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ABUNDANCE OF DIURNAL RAPTORS ON OPEN SPACE GRASSLANDS IN AN URBANIZED LANDSCAPE[1]

MARK E. BERRY AND CARL E. BOCK
Department of Environmental, Population, and Organismic Biology, University of Colorado, Boulder, CO 80309-0334, e-mail: carl.bock@colorado.edu

SANDRA L. HAIRE
U.S. Geological Survey, Midcontinent Ecological Science Center, 4512 McMurry Ave., Fort Collins, CO 80525-3400

Abstract. We conducted point counts of diurnal raptors on Boulder, Colorado, grasslands for three winters and summers, and compared results to landscape features of the count areas. Four wintering species were scarce on plots that included significant amounts of urban habitat, with a critical landscape threshold at about 5–7% urbanization: Bald Eagle (*Haliaeetus leucocephalus*), Ferruginous Hawk (*Buteo regalis*), Rough-legged Hawk (*B. lagopus*), and Prairie Falcon (*Falco mexicanus*). Counts of the first three species also were positively correlated with proximity of the count plots to the nearest colony of black-tailed prairie dogs (*Cynomys ludovicianus*). Two breeding species, the Red-tailed Hawk (*B. jamaicensis*) and Swainson's Hawk (*B. swainsoni*), were more abundant on plots dominated by lowland hayfields and tallgrass prairies, as opposed to upland mixed and shortgrass prairies. They, along with the ubiquitous American Kestrel (*Falco sparverius*), were not sensitive to the amounts of urbanization (up to 30%) that occurred in the landscapes sampled. Results of this study suggest that urban open space grasslands can support sizable populations of most diurnal raptors, as long as prey populations persist, but that some species are highly sensitive to landscape urbanization.

Key words: conservation, eagles, falcons, grasslands, hawks, landscape, open space, raptors, urbanization.

INTRODUCTION

Studies of habitat selection by diurnal raptors frequently have focused on attributes such as prey availability, vegetation structure, abundance of perch and nesting sites, and interspecific competition (Janes 1985, Preston 1990). Urban development can negatively impact raptors through habitat alteration, habitat loss and fragmentation, and direct human disturbance of nesting and roosting sites (Senner et al. 1984, Cringan and Horak 1989). However, some raptor species can thrive in human-modified landscapes, if the habitats retain ecologically important features (Bird et al. 1996).

Abundances of animal populations can be influenced by landscape setting, especially where habitats are fragmented by human activities (Soulé 1986, Andren 1994, Wiens 1995). This may be especially true for birds of prey, given their low densities, large home ranges, and the resulting scale at which they operate (Olendorff 1984).

Most studies of the responses of terrestrial vertebrates to habitat fragmentation have focused on woodlands (Andren 1994, Robinson et al. 1995). Relatively little is known about the impacts of fragmentation in grasslands (but see Herkert 1994, Vickery et al. 1994). The city of Boulder, Colorado, owns over 100 km^2 of open space (hereafter Boulder Open Space; City of Boulder 1995; Fig. 1), most of which is grassland. The objective of this study was to examine relationships between abundances of diurnal birds of prey on Boulder, Colorado, open space grasslands, and the degree of urbanization of landscapes in which these grasslands were embedded.

Boulder grasslands do not exist as isolated patches, but as part of a belt of largely agricultural land enclosing the city (Fig. 1). Therefore, metrics derived from island biogeographic theory, such as patch size and isolation (Bolger et al. 1997), cannot be applied readily to Boulder Open Space. Grasslands at the urban edges are not strictly isolated from similar habitats in adjacent rural areas. Nevertheless, they occur in very different landscape mosaics that may impact their animal populations (Wiens 1995).

An alternative to the patch size/patch isolation

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approach to landscape ecology is to quantify the landscape composition of a particular sampling plot in terms of such variables as percentages of various cover types represented. In the present study, we counted raptors on plots that differed in habitat composition, including amount of urban development. We then compared count results with the habitat composition of the plots, using a land-cover data base for the Boulder Valley derived from a Landsat Thematic Mapper image.

METHODS

STUDY AREA AND PLOTS

Boulder Open Space lies at the intersection of the western Great Plains and the eastern edge of the Rocky Mountain foothills (Fig. 1). Habitats include narrow riparian corridors along streams, tallgrass prairies and hayfields in adjacent lowland floodplains, and mixed and shortgrass prairies on upland slopes and benches, all against a montane backdrop of ponderosa pine (*Pinus ponderosa*) woodland (Moir 1969, Bock et al. 1995, Bennett 1997). Of particular importance to raptors, lowland tallgrass prairies and hayfields frequently supported high densities of prairie voles (*Microtus ochrogaster*) during our study, whereas colonies of black-tailed prairie dogs (*Cynomys ludovicianus*) were scattered through upland grasslands (pers. observ.).

In the fall of 1993, we established 34 300-m radius circular sampling plots spaced widely across Boulder Open Space, including replicates of the various grassland habitats and the available range of urban landscape settings. The edge of each plot was separated by at least 500 m from its nearest neighbor.

POINT COUNTS

We counted raptors between November and March for the winters of 1993–1994, 1994–1995, and 1995–1996, completing four 10-min 300-m radius fixed-distance point counts (Ralph et al. 1995) per year on each of the 34 plots. Breeding season raptors were counted between late May and mid-July, with four counts in 1994 and three each in 1995 and 1996. We divided the number of raptor observations by the number of counts conducted to yield detections per count as a metric of relative abundance among plots.

Counts were conducted in the mornings of clear and relatively calm days. Snow cover was present during some winter counts. However, each round of counts was completed in less than one week, during which snow conditions did not change appreciably. Birds were counted whether flying or perched. All observations were made by a single observer standing at the plot center. The first and second authors conducted all counts, and each round of counts was completed by the same individual to control for any observer differences. Each observation point included at least 100 m of open space grassland in all directions, so that the observer had a clear view of the sky and the horizon out to the 300-m detection limit on all plots. Thus the observers were equally conspicuous to all raptors within at least 100 m of plot centers, so that observer impacts on raptor behavior likely were constant among plots. Individual raptor species differed in detectability and sensitivity to observers. However, we used count data only for intraspecific comparisons among plots.

LANDSCAPE DESCRIPTION

The study area included grasslands that are part of Boulder Open Space, and the area extending approximately 1 km in all directions around these properties (Fig. 1). A Geographic Information Systems (GIS) land cover data base was generated for this area using an August, 1995, Landsat Thematic Mapper (TM) image, ancillary data from existing GIS coverages, and ground truth data. The image was geo-rectified in State Plane coordinate system (GRS 1980, Zone -501/3451, North American Datum 83), and re-sampled to 27.4 × 27.4-m pixel size. Image classification was accomplished using ERDAS IMAGINE software version 8.2 on a Sun Sparc Workstation. Map accuracy was confirmed, and certain revisions made, based upon ground truth information from the bird count plots, our familiarity with the study area, and review by Boulder Open Space Department personnel.

Locations of the 34 sampling points were determined with Global Positioning Systems. We then described the rectangular landscape setting of each point at the scale of 23 × 23 cells (~ 40 ha), in terms of percentages of various land cover types. Each 300-m radius count circle (28.3 ha) therefore comprised 71% of the rectangle enclosing it, in which available habitats were quantified.

Prairie dog towns in the study area were dig-

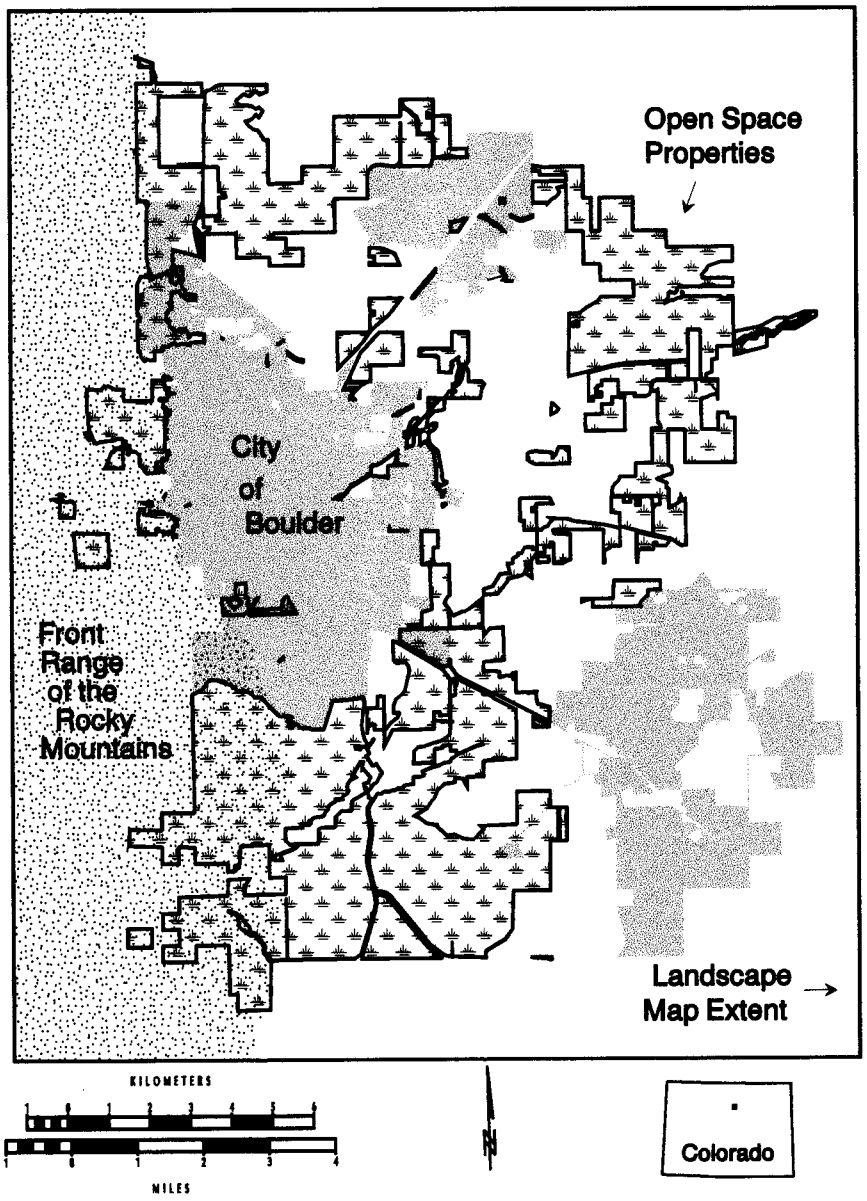

FIGURE 1. Map of the study area, showing the distribution of Boulder Open Space properties in relation to the Rocky Mountain Front Range (stipple), and the City of Boulder and outlying residential areas (shaded). White areas on the map are mostly private rangelands and hayfields in the Boulder Valley.

itized by the Boulder Open Space Department from 1:24,000 aerial photographs. We calculated the distance from the center of each study plot to the edge of the nearest prairie dog town ($\bar{x}$ = 1,615 m; range: 0–3,963 m) using Arc/Grid (ESRI 1996). Many of the prairie dog colonies in our study area were exterminated by an outbreak of bubonic plague in the summer of 1994. The coverage of prairie dog towns used in the analysis was based upon post-plague distributions in 1996, which approximated the conditions during the majority of our study.

TABLE 1. Numbers of detections of diurnal raptors during 300-m radius point counts on 34 Boulder Open Space grassland plots, 1993–1996.

Species	Number of detections	
	Winter	Summer
Turkey Vulture (*Cathartes aura*)	3[a]	21
Bald Eagle (*Haliaeetus leucocephalus*)	27	0
Northern Harrier (*Circus cyaneus*)	23	1[a]
Swainson's Hawk (*Buteo swainsoni*)	0	15
Red-tailed Hawk (*Buteo jamaicensis*)	157	22
Ferruginous Hawk (*Buteo regalis*)	33	1[a]
Rough-legged Hawk (*Buteo lagopus*)	32	0
Golden Eagle (*Aquila chrysaetos*)	15	4
American Kestrel (*Falco sparverius*)	61	35
Merlin (*Falco columbarius*)[b]	2	0
Prairie Falcon (*Falco mexicanus*)	11	2[a]

[a] Data from this season for this species not used in landscape analysis, due to small number of detections.
[b] Landscape associations not analyzed, given paucity of data.

STATISTICAL ANALYSES

We compared raptor detections per count with landscape variables across the 34 study plots using Spearman rank correlations, with Bonferroni's adjustment for joint significance of the multiple comparisons for each species (3 tests per species; $P = 0.017$).

RESULTS

On average, 91.3% of the count plot landscapes consisted of three habitats: urban development, upland grasslands, and lowland grasslands. The urban category ($\bar{x} = 7.7\%$ of the plot habitat; range: 0–29.9%) included both developed areas (pavement, buildings) and urban vegetation. Upland grasslands ($\bar{x} = 48.2\%$; range: 4.9–94.1%) included several categories of short and mixed-grass prairie (Bennett 1997), and dominated 17 of the 34 plots. Lowland grasslands were the most abundant habitat on the remaining 17 plots ($\bar{x} = 35.4\%$; range: 0–82.9%), and included both tallgrass prairies and hayfields, which were not readily distinguishable using the Landsat data.

We counted 465 diurnal raptors of 11 species during the three winter and summer seasons (Table 1). Counts of six species were significantly correlated with at least one landscape variable (Table 2). Bald Eagles (*Haliaeetus leucocephalus*) were detected only in winter, usually in areas with little urban habitat, and most frequently on plots near prairie dog towns (Table 2, Fig. 2). Their avoidance of urban landscapes was particularly striking, as only 1 of 15 plots where this species occurred included > 5% urban habitat.

Swainson's Hawks (*Buteo swainsoni*) were present only in summer. Their numbers were uncorrelated with urbanization or distance to prairie dog towns, and positively correlated with % lowland grasslands (Table 2). Red-tailed Hawks (*B. jamaicensis*) were present year-round, and were the most frequently-counted species in winter (Table 1). They were most common in landscapes dominated by lowland grasslands, and counts of Red-tailed Hawks were uncorrelated with urbanization or distance to prairie dogs (Table 2).

Both Ferruginous (*B. regalis*) and Rough-legged Hawks (*B. lagopus*) were present almost exclusively in winter (Table 1), when they avoided urbanized landscapes and aggregated near prairie dog towns (Table 2). Rough-legged Hawks were counted on 15 plots, only one of which was > 6% urbanized. Ferruginous Hawks occurred on 14 plots, 11 of which consisted of < 5% urban environments, suggesting a somewhat greater tolerance of urban landscapes.

The Prairie Falcon (*Falco mexicanus*) was seen only twice in three summers. The 11 winter detections were negatively correlated with % urbanization (Table 2), and this species was never seen on a plot that was > 5% urbanized (Fig. 2). Counts of Turkey Vultures, Northern Harriers, Golden Eagles, American Kestrels, and Merlins (scientific names in Table 1) were not significantly correlated with any of the landscape variables.

DISCUSSION

EFFECTS OF URBANIZATION

Counts of four wintering raptors—Bald Eagles, Ferruginous Hawks, Rough-legged Hawks, and Prairie Falcons—were negatively correlated with amount of urban development in the landscape. For these species, urbanization apparently represented a critical landscape threshold (Turner and Gardner 1991, With and Crist 1995). These results are consistent with the hypothesis that urbanization represented a limiting factor to winter abundances of these species in the Boulder Valley (Terrell et al. 1996, Schroeder and Vangilder 1997), and that as little as 5–7% urbanization was sufficient to cause most of them to avoid a particular landscape (Fig. 2).

Red-tailed Hawks and American Kestrels were the most abundant breeding and wintering diurnal raptors in the Boulder Valley, and neither

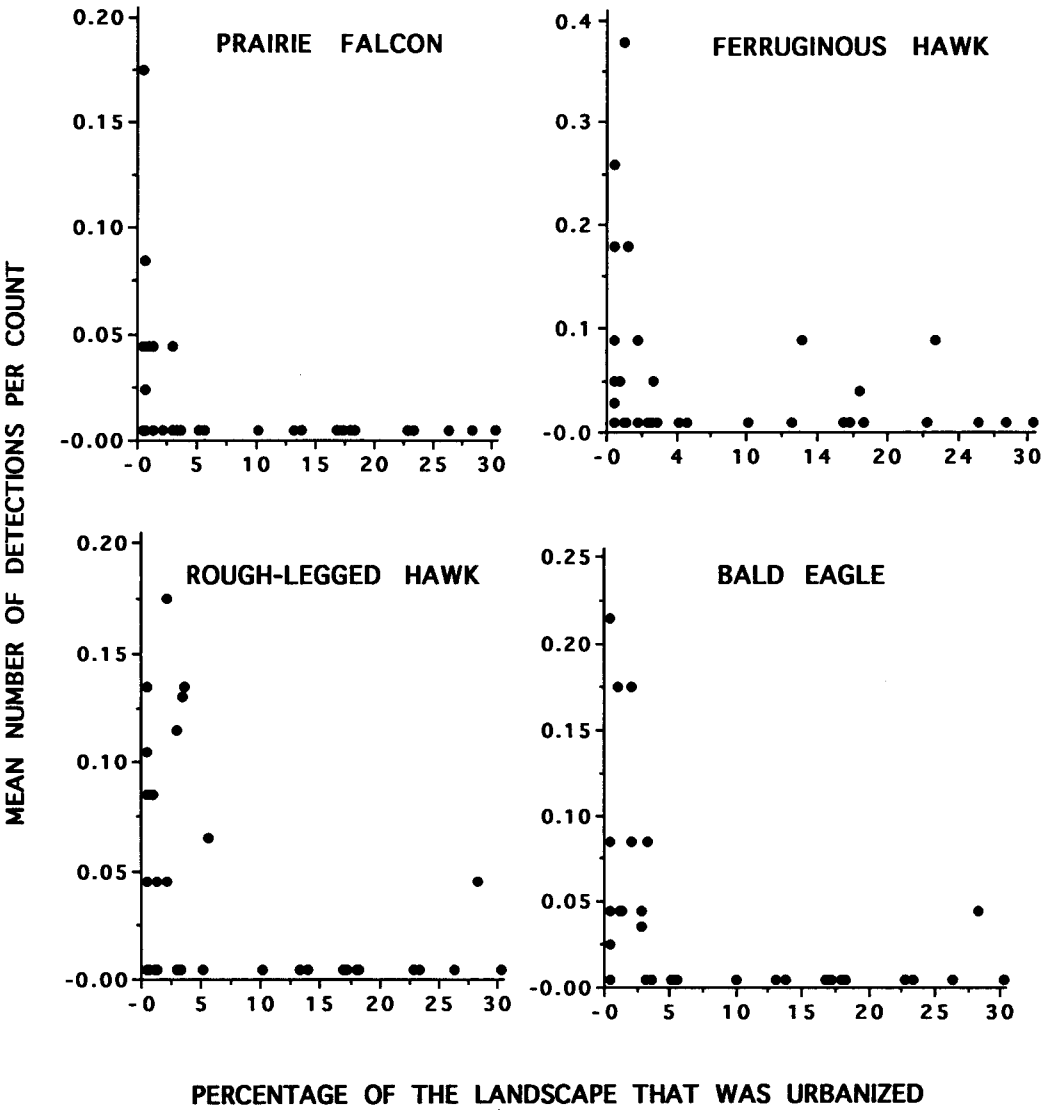

FIGURE 2. Detections per point count of four raptor species in relation to percentage landscape urbanization on 34 study plots in the Boulder Valley.

appeared sensitive to urbanization within the limits that it occurred on our plots. Kestrels have relatively small home ranges, and are well-suited to heterogeneous environments including mixtures of grasslands, riparian corridors, and mature urban vegetation (Bird and Palmer 1988, Varland et al. 1993). Red-tailed Hawks are similarly abundant in heterogeneous rural and agricultural landscapes (Bock and Lepthien 1976, Preston and Beane 1993, Preston and Beane 1996).

Other species whose counts were not correlated with landscape urbanization were the Turkey Vulture, Northern Harrier, Swainson's Hawk, and Golden Eagle. For two reasons, we are unwilling to conclude that these species were insensitive to urban development. First, other studies suggest that some of these species may

TABLE 2. Spearman rank correlations between numbers of diurnal raptors detected per point count and landscape features of 34 40-ha study plots on Boulder Open Space grasslands.

Species	Landscape features		
	% urbanized	% lowland grassland[a]	Distance (m) to nearest prairie dog town
Turkey Vulture	−0.18	−0.12	−0.25
Bald Eagle	−0.48*	0.09	−0.51**
Northern Harrier	−0.12	0.26	−0.05
Swainson's Hawk	−0.05	0.45*	−0.12
Red-tailed Hawk	−0.15	0.76**	−0.12
Ferruginous Hawk	−0.48*	−0.13	−0.45*
Rough-legged Hawk	−0.45*	0.06	−0.41*
Golden Eagle	−0.11	−0.17	−0.03
American Kestrel	−0.07	0.38	0.01
Prairie Falcon	−0.44*	0.08	0.12

[a] Correlations with % upland grassland are not shown, because this variable was strongly correlated with % lowland grassland (Rho = −0.92). The two species positively correlated with % lowland grassland were the only ones significantly correlated (negatively) with % uplands.
* $P < 0.05$ (= $P < 0.017$ with Bonferroni adjustment), ** $P < 0.01$ (= $P < 0.003$ with Bonferroni adjustment).

be negatively affected by urbanization elsewhere (Horak 1986, England et al. 1995). Second, the lack of significant correlations in our study could be an artifact of the relatively small numbers of detections of these species.

There have been few previous studies quantifying responses of diurnal raptors to urban landscapes, especially in western North America (Cringan and Horak 1989). In Larimer County, Colorado, Christmas Bird Counts of Golden Eagles and Merlins significantly declined during a 40-year period of urban development (Horak 1986). The low counts of both species in our study area and lack of spatial correlation with present urbanization suggest that these species may have found the entire Boulder Valley generally unsuitable in 1994–1996. Merlins, however, are known to breed and winter in cities elsewhere in their range (Sodhi et al. 1993).

Smallwood et al. (1996) found that hawks as a group (mostly Red-tailed Hawks) avoided human settlements in the Sacramento Valley of California. However, Red-tailed Hawks were more common in urbanized areas in New Jersey (Bosakowski and Smith 1997), probably because these were the areas with mixtures of wooded and open landscapes preferred by this species. In California, Swainson's Hawks nested in urban environments with mature trees, but reproductive success was very low (England et al. 1995).

Near Denver, Colorado, wintering Ferruginous Hawks hunted prairie dogs with equal frequency on grassland patches imbedded in a highly suburbanized landscape, and on a large open space nearby (the Rocky Mountain Arsenal; Plumpton and Andersen 1998). Following a plague outbreak on the arsenal, Ferruginous Hawks concentrated especially in the suburban areas. These results are not consistent with ours from Boulder Open Space, where Ferruginous Hawks generally (but not entirely) avoided plots with > 5% urban development.

Bald Eagles avoided urban landscapes in the Boulder Valley, and have been found to be sensitive to urbanization in other circumstances as well (Buehler et al. 1991). We found no studies documenting Rough-legged Hawk abundance in relation to urbanization. However, this species is known to prefer expanses of relatively open terrain in winter (Schnell 1968, Bock and Lepthien 1976), which may explain its avoidance of the generally-wooded urban landscapes in the Boulder Valley.

Raptors have been found to be sensitive to human disturbance in a variety of circumstances (Knight and Knight 1984, Knight and Gutzwiller 1995, Brown and Stevens 1997). Boulder Open Space grasslands are heavily used for recreational activities such as hiking, mountain biking, and dog-walking, especially near urban neighborhoods. It seems likely that these activities could be dispersing certain raptors to the more remote parts of the open space system. Some birds of prey also might require habitat patches whose size and configuration are precluded by even a small amount of urbanization (Olendorff 1984), but this is an area of much-needed research.

FORAGING HABITAT

Availability of preferred prey and suitable foraging habitat also apparently influenced the distribution of diurnal birds of prey on Boulder Open Space. Red-tailed and Swainson's Hawks usually hunted over lowland hayfields, where the most abundant prey were prairie voles (pers. observ.), where mowed vegetation probably made prey conspicuous, and where nearby riparian woodlands provided both nest and perch sites preferred by these species (Preston 1990, England et al. 1997).

Bald Eagles, Ferruginous Hawks, and Rough-legged Hawks wintered in the vicinity of prairie dog towns (Table 2). The first two are well-

known prairie dog predators (Jones 1989, Bechard and Schmutz 1995, Preston and Beane 1996). Both apparently are much more abundant today in the Boulder Valley than they were in the early 1900s (Henderson 1909, Betts 1913), despite urbanization. Prairie dogs were present in the Boulder Valley a century ago (Armstrong 1972), but they almost certainly were more consistently persecuted then than now. Nearly all of the region was devoted to livestock grazing and haying at the turn of the century. Most ranchers and farmers considered prairie dogs incompatible with these activities, and major prairie dog control efforts already were underway throughout the western Great Plains by the early 1900s (Miller et al. 1994).

Rough-legged Hawks are not known as prairie dog predators (Jones 1989), and their associations with the vicinity of prairie dog towns is puzzling. Rough-legged Hawks may have hunted prairie dog towns because of carrion left behind by Ferruginous Hawks and Bald Eagles, or because smaller live prey were more conspicuous in the sparse vegetation around prairie dog burrows. We also frequently observed Rough-legged Hawks hunting lowland hayfields after they had been mowed.

CONSERVATION IMPLICATIONS

The western edge of the Great Plains, along the eastern front of the Rocky Mountains in Colorado, once was a heterogeneous mixture of tall- and mixed-grass prairies, riparian corridors, and wetlands. Today, it is rapidly being overtaken by suburban expansion, from Fort Collins in the north to Colorado Springs in the south (Mutel and Emerick 1992, Long 1997). Results of this study testify to the conservation value of protecting open spaces in this region for diurnal birds of prey, especially any remaining larger areas with little urban or suburban development, and with prairie dog towns. Our study should be replicated elsewhere to determine whether the apparent critical landscape threshold of 5–7% urbanization is generally true for raptors in grasslands, and to search for possible causes of this relationship.

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