RESPONSES OF WINTERING GRASSLAND RAPTORS TO HUMAN DISTURBANCE

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Human activities can affect the geographic distribution, dispersion patterns, habitat use, fecundity, survival, and activity and energy budgets of wildlife populations (Knight and Cole 1991). In most cases, the magnitude and frequency of disturbances determine whether or not the fitness of affected individuals will be altered. Additive and synergistic effects from multiple sources of disturbance can result in reductions of fitness, even when individual types of disturbance alone have no impact.

Experiments are necessary to understand which aspects of human activity affect wildlife, and to develop management schemes that minimize conflicts between animals and human activities (Knight and Skagen 1988, Gutzwiller 1991). One such management practice is the creation of restricted areas that spatially or temporally separate wildlife from potential disturbance. For these buffer zones to be effective, they need to be based on empirical evidence of wildlife responses to disturbance (Knight and Skagen 1988).

Most studies of wildlife disturbance have focused on the reproductive period and have addressed single species. As a result, we lack understanding of how concepts relating to human disturbance apply during the nonbreeding season. In addition, comparative studies that examine species assemblages can provide insights not evident from single-species studies (Skagen et al. 1991).

We recorded flushing responses (whether animals fled because of a disturbance) and flush distances (the distance between the disturbance and the animal when flushed) of wintering grassland raptors disturbed by pedestrians and vehicles. Our objectives were to compare species-specific responses to the 2 disturbance types, to examine the hypothesis that flush distances positively correlate with species' body size (Cooke 1980), and to calculate minimum distances for species-specific buffer zones.

STUDY AREA

We conducted our study on a 5,870-km² portion of northern Weld County, Colorado. Ranches and farms comprised 4,760 km² of this area; farms consisted primarily of alfalfa and winter wheat. The remaining 1,110 km² consisted of state-owned land (265 km²), the Central Plains Experimental Range (65 km²), and the Pawnee National Grassland (PNG) (780 km²). Walking and vehicle disturbances did not represent every form of disturbance, but were the most common forms of disturbance where we conducted our studies. Ranchers, maintenance crews, and birdwatchers frequently walked and drove within sight of perched raptors. The PNG is managed by the U.S. Forest Service and is shortgrass prairie consisting primarily of blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*). This area was described by Jameson and Bement (1969) and Olendorff (1973).

METHODS

Data Collection

We collected data during 50 visits to our study area between 16 December 1990 and 23 February 1991, and between 4 December 1991 and 9 January 1992. To reduce the probability of sensitizing or habituating raptors (Knight and Cole 1991), we minimized repeated encounters of individuals by dividing our study

area into 10 units, each approximately 585 km², and systematically rotating our visits among these sites. During each visit, we systematically surveyed every road within a unit, and we were careful to identify where the flushed raptors landed to avoid resampling individuals.

Previous trials indicated that perched raptors flushed prematurely if we initiated disturbances closer than 450 m (1,000 m for rough-legged hawks [*Buteo lagopus*]), so we used a range finder to determine starting points. We used the same range finder to measure flush distances and calibrated it each morning.

A walk disturbance consisted of 1 of us approaching a perched raptor, leaving the parked vehicle, and walking along the center of the road at a constant 1.5 m/second rate towards the bird. We only approached raptors where there was an unobstructed line of sight to them. If the raptor flushed, walking ceased and the range finder was used to measure the distance from the researcher to the base of the vacated perch. We also used the range finder to measure the perpendicular distance from the perch to the road center. We used a clinometer to estimate perching height. We sampled raptors perched <400 m from the road because, at distances >400 m, we had difficulty determining whether a raptor flushed as a result of our disturbance. Similarly, we did not sample raptors perched on the ground or at heights >20 m. After each trial we visually estimated cloud cover as <50%, 50–90%, or >90%, measured wind speed to the nearest 1.6 km/hour with an anemometer, and measured temperature to the nearest 1 C with an outdoor thermometer.

We used 2 similar station wagons (1/yr) for all vehicle disturbances and proceeded as for walk disturbances, except we remained in the vehicle and maintained a constant speed of 70 km/hour while approaching a perched raptor. If the raptor flushed, we dropped a marker onto the road, stopped the vehicle, and measured the distance from the marker to the base of the vacated perch with the range finder. All other measurements were made as for the walk trials.

We recorded species, sex (for American kestrels [*Falco sparverius*] and merlins [*F. columbarius*]), age (adult vs. immature for golden eagles [*Aguila chrysaetos*]), color morph (for rough-legged and ferruginous hawks [*B. regalis*]), perching height (m), distance from center of road to perch (m), perch type (pole, fencepost, tree, or windmill), and road type (gravel, dirt, or paved) for each trial. Disturbance types were alternated as raptor species were encountered to ensure balanced sample sizes.

Data Analyses

We tested for a year effect for flush distances using a univariate *t*-test, and for flushing responses using a chi-square test. There were no detectable between-year differences for flush distances ($t = 0.334$, 324 df, $P = 0.7383$) or flushing responses ($\chi^2 = 0.024$, 1 df, $P = 0.8778$), so we pooled the data.

We screened flush distance data from each species for normality by plotting histograms and examining residuals. After separating data by species and disturbance type, we performed multiple linear regressions (with flush distance [m] as the dependent variable) and logistic regressions (with flushing response [0 = no flush, 1 = flush] as the dependent variable). Each regression initially included time of day, cloud cover, wind speed, location, road type, perch type, age (for golden eagles), sex (for kestrels and merlins), color morph (for rough-legged and ferruginous hawks), perching height (m), and perch distance from road center (m) as independent variables. Backward elimination was used to remove insignificant ($P > 0.05$) variables. No strong collinearities were present among the significant remaining independent variables. We used R^2 values from linear regressions and Goodman-Kruskal Gamma (GKG) values from logistic regressions to assess goodness of fit of each model.

To detect interactions, we ran separate analyses of covariance for flush distance and flushing response from walking and vehicle disturbances. We included independent variables from the regression analyses (Table 1) and all possible interactions between these variables, except that perching height (PERHT) and perch distance from road center (PERDIS) were included as covariates and not included in interaction terms. For each of the 4 disturbance type-dependent variable combinations, 2 analyses of covariance were performed, 1 using PERHT and the other using PERDIS as the covariate. If neither variable was a covariate ($P > 0.05$), we performed an analysis of variance without PERHT and PERDIS; all other independent variables and interaction terms remained. We considered independent variables and interactions significant if the Type III Sums of Squares $P < 0.05$. For each disturbance type, we used Tukey's HSD tests (experiment-wise error rate = 0.05) (Montgomery 1991:78) to test whether mean flush distances differed, and chi-square tests to test whether the frequency of the flushing responses (0 = no flush, 1 = flush) differed between pairs of species, perch types, or road types. Procedures FREQ, GLM, LOGISTIC, and REG were used to analyze the data (SAS Inst. Inc. 1988:544, 623, 195, 864)

RESULTS

Three-hundred twenty-six trials were run for 6 species (Table 2). Northern harriers (*Circus cyaneus*) and red-tailed hawks (*B. jamaicensis*) were sampled but were not included in our analyses because sample sizes were ≤11.

Kestrels, merlins, rough-legged hawks, ferruginous hawks, and golden eagles were more likely to flush when approached by a human on foot than an automobile ($\chi^2 = 33.57$, 23.84, 41.05, 25.07, and 23.68, respectively; 1 df each;

Table 1. Independent variables selected in multiple linear regression and logistic regression analyses for flush distances and flushing responses of raptors exposed to walking disturbances in northern Colorado during the winters of 1990–1991 and 1991–1992.

Variable symbol	Variable description and coding
ROAD	Road type: 1 = gravel 2 = dirt 3 = paved
PERCH	Perch type: 1 = pole 2 = fencepost 3 = tree 4 = windmill
PERHT	Distance from ground to location of perched raptor (m)
PERDIS	Perpendicular distance from perch to center of road (m)

and all $P \le 0.0001$), but prairie falcons (*F. mexicanus*) were equally sensitive to both disturbance types ($\chi^2 = 2.01$, 1 df, $P = 0.1564$). Although flush distance did not vary with disturbance type for kestrels, merlins, and prairie falcons ($t = 0.45$, 35 df, $P = 0.6558$; $t = 0.49$, 15 df, $P = 0.6282$; and $t = 0.60$, 49 df, $P = 0.5524$, respectively), it was greater during walk disturbances for rough-legged hawks ($t = 4.18$, 68 df, $P = 0.0001$) and golden eagles ($t = 2.78$, 19 df, $P = 0.0119$) and greater during vehicle disturbances for ferruginous hawks ($t = 3.67$, 22 df, $P = 0.0013$). Overall, 97% of raptors we approached on foot flushed with a mean flush distance of 118 m, whereas 38% of raptors approached by car flushed with a mean flush distance of 75 m (Table 2). Date, time, and location of disturbance (i.e., road coordinates), as well as temperature, wind speed, cloud cover, age of golden eagles, and sex of kestrels and merlins were eliminated from the flushing response and flush distance models for all species and both disturbance types (all $P > 0.05$).

Walk Disturbance

Because flush distance varied among species ($F = 20.72$; 3,99 df; $P = 0.0001$), we developed

Table 2. Flushing responses and flush distances of raptors exposed to walk and vehicle disturbances in northern Colorado during the winters of 1990–1991 and 1991–1992.

Species	n	% flushed	Flush distances $\bar{x}$	SE	Range
Walk disturbance					
American kestrel	28	100	44	5	10–100
Merlin	14	100	76	13	17–180
Prairie falcon	33	91	92	8	24–185
Rough-legged hawk	45	100	177	19	55–900
Ferruginous hawk	24	92	63	9	13–165
Golden eagle	18	100	225	19	105–390
Total	162	97	118	8	10–900
Vehicle disturbance					
American kestrel	33	27	40	11	12–115
Merlin	10	30	62	12	44–85
Prairie falcon	27	78	85	11	18–200
Rough-legged hawk	62	40	71	8	9–170
Ferruginous hawk	16	13	195	85	110–280
Golden eagle	16	19	82	54	14–190
Total	164	38	75	7	9–280

individual regression models for each species (Table 3). Distance of perch to road center was a significant covariate ($P = 0.0001$), and scatterplots indicated a general trend of decreasing raptor flush distances with increasing perch-to-road distances. Analysis of covariance for flushing response failed to detect any significant variables, presumably because 97% of the raptors flushed at our approaches. Regression models for flushing response were only meaningful (contained explanatory variables) for the ferruginous hawk (probability of flushing = $1/1 + e^{[-3.665 + 0.029 PERDIS]}$, GKG = 0.818), and we found no interactions with flush distance or flushing response (flush distance $F = 0.29$; 3,99 df; $P = 0.8325$; flush response $F = 0.07$; 3,99 df; $P = 0.9758$).

Golden eagles flushed at greater distances than kestrels, merlins, prairie falcons, rough-legged hawks, and ferruginous hawks ($t = 18.47$, 43 df; $t = 12.95$, 30 df; $t = 14.40$, 49 df; $t = 5.27$, 61 df; and $t = 15.95$, 40 df, respectively; all $P < 0.0001$). In turn, rough-legged hawks flushed at greater distances than

Table 3.   Regression equations for flush distances of 6 raptor species exposed to walking disturbances in northern Colorado during the winters of 1990–1991 and 1991–1992.

Species	n	R^2	P	Equation
American kestrel	28	0.125	0.0408	68.152 − 2.879(PERHT)
Merlin	14	0.556	0.0116	221.093 − 47.001(PERCH) − 34.961(ROAD)
Prairie falcon	30	0.253	0.0125	185.739 − 43.219(ROAD) − 4.949(PERHT)
Rough-legged hawk	45	0.291	0.0007	113.422 + 87.766(PERCH) − 2.672(PERDIS)
Ferruginous hawk	22	0.241	0.0456	96.916 − 4.455(PERHT) + 0.432(PERDIS)
Golden eagle	18	0.296	0.0196	173.654 + 0.390(PERDIS)

kestrels, merlins, prairie falcons, and ferruginous hawks ($t = 17.05$, 70 df; $t = 10.28$, 57 df; $t = 12.00$, 76 df; and $t = 13.86$, 67 df, respectively; all $P < 0.0001$), and prairie falcons flushed at greater distances than kestrels ($t = 5.40$, 58 df, $P < 0.0001$). Dark-morph rough-legged and ferruginous hawks flushed at greater distances than light morphs ($t = 2.60$, 43 df, $P = 0.0127$ and $t = 2.38$, 22 df, $P = 0.0264$, respectively).

Vehicle Disturbance

We developed individual regression models for each species because raptor flushing response and flush distance varied among species ($F = 7.13$; 5,123 df; $P = 0.0001$ and $F = 5.33$; 5,110 df; $P = 0.0002$, respectively). We found no significant covariates or variable interactions for flushing response or flush distance from vehicle disturbance.

Prairie falcons were more likely to flush than kestrels, merlins, rough-legged hawks, ferruginous hawks, and golden eagles ($\chi^2 = 14.45$, 1 df, $P = 0.0001$; $\chi^2 = 7.31$, 1 df, $P = 0.0070$; $\chi^2 = 10.57$, 1 df, $P = 0.0010$; $\chi^2 = 17.21$, 1 df, $P = 0.0001$; $\chi^2 = 15.20$, 1 df, $P = 0.0001$, respectively) and flushed at greater distances from the approaching vehicle than kestrels, merlins, rough-legged hawks, and golden eagles ($t = 7.00$, 57 df; $t = 7.10$, 35 df; $t = 4.99$, 87 df; $t = 4.50$, 41 df, respectively; all $P < 0.0001$). Flushing responses and flush distances of dark-morph rough-legged and ferruginous hawks did not differ from those of light morphs ($\chi^2 = 0.70$ and 0.04, 1 df each, $P = 0.4040$ and 0.8489; $t = 0.77$ and 0.75, 59 df and 14 df, $P = 0.4444$ and 0.4657, respectively, for flushing response and flush distance).

Body Mass

We examined the relationship between raptor body mass and flush distance for each disturbance type. Mean body masses for each species were obtained by averaging the masses given for males and females in Johnsgard (1990). For walking disturbance data, a positive linear relationship existed ($P = 0.0188$), with lighter species flushing at shorter distances than heavier species; however, no such trend was evident in the vehicle disturbance data ($P = 0.7451$) (Fig. 1).

We used pooled data to examine species tolerance to disturbances by comparing the distances from disturbance with the cumulative flushing percentages for each species. Thresholds varied among species; small species rarely flushed at distances >125 m, whereas large species often flew when disturbances were >200 m away (Fig. 2).

DISCUSSION

Human disturbance activities may elicit various responses from wildlife and differences in persecution histories result in diverse wildlife responses to different activity types (Knight et al. 1989, Knight and Cole 1991). In our study, most species were more likely to flush when approached by a human on foot than when approached by an automobile. Skagen (1980)
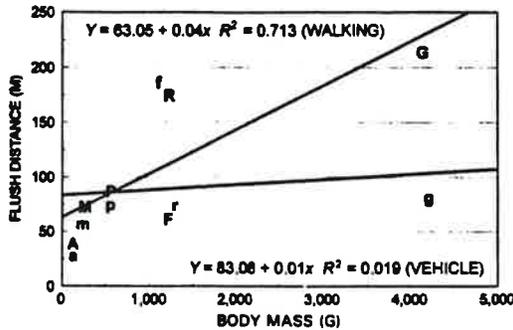
Fig. 1.   Relationship between mean flush distances and mean body masses for 6 raptor species in northern Colorado during the winters of 1990–1991 and 1991–1992. Mean masses of males and females (Johnsgard 1990) were averaged to obtain mean body masses. Each species is represented by the first letter of its common name (A = American kestrel, M = merlin, P = prairie falcon, R = rough-legged hawk, F = ferruginous hawk, G = golden eagle); uppercase letters symbolize walking disturbance data and lowercase letters symbolize vehicle disturbance data.
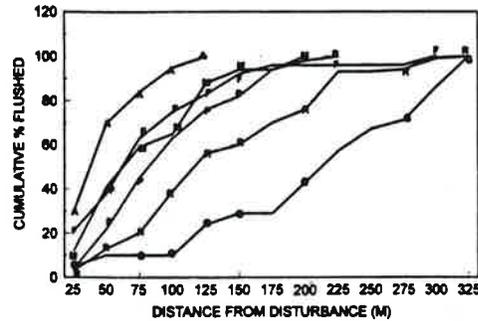
Fig. 2.   Relationship between distances from disturbance (combined walking and vehicle data) and cumulative percentages of individuals flushing for populations of 6 raptor species in northern Colorado during the winters of 1990–1991 and 1991–1992. Each species is represented by the first letter of its common name (A = American kestrel, M = merlin, P = prairie falcon, R = rough-legged hawk, F = ferruginous hawk, G = golden eagle).

reported that bald eagles (*Haliaeetus leucocephalus*) were less likely to flush from humans approaching in vehicles than from pedestrians. Similar behavior has been reported for waterbirds (Klein 1993). That a person approaching in plain view of a raptor elicits a stronger response than a person within an approaching vehicle suggests that humans approaching slowly are viewed as a greater disturbance than vehicles, which are moving rapidly and screen humans.

The spatial context in which disturbance occurs can influence the response shown by wildlife (Knight and Cole 1991). We found that rough-legged hawks perched nearer to the road flushed at greater distances during walking disturbances than individuals perched farther away. Similarly, American kestrels, prairie falcons, and ferruginous hawks perched closer to the ground flushed at greater distances than those perched higher. This suggests that tolerance to disturbance decreases when the stimulus is closer and, thus, more focused. Other studies of raptors support this pattern (Russell 1980, Skagen 1980, Knight and Knight 1984).

For merlins and prairie falcons, walking disturbances on paved roads resulted in shorter flight distances than a similar disturbance on gravel roads. Presumably, raptors perched along paved roads have habituated to the greater traffic volume associated with paved roads. Alternatively, individuals with greater tolerance limits to disturbance may be using areas with greater disturbance levels (Fraser 1983, Fraser et al. 1985, Buehler et al. 1991, McGarigal et al. 1991). Wintering bald eagles showed lower flushing responses along rivers and estuaries with high levels of recreational boating activity than along adjacent areas with little boating activity (Knight and Knight 1984, Buehler et al. 1991). Passerines in rural areas are less approachable than those in suburban areas where human activity is ubiquitous (Cooke 1980, Knight 1984, Knight et al. 1987, Kenney and Knight 1992). It is probably adaptive for wildlife, in the absence of persecution, to habituate to frequent, potentially disruptive human activities, as this allows individuals adequate time to perform necessary biological functions (Knight et al. 1987).

Flushing response and flush distance of golden eagles did not differ between adults and

immatures. Stalmaster and Newman (1978) reported that adult bald eagles were more intolerant of disturbance, but other studies have not reported differences attributed to age (Russell 1980, Knight and Knight 1984, Buehler et al. 1991).

Dark-morph rough-legged and ferruginous hawks exposed to walk disturbances flushed more often and at greater distances than light morphs. Because dark-morph raptors are uncommon in Colorado, they may be more conspicuous; consequently, they may experience more frequent human disturbance. Dark-morph buteos can be difficult to identify except at close range; therefore, birdwatchers may flush these raptors while trying to get a better view, or, as raptor identification manuals suggest, they may intentionally flush the birds in order to view underwing diagnostic characteristics (Clark and Wheeler 1987:75, Dunne et al. 1988:16, Johnsgard 1990:255). If this is the case, dark-morphs may be more likely to become sensitized to disturbance.

For walking disturbance, flush distances increased with raptor body size. Cooke (1980) reported a similar relationship in passerines, and suggested that larger birds were more wary of humans because of greater human persecution of larger, more visible species. Alternatively, the flush distance/body mass relationship may be based on the different energetics of large versus small raptors. Smaller raptors have greater surface area to body mass ratios, therefore they expend relatively more energy than larger raptors (Hayes and Gessaman 1980, Koplin et al. 1980, Wasser 1986). Disturbance results in increased energy expenditure caused by avoidance flights and a decreased energy intake caused by shortened foraging and feeding times (Stalmaster 1983). Small raptors, therefore, may be more energetically stressed if they are repeatedly forced to expend energy in avoidance flights. These birds might be expected to show a greater tolerance to disturbance in order to minimize energy expenditures.

The lack of a flush distance/body mass relationship for vehicle disturbances may indicate that individual variation in flush distance is greater for less-focused forms of disturbance. For example, the ferruginous hawk was the species least likely to flush because of vehicle disturbance, but individuals that flushed did so at great distances from the approaching vehicle. Perhaps there were 2 behavioral groups within the species as Klein (1993) proposed for great egrets (*Casmerodius albus*), green-backed herons (*Butorides striatus*), and yellow-crowned night herons (*Nycticorax violaceus*). Individual variation may explain the lack of meaningful regression models for flushing response and flush distance of raptors exposed to vehicle disturbances. Alternatively, other, unmeasured variables may be important, which also may explain the low R^2 values of flush distance models and the lack of meaningful flushing response models for walking disturbances. For example, we measured no variables that explained why the 3 falcon species' flush distances were similar regardless of disturbance type whereas flush distances for the hawks and the eagle correlated with disturbance type.

MANAGEMENT RECOMMENDATIONS

Behavioral restrictions can be used to allow coexistence of wildlife and human activities (Knight and Cole 1991). However, because raptor response to disturbance varies among species and between populations, management plans should be tailored to each species, habitat, and season. Furthermore, because humans in vehicles are less disruptive to raptors than pedestrians, management plans can offer different restrictions based on disturbance type.

Spatial buffer zones are commonly used to protect nesting sites from disturbance (Knight and Skagen 1988); however, buffer zones for wintering raptors also could be effective if placed around sensitive foraging areas. From our study, buffer zones that would prevent

flushing by approximately 90% of the wintering individuals of a species are: American kestrel, 75 m; merlin, 125 m; prairie falcon, 160 m; rough-legged hawk, 210 m; ferruginous hawk, 140 m; and golden eagle, 300 m (Fig. 2). In addition, our work suggests that, for some species, horizontal spatial restrictions can be shortened if perching sites with greater vertical height are made available.

Buffer zone recommendations could serve as guidelines that land-management agencies could present to birdwatchers, recreationists, and others who visit areas with sensitive species. Although our buffer zone recommendations are for use by wildlife managers working with the same raptor species in similar habitats (e.g., prairies, rangelands, or agricultural areas), our protocol could be used to collect data for most other species and habitats.

SUMMARY

We measured the flushing responses and flush distances of 6 species of diurnal raptors (American kestrels, merlins, prairie falcons, rough-legged hawks, ferruginous hawks, and golden eagles) exposed to walking and vehicle disturbances during winter in northern Colorado. Walking disturbances resulted in more flushes than vehicle disturbances for all species except prairie falcons. Although flush distance did not vary with disturbance type for the 3 falcon species, rough-legged hawks and golden eagles flushed at greater distances for walking disturbances and ferruginous hawks flushed at greater distances for vehicle disturbances. Merlins and prairie falcons perched along paved roads had shorter flush distances to walking disturbances than individuals perched along gravel roads. Rough-legged hawks perched nearer to the road flushed at greater distances than those farther away. American kestrels, prairie falcons, and ferruginous hawks perched closer to the ground had greater flush distances than those perched higher. Dark-morph ferruginous and rough-legged hawks flushed at greater distances than light morphs. For walking disturbances, a linear relationship existed between flight distance and body mass, with lighter species flushing at shorter distances; however, this trend did not hold for vehicle disturbances.

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