands National Park] … because the hikers were more likely to be in unpredictable locations and often directly approached [the] sheep". Actually, this is an artifact of the experimental design, and not a result of research: the researchers, for some reason, <u>told</u> the hikers (who were research assistants) to approach the sheep! So the study actually compared apples and oranges: bikers who stay on a road, vs. hikers who approach bighorn sheep! Nothing useful can be concluded from such a study, except that people who approach bighorn sheep disturb them. Of course, there is nothing to prevent mountain bikers from getting off their bikes and doing the same thing. It's unfortunate that the opportunity was lost to gain more valuable knowledge. I wrote the authors, asking why they had done this, but I got no reply. It would appear that the intention was to exonerate mountain biking (this also applies to most of the other studies).

It is interesting that "when bighorn sheep did respond to human activity, they noticed vehicles and mountain bikers, on average, from twice the distance they noticed hikers" (p.577). This would seem to imply that, were hikers to remain on the trail where the mountain bikers were, they might have equal or lower impacts than the mountain bikers.

It is also unfortunate that there was no control group, so that they could determine the effect of the presence of roads, with and without people on them. They did note that "avoidance of the road corridor by some animals represented 15% less use of potential suitable habitat in the high-[visitor-]use area over the low-[visitor-]use area. ... human presence in bighorn sheep habitat may cause sheep to vacate suitable habitat" (p.573). This argues for eliminating all recreation in the area, especially since the absence of water forces recreationists to bring motor vehicles carrying water and other supplies: "mountain bikers frequently use the 161-km White Rim trail, a 4-wheel-drive road. Caravans of mountain bikers accompanied by support vehicles are common. Day use along the Shafer and White Rim trails exceeded 17,500 vehicles during the study period, 1993-1994. This use was concentrated from March to October, with peak use of 134 vehicles/day in May" (p.575).

The authors conclude "Contrary to our original expectations and the concerns of park managers, the increase in numbers of mountain bikers visiting the park does not appear to be a serious threat to desert bighorn sheep, probably because mountain bikers are restricted to predictable situations such as the currently designated road corridors" (p.580). For several reasons, this conclusion is not justified: (1) as they reported, all recreationists drive the sheep away from parts of their habitat, causing loss of energy as well as habitat; (2) permitting bikes causes the total number of visitors to increase significantly; (3) bikes can't travel alone -- they require motorized support vehicles, further increasing impacts (e.g. worsening air quality); (4) there is nothing to prevent mountain bikers from getting off their bikes and approaching the wildlife; if hikers do that, so will mountain bikers; there is no reason to exonerate mountain bikers.

They note, significantly, "However, these results should not be extrapolated to other public lands where mountain bikers are not confined to designated trails and may surprise sheep in novel situations" (p.580). Gary Sprung didn't mention this, thus encouraging inappropriate use of this study's already-questionable results.

I would like, however, to commend the authors for stating "we recommend that park managers manage levels of backcountry activity at low levels" (p.580). The best policy would be to ban all vehicles, including bicycles (as well as animals used as vehicles). That would reduce human impacts, without directly restricting who could go there (perhaps occasional exceptions could be made for the disabled).

Gary next cited Gander and Ingold (1997), claiming that "hikers, joggers & mountain bikers [are] all the same to chamois". But again, this is not an accurate representation of the results: "They fled over longer distances in jogging and mountain biking experiments … carried out late in the morning" (p.109). Also, "the three activities carried out on the ground could have long-term consequences as they prevent the animals from using areas near trails. Thus, depending on the density of trails and the intensity of recreational activities in a certain area, animals may lose a large part of their habitat" (p.109).

The authors conclude "Our results show that specific restrictions on mountainbiking above the timberline are not justified from the point of view of chamois" (p.109). Once again (is there a pattern here?), this conclusion is not justified. It ignores the fact that mountain bikers are able to travel several times as far as hikers, and thus negatively impact several times as much wildlife. It also ignores the fact that bicycles enable a large increase in numbers of human visitors (note that this places the blame on the <u>bicycle</u>, not the <u>bicyclists</u> -- my argument doesn't depend on there being any difference between hikers and mountain bikers). And, of course, <u>wherever the number of visitors increases, there is pressure to build more trails, destroying even more habitat</u>. Once again, it would appear that this study was undertaken with the intent of excusing mountain biking.

Gary next cites a study of bald eagles by Robin Spahr (1990). "Spahr found that walkers caused the highest frequency of eagle flushing". However, this study is difficult to interpret. Eagles don't congregate in large numbers, like sheep, so it is hard to ensure that all treatments are equally balanced: it is hard to imagine that the conditions under different treatments (or even within treatments) were equal. Also, the bikers were apparently instructed to ride by without looking at the eagles, whereas some of the walkers were told to look and point at the eagles (the paper is vague on this point). In other words, the study was comparing apples with oranges. Thus, I don't know if this was really a controlled study. Spahr also found that "bicyclists caused eagles to flush at [the] greatest distances", which would tend to indicate that bicyclists have greater impacts. Distances are also notoriously difficult to measure accurately. We are given no information about the "rangefinder", in order to judge its accuracy. At best, these are mixed results. And, once again, the greater distances that bikers travel are ignored, as well as the greater visitor numbers that the bicycle enables. Therefore, the study cannot be said to support any conclusion about how hiking compares with mountain biking, and certainly not Gary's statement: "Hikers have greater impact on eagles than cyclists". To Spahr's credit, she did not attempt to generalize beyond her data.

Gary concludes "Mountain biking, like other recreation activities, does impact the environment. On this point, there is little argument. But … a body of empirical, scientific studies now indicates [sic] that mountain biking is no more damaging than other forms of recreation, including hiking [Gary's emphasis]. Thus, managers who prohibit bicycle use (while allowing hiking or equestrian use) based on impacts to trails, soils, wildlife, or vegetation are acting without sound, scientific backing." *Au contraire*, as I have indicated, the very studies that Gary and IMBA cite as support for mountain biking actually show that mountain biking does much more harm to the environment than hiking! Gary goes on to fault "the wisdom of prohibiting [sic] particular user groups". However, as I explained earlier, mountain bikers are not prohibited from using any trails. Bicycles are occasionally prohibited. Mountain bikers are merely required to follow the same rules as everyone else, and walk.

At the bottom of the same web page is the notice: "IMBA wishes to obtain and incorporate into future revisions of this document any new or additional empirical science regarding the impacts of mountain biking. IMBA welcomes input [my emphasis]. To offer information, please contact the author at gary@imba.com". On April 25 I emailed Gary (and Pete Webber, pete@imba.com) the Wisdom et al study, which demonstrates that mountain bikers have a greater impact on elk than hikers. Not only hasn't this new research been incorporated into his paper, but I haven't even received a reply. It would appear that IMBA isn't really interested in achieving a scientific answer to this question.

In 2003, Jason Lathrop wrote an excellent "critical literature review" on the ecological impacts of mountain biking, raising some questions found nowhere else. He quotes the BLM: "An estimated 13.5 million mountain bicyclists visit public lands each year to enjoy the variety of trails. What was once a low use activity that was easy to manage has become more complex". He criticizes all of the studies for not using realistic representations of mountain biking. For example, on Thurston and Reader, he says "this study's treatment passes at best loosely approximate the forces exerted by actual mountain biking. On real trails, riders possess widely varying levels of skill, resulting in variant speeds, turning, and braking. This study does not address these variables." Lathrop also makes the excellent point that "Direct mortality [of animals] is virtually unstudied. I could find no references to it in the literature. Anecdotal evidence suggests, however, that small mammals are vulnerable to impact and are not uncommonly killed."

And: "Taylor (2001) concluded that short-term behavioral changes do not vary between bicyclists and hikers on a per-encounter basis. However, because bicyclists are capable of and, in most areas, typically do travel much farther than hikers, it is reasonable to conclude that they will create a somewhat higher total number of encounters and flushings."

Cessford (1995) did an oft-quoted review (which I am including only because it is so widely cited) that, like all others, uncritically accepts Wilson and Seney (1994) as proof that mountain biking impacts are no worse than those of hikers. His paper is mostly speculation, based on few actual research findings. He disparages negative information about mountain biking by such devices as claiming that problems are caused by a minority of mountain bikers, exhibiting "poor riding habits", that accidents involving hikers and bikers are "rare", that hikers' dislike for being around bikes in the woods, and feelings that bikes cause greater environmental harm than hiking, are mere "perceptions". He blames hikers for "misperceiving" mountain bikers, claiming that "the two groups are more similar than is generally perceived. … The bicyclists … are basically hikers who are using mountain bikes to gain quicker access to the wilderness boundary". He speculates, without any evidence, that "the degree of conflict with mountain biking may diminish over time as other users become more familiar with bike-encounters and riders themselves". A more likely interpretation is that hikers who dislike being around bikes simply stop using trails that are open to bikes, thereby lessening the conflict!

Finally, in 2004, Wisdom et al did a very well controlled study comparing the impacts of ATV riders, mountain bikers, and hikers on elk and mule deer. They say we have an "urgent need for timely management information to address the rapid growth in off-road recreation. … Mountain biking [is] … increasing rapidly". Recreationists were allowed to stop for less than a minute to look at the animals. All measurements were made electronically, using an Automated Telemetry System and GPS, allowing control measurements to be made "blind", with no humans present! "Use of the automated telemetry system to track animal movements, combined with the use of GPS units to track human movements, provided real-time, unbiased estimates of the distances between each ungulate and group of humans [the recreationists were in pairs]". He pointed out that direct measurements, *a la* Taylor and Knight, tend to be biased, because some animals can't be observed. The area was entirely fenced, allowing researchers to completely control human access.

They found: "Movement rates of elk were substantially higher during all four off-road activities as compared to periods of no human activity. … For the morning pass, movement rates of elk were highest during ATV activity, second-highest during mountain bike riding, and lowest during hiking and horseback riding. … Peak movement rates of elk during the morning pass were highest for ATV riding (21 yards/minute), followed by mountain bike riding (17 yards/minute) and horseback riding and hiking (both about 15 yards/minute). … By contrast, peak movement rates of elk during the control periods did not exceed 9 yards/minute during daylight hours of 0800-1500, the comparable period of each day when off-road treatments were implemented. Interestingly, movement rates of elk were also higher than control periods at times encompassing sunrise and sunset for the days in which an off-road activity occurred, even though humans were not present at these times of the day. These higher movement rates near sunrise and sunset suggest that elk were displaced from preferred security and foraging areas as a result of flight behavior during the daytime off-road activities. In particular, movement rates of elk at or near sunrise and sunset were higher during the 5-day treatments of mountain bike and ATV activity".

"Higher probabilities of flight response occurred during ATV and mountain bike activity, in contrast to lower probabilities observed during hiking and horseback riding. Probability of a flight response declined most rapidly during hiking, with little effect when hikers were beyond 550 yards from an elk. By contrast, higher probabilities of elk flight continued beyond 820 yards from horseback riders, and 1,640 yards from mountain bike and ATV riders. In contrast to elk, mule deer showed less change in movement rates during the four off-road activities compared to the control periods". (Perhaps they seek cover, rather than running away.)

"The energetic costs associated with these treatments deserve further analysis to assess potential effects on elk survival. For example, if the additional energy required to flee from an off-road activity reduces the percent body fat below 9 percent as animals enter the winter period, the probability of surviving the winter is extremely low. Animal energy budgets also may be adversely affected by the loss of foraging opportunities while responding to off-road activities, both from increased movements, and from displacement from foraging habitat. … Our results from 2002 also show clear differences in elk responses to the four off-road activities. Elk reactions were more pronounced during ATV and mountain bike riding, and less so during horseback riding and hiking. Both movement rates and probabilities of flight responses were higher for ATV and mountain bike riding than for horseback riding and hiking."

It is also instructive to note that only one pair of ATV users were needed to cover the 20-mile study area, but two pairs of mountain bikers and three pairs of hikers were needed, to cover the distance in the time allotted, underscoring the different relative distances that the three groups are capable of covering.

Summary:

Mountain bikers have turned to scientific research to try to make mountain biking seem less harmful, and in particular, to studies comparing it with hiking. Although they have interpreted this data as indicating that mountain biking impacts are no greater than those of hiking, a more careful look at these studies leads to the conclusion that mountain biking impacts are actually several times greater than those of hikers.

Some of the important characteristics of mountain biking that have been ignored are: speed; distance traveled; the increase in number of visitors that bikes allow; increased trail-building, with its attendant habitat destruction; the displacement of soil (other than downhill); the killing of roots and soil organisms and ecosystems; most effects on wildlife; manner of riding (skidding, braking, acceleration, turning, and representativeness); tire tread; and noise (bikes are relatively quiet, but a rattling chain may be perceived as "alien" to natural surroundings).

In addition, measuring techniques need to be described in more detail, "blind" measurements should be considered (where the measurers don't know what treatment they are measuring), controls need to be added, and "intangibles" (e.g. loss of feelings of safety and loss of the primitive feel of natural settings) need to be taken more seriously. The direct killing of small animals deserves attention.

On the other hand, why do we need research to prove what is obvious? We don't need any research to know that we shouldn't step in front of a speeding truck. Or mountain bike.

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Published on Wildlands CPR (http://www.wildlandscpr.org)
By Shannon Donahue
Road-RIPorter Issue: Autumn Equinox 2008, Volume 13 # 3
September 18, 2008

Paving Paradise: The Ecological Effects of Road Improvement

As the human population grows, our wildlands face threats from increased access for recreation and resource extraction, subdivision for residential and commercial development, and movements to pave and improve many of our secondary and tertiary roads. Road improvements include paving, widening, and/or other methods. While paving may afford conveniences that satisfy commercial and residential demands, such improvements increase the detrimental ecological impacts of roads including direct effects such as fragmentation and loss of secure wildlife habitat (Forman & Alexander, 1998), increased vehicle-wildlife collisions (Trombulak & Frissell, 2000), construction-related wildlife mortality (Trombulak & Frissell, 2000), changes in groundwater flow and stream morphology (Malecki, 2005), spread of wildfire (Pew & Larsen, 2001) and invasive species (Gelbard & Belnap, 2003; Trombulak & Frissell, 2000), and increased chemical pollutants that leach into our watersheds and harm flora and fauna (National Research Council, 2005; Tromulak & Frissell, 2000; Forman & Alexander, 1998).

Increased human access due to road improvements intensifies all of the above problems, leading to degradation of ecosystems and loss of biodiversity (Ledec & Posas, 2003). Human contact with wildlife is also increased, posing threats to both wildlife and human safety (Herrero et al., 2005; Benn and Herrero, 2002; Herrero, 2002). In this article, I review how road paving and improvements can lead to increased ecological impacts.

Vehicle-wildlife collisions

Vehicle collisions with wildlife present danger for both humans and wildlife, and economic losses in the form of vehicle damage, health care for human injuries, and loss of revenue attached to hunting of game species (Schwabe & Schuhmann, 2002; Langley et al., 2006; Gordon et al., 2004). By the end of the 20th century, vehicle collisions with wildlife replaced hunting as the leading direct cause of mortality in terrestrial vertebrates (Forman & Alexander, 1998).

Leblond et al. (2007) identify road improvement as a major contributing factor to the growing rate of vehicle-wildlife collisions. As early as the 1970s, it was found that small mammals had higher mortality with increased traffic and speeds (Oxley et al., 1974). Studies in Brazil found higher rates of roadkill following road paving (Coehlo et al., 2005; Bueno et al. 2005). Also, an upgraded road in Australia resulted in a dramatic increase in the number of road-killed Tasmanian devils and eastern quolls (Jones, 2000).

The barrier effect: road avoidance and habitat fragmentation

Despite the wide-ranging effects of roads on a landscape level, most transportation engineers consider only the ecological effects on the land occupied by the road itself and the narrow verge immediately flanking it (Forman, 2000). Forman and Alexander (1998) report that road width and traffic density determine the intensity of the "barrier effect" that results in avoidance of roads by wildlife, leading to habitat fragmentation and dividing existing populations into smaller, isolated metapopulations. Metapopulations are more susceptible to stochastic extinction due to genetic isolation and increased pressure on resources, while habitat fragmentation impedes recolonization (Noss et al., 1996; Forman and Alexander, 1998).

Elk (Cervus elaphus), moose (Alces alces), grizzly bear (Ursus arctos), gray wolves (Canis lupus), mountain lions (Puma concolor), Canada lynx (Lynx canadensis), American marten (Martes americana), wolverines (Gulo gulo), and other mustelids are all known to avoid roads (e.g., Ward, 1976; Frederick, 1991; Dickson et al., 2005; Dussault et al., 2007), especially those with higher speeds and volumes, making them highly susceptible to the barrier effect. Carnivores are especially sensitive to roads and human development, presenting wider implications for the ecosystem because top carnivores can regulate populations of prey species that may become overpopulated in their absence (Weaver, 2001).

Spread of invasive species

Roads facilitate the spread of invasive and exotic species through seeds carried along vehicles and the air turbulence caused by passing vehicles, both problems that increase as greater numbers of vehicles travel on roads once they are improved (Trombulak & Frissell, 2000; Forman & Alexander, 1998; Gelbard & Belnap, 2003). Road improvements increase the degree of clearance and allow more penetration of sunlight, increasing the edge effect of existing roads (Noss, 1995). The area covered by invasive plant species such as knapweed tends to be wider along paved roads than unimproved roads (Gelbard & Belnap, 2003).

Wildfire

Human access often increases the levels of accidental and intentional ignition of wildfires (Brosofske & Cleland, 2007). Pew and Larsen (2001) found that the occurrence of human-caused wildfire was highest along roads and railroads, but that the rate of ignition dropped off with distance from human infrastructure, and dramatically more with distance from unimproved roads than from paved roads.

Chemical pollutants

Paved roads leach chemical pollutants both from the paving materials and from deposition of exhaust and tire rubber from the vehicles that travel them (Forman & Alexander, 1998; National Research Council, 2005). Asphalt roads leach carcinogenic polycyclic aromatic hydrocarbons (PAH's) from both car exhaust deposition and asphalt that are harmful to highway workers as well as flora and fauna and leach into the watershed (Sadler et al. 1997). Nitrogen oxide and ozone from vehicle exhaust damage plant life and pollute the atmosphere (Forman & Hersperger, 1996).

Conclusion

Road improvements exacerbate the negative ecological effects of the existing road system by increasing access, traffic speed and volume, and contributing to higher levels of pollutants produced by paving materials and vehicle traffic. Transportation-related mortality, road avoidance, and airborne dust can be reduced with lower speed limits, and unimproved roads can be maintained safely and effectively by adding gravel when needed and possibly through dust abatement strategies, although dust coating can damage plant life, attract wildlife to roads, and leach into groundwater (Missouri Department of Natural Resources, 2006; Lux, 2002).

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Published on Wildlands CPR (http://www.wildlandscpr.org)
By Kinza Cusic, Road-RIPorter Issue: Mar/Apr 2001, Volume 6 #2

March 2, 2001

The Ecological Effects of Roads on Wetlands

Wetlands, vitally important ecological systems, have a history of inadequate protection. The impacts of road construction and road operation on wetlands are numerous and broad in scope; negative impacts range from changes to the chemistry and biology of the local area to changes in hydrology that go well beyond the immediate area. Loss of wildlife habitat, loss of species and biodiversity, and introduction of alien species are among the consequences of such changes. These impacts result from a roadøs location, construction, maintenance, manner of use, and further effects that occur once the road is in place.

Wetlands are extremely important habitats with a variety of functions. One of the most important is the prevention and reduction of flooding due to their ability to hold large amounts of water. Because of their capacity to hold so much water, wetlands also control erosion. In addition, wetlands recharge groundwater, improve water quality and provide habitat for wildlife. Eighty percent of Americaøs breeding bird population and more than fifty percent of the eight hundred species of protected migratory birds rely on wetlands (Mitsch and Gosselink 1993).

Knowing these ecological functions, it is vital to understand what effects roads can have on them. Roads have six general effects on wetland ecosystems that those who are concerned about preserving them must consider (Trombulak and Frissell 2000; Findlay and Bourdages 2000).

Alteration of the Physical Environment

Wetlands are dependent on hydro-periods, where flooding occurs seasonally and for a length of time. Once the hydrological processes are disrupted, many changes occur in a dominoeffect. When a road is introduced into a wetland, it acts as a dam in the system, which can affect areas some distance away.

A road can cause the upland side of a wetland to flood and the downland side to drain, diverting the surface water flow in the process and causing the biological characteristics to change. A road can also critically impact the subsurface water flow in a wetland, depressing the water table and affecting the amount of groundwater available (Darnell 1976). This depression can affect many water-dependent fauna and plants.

Often during road construction, channels are excavated to divert water straight towards culvert installations. This channelization can substantially alter the rate and character of surface and subsurface flow (Darnell 1976). Channelization can destroy both upstream and downstream wetland areas by giving them either too much or too little water. This effect is reported to reduce the diversity of the habitat and cause shifts in species composition (Darnell 1976).

As soil erosion accelerates due to this alteration in water volume and levels, there is a reduction in bank stability, and therefore, an increase in sediment loading. These fine sediments can increase the turbidity of the water, clouding it and preventing sufficient light penetration, which adversely affects the health of the flora and fauna (Darnell 1976).

Alteration of the Chemical Environment

Roads facilitate the alteration of the chemical environment. Highways can introduce oil and heavy metals, such as lead, aluminum, and cadmium, which can contaminate a wetland (Adamus and Stockwell 1983). In aquatic environments especially, these contaminants can travel far and fast. Such contamination can have adverse impacts on wildlife health, especially to animals higher up the food chain.

Salt from deicing roads also alters the chemical environment by contributing ions to the soil, changing the pH, and altering the soiløs chemical composition (Darnell 1976).

Fragmentation of Habitat

Roads act as barriers that fragment wetlands habitat and have short and long term impacts on wildlife. îFragmenting landscapes into disjunct patches and restricting and isolating wildlife populations by amplifying the risks associated with movement have drastic consequences for the preservation of biological diversity" (Harris and Gallagher 1989). Over the short term, roads cause an obvious loss of habitat as well as increased wildlife mortality. Over the long term, the damage can be much more severe.

Roads can disrupt population and metapopulation dynamics that maintain local and regional wildlife populations (Jackson and Griffin 1998). Roads fragment the migration and interaction between populations, which can eventually cause a loss of genetic variability (Reh and Seitz 1990). Thus, roads that fragment habitat, particularly in critical breeding habitat or between separate and different habitats, can adversely affect species. For every population, there is a threshold of mortality. When mortality rates exceed this threshold, there is a risk of extinction (Means 1999).

Increased Wildlife Mortality Rates

Roads increase the chance of wildlife-vehicular collisions (Trombulak and Frissell 2000). Often wildlife is migrating toward decreasing habitat or between fragmented habitats and must cross a road, where mortality is more likely. Scavenger species, too, suffer higher mortality rates when they feed on roadkill and are struck, with a potential impact on predatorprey population dynamics (Bernardino and Dalrymple 1992).

Modification of Animal Behavior

Animal behavior is also modified through road avoidance and disturbance (Forman and Alexander 1998). Terrestrial animals, such as amphibians and turtles, as well as others, exhibit reluctance in crossing roads (Fahrig et al 1995). Also, roads create their own microclimates. As temperatures rise, a warm column of air causes an effective barrier to some animals such as birds and butterflies (Van der Zande 1980).

Bird species are particularly sensitive to traffic noise pollution and undergo population density depressions from the presence of a road at distances from 200m to 2000m (Van der Zande 1980). Many choose not to nest near roads. While some species avoid roads altogether, others, particularly reptiles, are drawn towards the heat of a road, which can have fatal consequences (Trombulak and Frissell 2000).

Introduction of Exotic Species

Roads act as a dispersal corridor, enabling exotic species to penetrate into previously inaccessible areas. Vehicles or vehicular effects may introduce exotic species. Plants mayspread along roads due to vehicle-caused air turbulence (Forman and Alexander 1998). In wetlands where roads have been constructed, the native plants are already stressed due to a disturbance in flood frequencies and therefore cannot fend off the colonizers (Mitsch and Gosselink 1993). This can have large impacts on the overall health and biodiversity of the wetland.

Conclusion

The ecological effects of roads on wetlands range from the alteration of the physical and chemical environment to the unfavorable impacts on wildlife populations due to habitat fragmentation, modification of animal behavior and collisions with vehicles. In view of such ecological impacts, it is important to look for ways in which to lessen the effects. Certainly avoidance of road construction through wetland systems is the best alternative available.

¤ *Kinza Cusic is an Environmental Studies graduate student who interned with Wildlands CPR.*

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From: Leeona Klippstein [leeona@earthlink.net]
Sent: Sunday, January 31, 2010 7:33 PM
To: Tornek, Terry; Bogaard, Bill; Gordo, Victor; Madison, Steve; Haderlein, Steve; Robinson, Jonathan (ITSD); McAustin, Margaret; McIntyre, Jacqueline; Holden, Chris
Cc: Fuentes, Theresa; Laveaga, Rosa; Jomsky, Mark; Craig Sherman; gaboon@sbcglobal.net; Mary E Barrie; Hugh Bowles; Beck, Michael; Marietta
Subject: Public Comments on Agenda Item #6 for 2/1/10 City Council (5)

Attachments: Roads on Anthropods Wildlands CPR.docx; marion_wimpey_2007[1]mountainBikes publication.pdf; Impacts of MountainBikesWildlands CPR.docx; Effects of Roads on Wetlands Wildlands CPR.docx; Naylor+et+al+2009 +Behavioral+Responses+of+North+American+Elkto+Recreational+Activity[1].pdf

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From Spirit of the Sage Council for Agenda Item #6, for submission to the City Council - Public Comment on 2/1/10 , or thereafter. The comment letter is includes 15 attachments that will follow in groups of 3 in 5 emails. This is group 5.

If you are unable to retrieve the attachments, please contact me to resend.

Thank you

Leeona Klippstein, Executive Director
Spirit of the Sage Council
(626) 676-4116

Published on Wildlands CPR (http://www.wildlandscpr.org)
By Leslie Hannay, Road-RIPorter Issue: July/August 2001, Volume 6 #4

June 5, 2001

Effect of Roads on Arthropods

Arthropods make up a significant part of the biodiversity on this planet, and are important in many ways to the overall health of ecosystems and to our understanding of natural biotic systems. At the base of many food chains, arthropods are important components of the diets of invertebrates and birds, and are also an integral part of the nutrient- and energy-processing abilities of the soil (Coleman & Crossley 1996). Arthropods also tend to demonstrate opportunism and rapid response to change. By studying arthropod responses to ecological change, we can better understand the effects of human disturbance and landscape modification on terrestrial systems (Morris 2000, Major et al 1999).

The impact of roads on arthropods is considerable. Roads affect terrestrial arthropods directly by destroying their habitat, and by increasing the risk of being crushed by vehicles or trampled by pedestrian traffic. Roads also fragment arthropod habitat, exacerbate the spread of exotic and invasive species, and create pollution in the air and on the ground.

Habitat Destruction

Roads destroy arthropod habitat on the road bed itself and on road verges by altering vegetation, changing soil dynamics, and modifying microclimates. The most obvious effect is the conversion of habitat into road surfaces. Vegetation is replaced by less permeable surfaces, thereby eradicating food sources, nesting areas, and hiding places that are essential to arthropod survival (Mader 1984). Similarly, soil dynamics are modified by road construction, which flattens terrestrial niches and causes substantial soil compaction. This contributes to increased runoff and decreased soil porosity, which impede arthropod survival in the immediate area of the road (Noss 1999). Microclimate also changes as a result of road construction. Road surfaces tend to absorb solar radiation at a higher rate than unmodified surfaces, increasing soil and air temperatures. Increased wind due to the removal of vegetation around the road, as well as the reduced capacity of the soil to retain moisture due to compaction, combine with these higher temperatures to create a more arid and hotter microclimate above the road surface (Haskell 2000).

The conversion of habitat along roadsides is also significant. Often, the disturbed areas on either side of a road support entirely different vegetation from that which was present before road construction; the effects upon forest fauna may persist up to 100 meters from the road itself (Haskell 2000). This altered vegetation sustains different species with varying success, due to changes in nesting habitat, food supply, and opportunities to hide from predators. Roadsides may receive a greater influx of nutrients from passing vehicles, increased water availability, and nearby agricultural landscapes, resulting in a greater abundance of weeds on roadsides (Major et al 1999). The composition of plant and animal species on road verges will differ notably from non-roadside habitats, which intensifies competition and broadens the disturbed area (Mader 1984). Even in cases where roadside plants remain the same, the physiology and growth of these plants, and the insects they sustain, often differs completely from areas that are more distant from roads (Martell 1995, Lightfoot & Whitford 1991, Spencer et al 1988).

Frequent mowing along roads contributes to the environmental instability of roaded areas (Morris 2000). A common response of arthropods to shortened vegetation is a reduction in the abundance and diversity of most groups and species. Such unstable conditions favor a few opportunistic and robust species, often nonnative, to the detriment of those that are slower to adapt (Morris 2000, Mader 1984, Hollifield & Dimmick 1995, Haskell 2000). The combined effects of changing roadside vegetation may lead to a more uniform set of species, an eventuality that increases the chance of local extinction, especially of small populations of flightless groundforaging insects (Vermeulen 1994). As previously mentioned, roadsides also change microclimates (Major et al 1999, Mader 1984). In one study, increased aridity and temperature on tropical forest roadsides diminished insect diversity up to 40 meters from the road, which acutely affected insectivore populations in the study area (Grindal and Brigham 1998).

Roadkill and Trampling

Although there are no figures for arthropod roadkill, it is known to have a major impact on roadside arthropod populations (Oxley & Fenton 1974, Mader 1984). In one study of ORV impacts on desert biota, it was observed that arthropod tracks were found 24 times as often on sites that were closed to motorized traffic as on ORV-impacted sites (Luckenbach and Bury 1983). Treading by humans has also been detrimental to arthropods. Even moderate trampling (5 treads per month) reduced a wide range of invertebrate species by up to 82 percent over a twelve-month period (Morris 2000). Road construction also contributes to direct mortality of slowermoving, flightless arthropods, which cannot avoid being crushed by construction machinery.

Habitat Fragmentation

Roads constitute major barriers to arthropod dispersal (Mader et al 1990, Haskell 2000, Vermeulen 1994). Linear barriers affect the movement of ground-dwelling animals, stimulating lengthwise dispersal and inhibiting lateral movement (Mader et al 1990). This reluctance of arthropods to cross roads may be due to changes in microclimate at road edges, pollution and noise from traffic, environmental instability, changes in the composition of flora and fauna along roads, and the immediate danger to animals of being killed by oncoming traffic. Carabid beetles have been found to avoid crossing road shoulders almost entirely, and were not observed ever crossing the road itself (Mader 1984). Despite the theoretical value of roads as connective corridors for recolonizing areas, studies on arthropods have shown that they tend to travel only short distances in a year. This suggests that roads act as a mechanism for the infiltration of opportunistic species to the detriment of local populations (Vermeulen 1993, Lightfoot 1991). Fragmentation, reduction, and isolation of carabid habitat are most likely the main causes of the significant decrease in the species since the last century (Turin 1989 in Vermeulen 1994).

Spread of Exotics, Invasives, and Opportunists

Roads intensify invasion by exotic and invasive species. Humans act as vehicles for the dispersal of exotics; roads provide movement corridors, create a disturbed environment for the establishment of opportunistic species, and alter vegetation, which differentially favors some species (often pioneers or invasives) over others (Simberloff 1989, Lightfoot 1991, Noss 1999). This has been demonstrated, to the great detriment of a number of agroecosystems and agricultural economies, by crop infestation by nonlocal pests (Fye 1980, Kemp & Barrett 1989, Snodgrass & Stadelbacher 1989, Oi and Barnes 1989). For example, the balsam wooly adelgid has nearly destroyed two varieties of firs in the southern Appalachians. It has been directly linked to roads as means of dispersal (Campbell 1996).

Pollution

Pollution caused by roads includes lead and fuel additive emissions from vehicles, salt from de-icing compounds, dust, ozone, exhaust fumes (cadmium, sulfur dioxide, nitrous oxides), and noise (Mader 1984, Hopkin and Howse 1998, Lightfoot & Whitford 1991, Oxley & Fenton 1974). Lead and other heavy metals from exhaust accumulate along roads and affect wildlife. A study near Washington, D.C. found increased lead, zinc, nickel, and cadmium in earthworms near roads (Oxley and Fenton 1974). Another study suggests the possible lead contamination of honey bees along a roadway (Pratt & Sikorski 1982 in Lightfoot and Whitford 1991).

Salt from de-icing compounds is the most apparent source of stress on roadside systems, since salt accumulation often leaves bare patches in vegetation and visibly damages trees on road verges (Spencer et al 1988). Salt has been shown to decrease predator efficiency, change the suitability of host plants for arthropods, alter interactions between herbivores and their natural enemies, and to drastically affect the health of roadside vegetation upon which arthropods are dependent (Martel 1995, Spencer et a, Hopkin and Howse 1995). Salt accumulation also degrades soil quality, reducing the suitability of roadside habitat for soil-dwelling arthropods.

Increased nitrogen levels on roadsides have been shown to increase productivity of vegetation, resulting in higher insect infestation. This increase in nitrogen may be due either to nitrous oxide emissions from vehicle exhaust, or to runoff from the road surface (Lightfoot and Whitford 1991). Not all studies have confirmed an increase in vegetal productivity, however. Overall, the roads tend to increase stress to roadside ecosystems, which makes for a less stable environment that is more vulnerable to disease and pest infestation.

Conclusion

Existing road networks affect arthropod populations by destroying habitat, changing interspecies relationships, fragmenting dispersal corridors, facilitating the introduction and establishment of exotics, and polluting biotic systems. While roads generally decrease species diversity, proper restoration techniques have increased species richness by as much as 300 percent (Hollifield and Dimmick 1995). In light of the reliance of higher-level taxa upon arthropods as a food source, as well as the importance of arthropods in processing soil nutrients and energy, the impacts of roads on arthropods are important for ecosystem conservation as a whole.

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