ANTHROPOGENIC EFFECTS ON WINTER BEHAVIOR OF FERRUGINOUS HAWKS

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Abstract: Little information is known about the ecology of ferruginous hawks (*Buteo regalis*) in winter versus the breeding season and less about how the species adapts to fragmented grassland habitats. Accordingly, we studied the behavior of 38 radiotagged ferruginous hawks during 3 winters from 1992 to 1995. We used 2 adjacent sites in Colorado that were characterized by low and high levels of anthropogenic influence and habitat fragmentation: the Rocky Mountain Arsenal National Wildlife Refuge (RMANWR; low-level influence), and several adjacent Denver suburbs (high-level influence). Relative abundance of ferruginous hawks differed by treatment area and year ($P < 0.001$); hawks were most numerous where black-tailed prairie dogs (*Cynomys ludovicianus*) were most plentiful. Daily Minimum Convex Polygon (MCP) home range areas did not differ ($P = 0.28$) for RMANWR ($\bar{x} = 4.71$ km^2, SE = 1.33, $n = 25$) and suburban hawks ($\bar{x} = 2.30$ km^2, SE = 0.50, $n = 13$). The number of perches occupied per day between the sites was not different ($P = 0.14$), but hawks at RMANWR used pole and ground perches more frequently and for a greater portion of the daily time budget ($P < 0.05$). Hawks at RMANWR spent less time roosting after sunrise ($\bar{x} = 61$ min) than did suburban hawks ($\bar{x} = 138$ min; $P = 0.004$) and spent less time roosting during the day (RMANWR = 100 min; suburb = 189 min; $P = 0.009$). Prey acquisition and associated intra- and interspecific interactions were not different ($P > 0.05$) at RMANWR and suburban sites. Ferruginous hawks appear to modify their behavior in fragmented, largely human-altered habitats, provided some foraging habitats with adequate populations of suitable prey species are present.

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As habitats become fragmented, local extirpation becomes increasingly likely for species with specialized resource requirements (Harris 1984, Temple 1986, Robinson 1991; Morrison et al. 1992:70), predators (Temple 1986), species with large spatial requirements (Robinson 1991), and species with restricted or small geographic ranges (Simberloff 1994). However, how animals adapt to fragmented habitats is not well documented. Many birds possess adaptations for moving among habitat fragments, making use of newly created habitats, and occupying, avoiding, or vacating newly altered habitats (see review by Knopf 1986). Thus, birds are excellent subjects for the study of anthropogenic or human-related effects, particularly those bird species thought sensitive to such influences.

The ferruginous hawk is an ecological specialist that occupies a specific and narrow range of habitats and has specialized prey requirements (Schmutz 1987, 1989). We describe and contrast winter habitat use by ferruginous hawks between areas subjected to different degrees of human habitat alteration and attendant human activity. We selected ferruginous hawks for several reasons: (1) we know little about the effect of habitat fragmentation on this species, (2) we lack information about habitat requirements and behavior in winter, (3) ferruginous hawks were abundant in some suburban areas of Colorado and were apparently tolerant of human presence in these environments, and (4) they were highly conspicuous and sedentary in winter whereby foraging behavior was readily observed.

STUDY AREA

The study area spanned portions of Adams, Denver, and Weld counties, Colorado (Fig. 1). We conducted fieldwork in 2 adjacent sites: RMANWR and the Denver suburbs of Brighton, Broomfield, Eastlake, Northglenn, Thornton, and Westminster (collectively, the subur-

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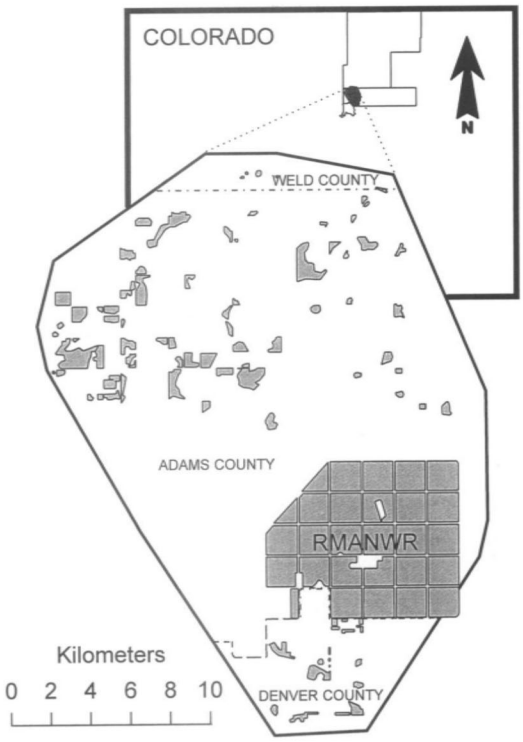

Fig. 1. Study area showing Rocky Mountain Arsenal National Wildlife Refuge and habitat patches composing the adjacent suburban study site, 1992–95. Remaining grassland fragments are shaded.

ban site). These sites differed principally in the extent of human alteration and degree of fragmentation and insularization of habitats. Elevation was about 1,500 m above mean sea level. In undeveloped areas of both sites, shortgrass prairie characterized vegetation and included weedy forbs, cheatgrass (*Bromus* spp.), and crested wheatgrass (*Agropyron cristatum*). Sand sagebrush (*Artemisia filifolia*), rubber rabbitbrush (*Chrysothamnus nauseosus*), and yucca (*Yucca* spp.) occurred throughout the study area; plains cottonwood (*Populus sargentii*) and willow (*Salix* spp.) dominated in riparian areas and where planted in some upland areas. In locations where humans have not extirpated them, black-tailed prairie dogs maintained vegetation at disclimax. Deciduous trees and utility poles used as roosts and perches by ferruginous hawks were plentiful in both sites.

RMANWR

The RMANWR was the largest contiguous block of undeveloped habitat within the area (70 km^2). Anthropogenic alterations were minimal and consisted primarily of buildings centrally located in several small complexes. There also were unimproved roads and utility poles. A perimeter fence enclosed the site and allowed strict control of human access.

Suburban Site

The suburban site approximated a collection of remnant habitat fragments that were small and scattered within a human-altered landscape. The extent of anthropogenic change in the suburban site spanned a continuum from minimal alteration of grasslands into rangeland, through outright destruction or complete removal of habitats for urban development.

METHODS

Estimates of Relative Abundance

We estimated relative abundance (Fuller and Mosher 1987) of ferruginous hawks at RMANWR and suburban study sites. We conducted 5 surveys each winter from December through February, 1993–94 and 1994–95. We replicated surveys every 2 weeks, and we randomized survey sequence and starting points a priori. We established a 38.6-km road transect in each site and surveyed between sunrise and 1100 at an average rate of 33 km/hr. At each ferruginous hawk sighting, we recorded the hawk's location and activity and estimated perpendicular distance from the transect route via a parallax rangefinder. We made an index of prey availability for each site by estimating the linear amount of occupied prairie dog town bisected by the survey route. We compared sighting probabilities between study sites (Andersen et al. 1985) via detection frequency distributions.

Data Collection

We trapped hawks using the Lockhart method (Harmata 1984, Bloom 1987). We also used weakened and padded leg-hold traps baited with live mice (Plumpton et al. 1995) or cottontail rabbit (*Sylvilagus* spp.) carcasses wrapped with noose carpets and dropped from a vehicle in view of perched hawks. We attached radiotelemetry transmitters to the rachis of the central rectrix or to 2 center rectrices of captured hawks. We clipped a small notch into 2 secondary feathers (Young and Kochert 1987) to aid in identifying radiotagged hawks in flight. Research followed approved University of Minnesota animal care and use protocols.

We randomly selected hawks for observation from the radiotagged cohort. Selection was again randomized after successfully tracking all radiotagged hawks for a complete day and with each additional capture. We radiolocated hawks before daylight and continuously recorded behaviors (Martin and Bateson 1986) throughout the daylight interval (specifically, at the start of each perch event, we recorded time to the nearest minute, noted perch substrate, and estimated location). To allow calculation of duration on the perch, we again recorded the time at the termination of that perch. We observed hawks from the farthest distance that allowed continuous visual contact (typically 0.5–1.5 km). We computed daily MCP home range areas with program MCPAAL (Stuwe and Blohowiak 1985).

We reconstructed diurnal time budgets for each hawk at each site. Time budgets included perched locations only because flight time was a negligible portion of the daily time budget during winter. Additionally, location estimates of flying hawks are imprecise, and flight could not be attributed to a particular behavior with certainty. Time budgets considered (1) activity level (total number of perch events per day); (2) number of perch events by substrate (e.g., poles, buildings, and other human-made structures, deciduous trees, and open ground); (3) mean duration of perch by substrate; (4) total daily duration allocated by substrate; (5) proportion of the total daily time budget allocated by substrate; and (6) the duration spent roosting during daylight. We defined diurnal roosting as the interval between daylight and the hawk's first change in location, and the interval between the final location and darkness.

We monitored feeding behavior concurrently with continuous observations. Whenever possible, we recorded prey species, the method of prey acquisition (e.g., killed by the hawk under observation, kleptoparasitized, scavenged as carrion), and other inter- and intraspecific interactions and their outcomes.

Experimental Design

We monitored radiotagged hawks in 2 treatment areas: RMANWR and the adjacent suburban site. This study was a mensurative experiment (Sinclair 1991), and treatments were inherently organismic because it was impossible to randomly assign captured hawks to each treatment. We assumed that we captured hawks randomly from our treatments, and we used radiotagged hawks as replicates within treatments.

We used general linear models (PROC GLM; SAS Institute 1988) to test for year effect and used the Shapiro-Wilk statistic to test continuous data to determine normality (Shapiro and Wilk 1965, SAS Institute 1988). We evaluated homogeneity of error variances between treatments via the folded-form F'-statistic (PROC TTEST; SAS Institute 1988).

We used t-tests when data satisfied parametric statistical assumptions, and nonparametric equivalents when data failed to satisfy these assumptions. We tested non-normally distributed percentage (proportion) data from time budgets with Kruskal-Wallis (H) tests (SAS Institute 1988).

We used Z-tests to contrast the proportions of predatory and competitive encounters in both treatment areas. We used 2-way frequency tables to test for differences between treatment areas in count data such as relative abundances and perch use (SAS Institute 1988). We averaged repeated observations of individual hawks (i.e., days observed; Martin and Bateson 1986: 29); thus, sample sizes (n) represent the number of hawks from which we collected data. We considered all differences significant when $P < 0.05$.

RESULTS

From 1 October 1992 to 19 February 1995, we monitored 38 radiotagged ferruginous hawks (RMANWR: $n = 25$ [1992–93 $n = 10$, 1993–94 $n = 12$, 1994–95 $n = 8$]; suburban site: $n = 13$ [1992–93 $n = 2$, 1993–94 $n = 6$, 1994–95 $n = 6$]). We recaptured 5 hawks in multiple winters at RMANWR, and 1 at the suburban site. We captured predominantly adult hawks (after-second-year age class; $n = 31$) and a few hatch-year–second-year hawks ($n = 7$). We collected data over 148 days (RMANWR: 104 days; suburban site: 44 days). There were no differences (Type III sums of squares) based on year ($P > 0.05$) for any variable except mean duration of ground perches ($P = 0.03$). However, the mean duration of ground perches showed no difference between treatment areas ($P = 0.143$), so we pooled data among years.

Relative Abundance

Relative abundance of ferruginous hawks differed by treatment area and year ($\chi^2_1 = 16.4$, $P < 0.001$). Detection distances for hawks in the

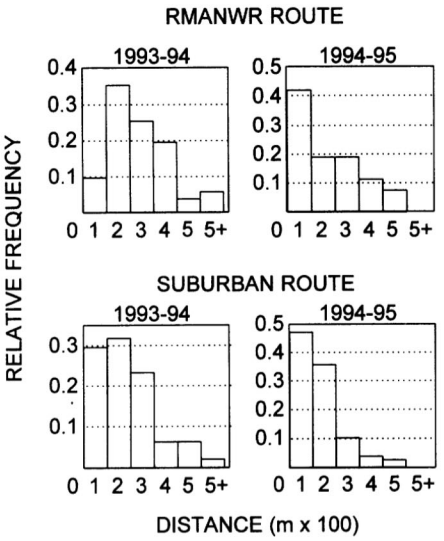

Fig. 2. Detection frequency distributions from roadside surveys of wintering ferruginous hawks in Colorado. Surveys were conducted in 2 treatment areas: the Rocky Mountain Arsenal National Wildlife Refuge (low anthropogenic influence) and a suburban study site (high anthropogenic influence) during 1993–94 and 1994–95.

treatment areas were similar, with most observations falling in the distance categories nearest the transect route (Fig. 2). During 1993–94, we observed equal hawk numbers at RMANWR ($\bar{x}$ = 10 hawks/survey) and in the suburban site ($\bar{x}$ = 9 hawks). However, in 1994–95, we recorded half the number of hawks per survey at RMANWR ($\bar{x}$ = 5), while the number at the suburban site nearly doubled ($\bar{x}$ = 16).

Prey availability also varied by year. During 1993–94, RMANWR had 12.2 km of active, roadside prairie dog colonies, and the suburban site had 15.8 km. In 1994–95, sylvatic plague (*Yersinia pestis*) eliminated prairie dogs over 92% of the area inhabited by prairie dogs at RMANWR in the previous year. After the plague epizootic, the RMANWR route bisected only 3.5 km of extant town, while the suburban route bisected 14 km.

Space Use and Time Budgets

The sizes of daily MCP home ranges did not differ (H_1 = 1.159, P = 0.281) between RMANWR ($\bar{x}$ = 4.71 km^2, SE = 1.33, n = 25) and the suburban site ($\bar{x}$ = 2.30 km^2, SE = 0.50, n = 13). Activity level, indexed by the number of perch positions occupied per day, was not different (t_{36} = −1.485, P = 0.146) in the 2 treatment areas (RMANWR: $\bar{x}$ = 18, SE = 1.39, n = 25; suburban: $\bar{x}$ = 14, SE = 1.66, n = 13). RMANWR hawks (n = 13) used ground and pole perches more frequently, and suburban hawks (n = 13) used deciduous tree perches more frequently (χ^2_2 = 67.7, P < 0.001). Pooled t-tests and nonparametric 1-way analyses of rank scores also indicated differences in the number, duration, and proportion of total time budget for use of perch substrates by treatment area (Table 1).

Ferruginous hawks in the treatment areas exhibited similar temporal patterns in activity level (Fig. 3). Although suburban hawks were slightly less active than hawks at RMANWR,

Table 1. Perch use by ferruginous hawks wintering in 2 adjacent sites with different levels of habitat alteration and human disturbance: the Rocky Mountain Arsenal National Wildlife Refuge, Colorado (low anthropogenic influence, n = 25) and an adjacent suburban area (high anthropogenic influence, n = 13), 1992–95.

Perch	Variable[a]	RMANWR $\bar{x}$	RMANWR SE	Suburban $\bar{x}$	Suburban SE	P
Pole or building	Number/day	8	1.22	4	1.45	0.005[b]
	Sum (min)	192	27.58	96	36.35	0.012[b]
	Mean (min)	31	4.26	21	5.86	0.074[b]
	Percentage/day	36	4.87	18	6.08	0.013[b]
Ground	Number/day	6	0.76	3	0.71	0.004[c]
	Sum (min)	173	24.50	75	27.16	0.006[b]
	Mean (min)	26	2.99	18	4.08	0.143[c]
	Percentage/day	34	4.89	15	5.10	0.006[b]
Tree	Number/day	4	0.33	8	1.22	<0.001[c]
	Sum (min)	160	24.38	366	48.01	0.001[b]
	Mean (min)	45	5.93	62	14.47	0.288[b]
	Percentage/day	31	4.58	68	8.27	<0.001[b]

[a] Mean per hawk per treatment area.
[b] Kruskal-Wallis and Wilcoxon 2-sample test.
[c] t-test.

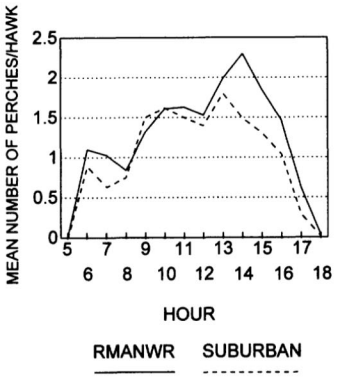

Fig. 3. Diurnal activity levels of ferruginous hawks wintering in 2 adjacent sites with different levels of habitat alteration and human activity: the Rocky Mountain Arsenal National Wildlife Refuge, Colorado (low anthropogenic influence, $n = 25$) and an adjacent suburban area (high anthropogenic influence, $n = 13$), 1992–95.

both groups exhibited similar peaks in activity throughout the day.

Hawks using RMANWR spent less time in the roost after daylight than did suburban hawks ($P = 0.004$), and hawks spent less time in the roost during daylight in the morning and evening combined ($P = 0.009$; Table 2). The daylight interval spent in the evening roosts did not differ ($P = 0.416$) between hawks in RMANWR and suburban sites. The duration spent in the roost after sunrise was longer than that spent roosting before sunset for hawks in both sites (RMANWR: morning $\bar{x} = 61$ min, afternoon $\bar{x} = 39$ min; $H_1 = 5.384$, $P = 0.020$, $n = 25$; suburban site: morning $\bar{x} = 138$ min, afternoon $\bar{x} = 51$ min; $H_1 = 9.157$, $P = 0.002$, $n = 13$).

Foraging

We saw hawks feeding 44 times during 1,325 hr of observation spanning 148 winter days (RMANWR: 104 days, 927 hr, $n = 25$; suburban site: 44 days, 398 hr, $n = 13$). Successfully scavenging prey represented 25 (57%) of the observations, whereas we observed direct predation 8 (18%) times. Although we detected no differences in the proportion of any type of prey contact between RMANWR and suburban hawks (Table 3), sample sizes were too low for the normal approximation of the sampling distribution to be accurate in 2 of the 5 comparisons.

Table 3. Summary of observations of foraging ferruginous hawks at Rocky Mountain Arsenal National Wildlife Refuge, Colorado (RMANWR; $n = 104$ days) and an adjacent suburban study site ($n = 44$ days), 1992–95.

Proportions	RMANWR	Suburb	$P > Z$
Days with any prey contact	0.278	0.341	0.441[a]
Days with a kill	0.038	0.091	0.192[a]
Days with prey scavenge	0.163	0.181	0.794[a]
Kills with competition	0.75	0.75[b]	
Scavenges with competition	0.29	0.37[b]	

[a] $1 - b < 0.1$.
[b] Sample size was insufficient for use of normal approximation.

DISCUSSION

The size of the home range, the activity level within the home range, and the mean perch duration did not differ between the 2 treatment areas. This result suggests that anthropogenic influences do not strongly affect spatial requirements nor activity level, and that home range size may be independent of the size of the available foraging patch. In urbanized environments, Cringan and Horak (1989) indicated that raptor species with small spatial requirements typically fare better than species with large spatial requirements.

Hawks differed consistently in their use of perch types. Ferruginous hawks at RMANWR

Table 2. Roost use by ferruginous hawks wintering in 2 adjacent sites with different levels of habitat alteration and human disturbance: the Rocky Mountain Arsenal National Wildlife Refuge, Colorado (RMANWR; low anthropogenic influence, $n = 25$) and an adjacent suburban area (high anthropogenic influence, $n = 13$), 1992–95.

Roost	Variable[a]	RMANWR		Suburban		$P > \chi^{2b}$
		$\bar{x}$	SE	$\bar{x}$	SE	
Morning	Duration (min)	61	8.51	138	22.71	0.004
	Proportion[c]	0.10	0.01	0.22	0.04	0.003
Evening	Duration (min)	39	8.20	51	15.91	0.416
	Proportion	0.06	0.01	0.08	0.02	0.395
Combined	Duration (min)	100	11.93	189	34.61	0.009
	Proportion	0.15	0.02	0.30	0.05	0.007

[a] Mean per hawk per treatment area.
[b] Kruskal-Wallis chi-square approximation.
[c] Duration-daylight interval.

used more exposed perches such as utility poles and open ground, and they used deciduous trees as roosts. In contrast, suburban hawks used more deciduous trees for daytime perches and used fewer pole and ground perches. This difference may be in response to human presence, because the probability of a vehicle passing a roadside pole or prairie dog town was higher at the suburban site than at RMANWR. Additionally, small fragments found in the suburban site had higher perimeter:area ratios, with the perimeter abutting some human-altered environments. Thus, even in the interior of some suburban fragments, perched hawks were close to human-altered areas, direct human disturbance, or both. These same edge effects may explain the prolonged use of morning roosts in the suburban site.

Presence of the primary forage species for ferruginous hawks wintering on our study area, the black-tailed prairie dog, does not alone confer availability to foraging hawks. To be suitable for wintering hawks, foraging habitats also must be free from anthropogenic influences that would preclude use by hawks. Variables that could influence use of foraging habitats by wintering ferruginous hawks include size, shape, isolation within human-altered landscapes or proximity to human structures, and presence of human activity. The minimum size habitat patch required to insulate a hawk from anthropogenic effects that would otherwise render it unsuitable would likely depend on the edge effects in question. Also, the relative size, connectivity or isolation, perimeter:area ratio, shape (and thus "edge" width) varied at each patch, so "boundary effects" (Janzen 1986, Wiens 1994) also varied.

Unlike breeding birds whose habitat use can be driven by availability of nest sites, wintering birds often use particular habitats because of food requirements (Newton 1979, Hutto 1985). Clearly, habitat suitability for wintering ferruginous hawks on our study area is contingent upon the availability of extant black-tailed prairie dog towns. The reasons that ferruginous hawks use some human-altered habitat patches are prey availability and the juxtaposition of roosting and elevated perch structures. Anthropogenic influences thus can either enhance or degrade ferruginous hawk habitats. Clumps of mature deciduous trees, encouraged by humans, have enhanced habitats by providing roost sites and diurnal perches in urban settings. Likewise, hawks used fences and utility poles as elevated perches. The primary anthropogenic influence that impoverishes habitats is extirpation of prairie dogs or reduction of towns to a size or level of isolation within human-altered landscapes that makes habitat unsuitable to ferruginous hawks.

MANAGEMENT IMPLICATIONS

Many urban raptors persist, or even thrive, because they are tolerant of human-altered habitats and derive benefit from human-enhanced prey sources. In contrast, ferruginous hawks in this study and other *Buteo* spp., bald eagles (*Haliaeetus leucocephalus*), and golden eagles (*Aquila chrysaetos*) overwinter in a human-affected environment but rely on nonanthropogenic prey sources.

The habitat fragments in the suburban study site are at risk by virtue of an expanding human population and attendant habitat alteration. As humans further subdivide and isolate grassland fragments, these areas become increasingly unsuitable to wintering raptors. The principal prey resource in this area for ferruginous hawks and a variety of other wildlife is the black-tailed prairie dog. As an ecological specialist, the ferruginous hawk will suffer local extirpation without preservation of adequate prey habitats. Conservation of the black-tailed prairie dog in this community clearly would benefit representatives from the entire ecosystem. Conversely, loss of the black-tailed prairie dog in this area via human conversion of grasslands will result in secondary extinctions throughout the grassland community.

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