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HABITAT ASSOCIATIONS OF ROUGH-LEGGED AND RED-TAILED HAWKS IN RELATION TO URBANIZATION IN EASTERN BOULDER COUNTY, COLORADO

by

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Final Report

Submitted to:

City of Boulder Open Space and Mountain Parks

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Habitat Associations of Rough-legged and Red-tailed Hawks in Relation to Urbanization in Eastern Boulder County, Colorado

Thesis directed by Professor Carl E. Bock

The Rough-legged Hawk (*Buteo lagopus*) is widespread in winter on the plains of eastern Colorado. However, Christmas Bird Count data indicate that this species has declined significantly in the past 20 years, especially in urbanizing landscapes. This decline has been particularly steep since 1980 near Boulder, despite a large and growing municipal open space system that protects much seemingly suitable habitat. In the winters of 1999-2002, I conducted roadside surveys in eastern Boulder County looking for both Rough-legged and Red-tailed Hawks (*Buteo jamaicensis*), a species whose numbers in the county have been relatively high and stable. At each sighting I recorded data on several landscape and habitat variables, including the amount of urbanization occurring within 100 m (habitat scale) and 500 m (landscape scale) of each perch sight. Data also were collected from random plots generated using a map and grid system. Compared to random locations, Rough-legged Hawks avoided urban edges and habitats as well as landscapes with greater than 2 and 4 percent urbanization, respectively. Conversely, Red-tailed Hawks showed a preference for urban edge habitats. Because these two raptors take similar prey and are known to respond to prey density when selecting habitat, the observed patterns in habitat separation cannot be attributed to prey distribution. Rather, Rough-legged Hawks, with their higher wing aspect ratio are better at hunting on the wing, and may exploit relatively open country, whereas Red-tailed Hawks hunt more

frequently from a perched position, and therefore may prefer areas with perches such as trees and utility poles that are more common in developed areas. The decline of Rough-legged Hawks in Boulder County likely is the result of increasing urbanization and possible usurpation of habitat by the more adaptable Red-tailed Hawk. Despite protection of much suitable habitat as open space, it appears that the amount of urban edge has reached a critical threshold for a species such as the Rough-legged Hawk, that is both wide-ranging and associated with uninterrupted grasslands.

ACKNOWLEDGMENTS

I would like to thank my Thesis Advisor, Dr. Carl Bock for his guidance and assistance in helping me work through all aspects of this project. Additionally, I thank my Thesis Committee, Dr. David Armstrong and Dr. Sharon Collinge for their helpful advice, suggestions, and support. Thanks to Mark Brennan (Boulder County Parks and Open Space), Cary Richardson (City of Boulder Open Space and Mountain Parks), Bryan Posthumus (Jefferson County Open Space), and Brad Dallum (City of Lafayette Parks and Recreation) for their helpful assistance, as well as to the agencies mentioned above for allowing me access to various open space properties. Additional thanks to both Jill Skarstad and Dr. Robert Lynch for helping me navigate the intricacies of the EPOB Combined BA/MA Degree Program.

Funding for this study was generously provided by City of Boulder Open Space and Mountain Parks, as well as the Department of Environmental, Population, and Organismic Biology of the University of Colorado, Boulder.

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INTRODUCTION

Urbanization and Fragmentation Effects

As human population growth and expansion continue, the issues of habitat loss and landscape alteration are necessarily of primary concern. Human disruption of landscapes often causes significant changes (Vitousek et al. 1997), including a reduction in patch size and complexity in native habitats (Mladenoff et al. 1993). These changes can occur across both spatial and temporal scales, and usually proceed from an initial wildland state or area to an urban center (McDonnell and Pickett 1990). The changes occurring along the gradient include anthropogenically caused shrinkage, bisection, fragmentation, and perforation (Collinge and Forman 1998) of a native landscape by a dissimilar matrix.

Numerous studies have documented changes in bird and mammalian communities as fragmentation and urbanization occur (See Andren 1994, Debinski and Holt 2000, and Marzluff 2001 for reviews), and though some of the methods used in examining these processes may be suspect (Johnson 2001), patterns are emerging. For example, following the urbanization of an area, communities will generally experience a decrease in the number of native species remaining in the landscape (Marzluff, 2001), and those that do remain are restricted to fragmentary habitat patches (Bolger, 2001). Besides the loss of habitat experienced by native species, urbanization also brings with it a host of generalists and human commensal species, some of whom may invade surrounding undisturbed habitat and prey upon

(Winter et al. 2000), parasitize (Cruz et al. 2000), or compete with the native species, further causing declines beyond simple loss of habitat. Additionally, the presence of an urban matrix may inhibit the movement of less vagile species (Collingham and Huntley 2000), contributing to decreased dispersal ability and creating small groups of fragmentary populations where one large population once existed.

In bird communities these forces may produce a wide range of effects, though usually they act to the detriment of native communities (Johnson 2001) and to the benefit of synanthropic (Johnston 2001) species. For example, Bock et al. (1999) found that several Colorado native grassland songbirds avoided areas proximal to urban developments near Boulder, whereas a variety of suburban-nesting species increased on open space grasslands. Human activity associated with urban areas can have detrimental effects on foraging and other activities of songbirds (Fernandez-Juricic 2000). Johnson (2001) documented 18 grassland species that have been shown to be sensitive to patch size. With regard to raptors, Berry et al. (1998) found that several species were negatively sensitive to landscapes with as little as 5-10 percent urbanziation. Bosakowski and Smith (1997) found a strong correlation between raptor richness and patch size. However, several studies have shown that some raptors are tolerant of urbanization and human intrusion (Plumpton and Andersen 1998, Stout et al. 1998, Bosakowski et al. 1996). The life history traits of each species are most likely to determine its responses to alteration of landscapes (Hansen and Urban 1992)

The grasslands of Boulder County, Colorado support a wide variety of raptors in an agricultural and urbanizing landscape (Jones 1987, Berry et al. 1998).

One species that may be at risk for local extinction as urbanization increases in Boulder County is the Rough-legged hawk (*Buteo lagopus*), a species particularly associated with large expanses of low-stature tundra and grassland ecosystems (Brown and Amadon 1968).

Rough-legged Hawk Habitat Associations

The Rough-legged hawk migrates south from its Arctic breeding and nesting grounds each year during the winter months when conditions become unfavorable in the north (Brown and Amadon, 1968). Mathisen and Mathisen (1968) note that in the Nebraska Panhandle birds arrive on the wintering grounds beginning in October, and are generally found through March. During the winter months the hawk is reported to associate primarily with open grasslands, and to eat voles (*Microtus* spp.) (Brown and Amadon 1968, Bock and Lepthien 1976). Stahlecker (1975) examined Rough-legged Hawk numbers on Colorado Audobon Christmas Bird Counts from 1953-1972, and noted that the birds were common along the Front Range, and did not appear to be declining. Since this time, however, numerous changes have taken place across the Colorado Front Range and in Boulder County. Such changes include expansion of urban and suburban areas, and perforation of rural agricultural landscapes with increased exurban development (Anonymous 1996, Boulder County Land Use Department 2002). It remains unclear how these changes impact the Rough-legged Hawk.

Preston and Beane (1996) found Rough-legged Hawks did not show any preference for or avoidance of human traffic, woodlands, or prairie dog colonies on the Rocky Mountain Arsenal, near Denver, Colorado. In contrast, Fletcher et al. (1999) found significantly fewer Rough-legged Hawks perched along riparian corridors with recreational trails than along corridors without trails in Boulder County. A recent study on City of Boulder Open Space grasslands found the Rough-legged Hawk to be highly sensitive to urbanization (Berry et al. 1998), avoiding landscapes with greater than 5-10 percent urbanization. Swan et al. (2000) suggested that the pattern found by Berry et al. (1998) may be the mechanism behind recent declines of this bird across the Front Range of Colorado, as documented by Audubon Christmas Bird Counts. In other areas, however, the Rough-legged Hawk thrives in highly urbanized and even industrial landscapes (Bosakowski and Smith, 1992).

The Rough-legged Hawk exhibits varying patterns of small scale habitat selection. For example, Lingle (1989) found that Rough-legged Hawks wintering in the Platte and North Platte River Valleys of Nebraska preferred pastures and mowed fields, with low-stature vegetation. On City of Boulder Open Space, Berry et al. (1998) found Rough-legged Hawks hunting principally in two habitats: 1) lowland hayfields after they had been mowed, and 2) lands occupied by black-tailed prairie dogs *(Cynomys ludovicianus)*. The reason for the second habitat association remains unclear, as the species is not known to prey on prairie dogs. Berry et al. (1998) hypothesized that the hawks may scavenge remains of prairie dogs killed by other predators, or prefer to hunt prairie dog towns because of the high visibility of other, smaller, prey species they are known to kill. Smallwood et al. (1996) found that hawks generally avoid tilled agricultural land due to a lack of prey, though this effect has never been documented specifically in the Rough-legged Hawk.

Studies by Lingle (1989) and Berry et al. (1998) seem to establish that *B. lagopus* prefers to hunt open habitats with short vegetative ground cover. However, the results of a study done by Littlefield et al. (1992) in Oregon contradict these findings. These researchers found that Rough-legged Hawks tended to inhabit idle land more often than hayed areas, and that the raptors avoided grazed lands. The reason behind these contradictory results remains unclear, though Littlefield et al. (1992) suggest that decreased vole populations in hayed or grazed fields led to a decline in the number of hawks hunting these areas. Conversely, Berry et al. (1998) suggested that the hawks may show a propensity for areas with shorter vegetation as less cover exists in which prey species can hide. Smith and Murphy (1973) report that most buteos, as generalists, eat whatever prey proves least troublesome to take.

Rough-legged Hawk Diet

Because the Rough-legged Hawk primarily eats voles, this may be the factor that most influences the bird's habitat selection, and therefore its local abundances. In investigating the Rough-legged's dependence on voles, Garrison (1993) and Stahlecker (1975) both documented 3-6 year cyclic patterns in Rough-legged Hawk wintering populations. It remains unclear, however, whether these fluctuations were due to microtine cycles on the bird's breeding grounds or in the hawk's winter habitat. Salamorlard et al. (2000) suggested that in areas with sufficient prey diversity, raptor numbers will not mirror prey populations as closely, as the raptors will diversify their diet and exhibit a functional (behavioral) response rather than a numerical response to vole increases. This hypothesis is echoed by Korpimaki and Norrdahl (1991), as they note that generalist species are more likely to exist in southern latitudes where prey species richness is higher. This may not be true for the Rough-legged Hawk, as Galushin (1974) found that Rough-legged Hawks engage in pre-nesting searches for areas with the highest prey density on their breeding grounds, and finally nest in areas with high vole density. The Rough-legged Hawk could behave similarly on its wintering ground, and choose its winter habitat based on vole densities there.

The fact that the Rough-legged Hawk depends on voles and small mammals (Brown and Amadon 1968, Galushin 1974, Reid et al. 1997) in Boulder County could have profound impacts on the focus of conservation of this bird. Bock et al. (in press) found that *Microtus ochrogaster*, one the Rough-legged Hawk's prey species, avoided landscapes with 5-10 percent urbanization. However, Ims and Andreassen (1999), found that although experimental fragmentation influenced matriline diversity in root voles, it had no influence on overall population size. According to a review of experimentally manipulated landscapes and their effects by Debinski and Holt (2000), many small mammals actually exhibit increased density in fragmented areas, perhaps due to a relaxation in predatory pressures. It is important to note that patterns in the Bock et al. (in press) data may be due to higher predation rates brought about by predators moving from the urban area into the grassland matrix. This discrepancy may highlight a key difference in understanding urbanization vs. processes occurring at other types of edges. Bolger et al. (1997) showed a negative correlation between species richness, abundance, and patch size in rodents living in a fragmented habitat with an urban matrix. Although Bolger et al. (1997) did not explain the mechanisms behind the local extinctions, they hypothesized that they could be due to decreased habitat suitability or increased predation from the urban edge.

Dietary Overlap Between Rough-legged and Red-tailed Hawks

Red-tailed Hawks are common across the Front Range of Colorado (Jones 1987, Gietzen et al. 1996), and have been steadily increasing in numbers since the 1970's (Swan et al. 2000). They are known to be somewhat tolerant of urbanization pressures (Bosakowski et al. 1996, Stout et al. 1998), and are considered generalist predators, especially in the western United States (McInvaille and Keith 1974, Adamcik et al. 1979, Mari and Kochert 1995).

Because Red-tailed and Rough-legged Hawks' wintering ranges overlap broadly (Brown and Amadon 1968, Preston and Beane 1993), they have the opportunity to take the same prey. Red-tailed Hawks have been documented to eat voles (*Microtus* spp.), mice (*Peromyscus* spp., *Reithrodontomys* spp., *Mus musculus*), rats (*Sigmodon hispidus, Oryzomys paulustris*), hares and rabbits (*Lepus* and *Sylvilagus* spp.), ground squirrels (*Spermophilus* spp.), prairie dogs (*Cynomys* spp.), and occasionally other birds and reptiles (Preston and Beane 1993). Several studies have documented extensive dietary overlap between the Rough-legged Hawk and the Red-tailed Hawk. Craighead and Craighead (1956) found that in Michigan, meadow mice (voles) comprised 89 percent of wintering Red-tailed Hawk diets, and 84 percent of Rough-legged Hawk diets. Combined, small mammals composed 96 and 98 percent of Red-tailed and Rough-legged Hawk diets, respectively. In a further analysis of these data, Jaksic (1983) estimated the niche overlap between these two species to be 99 percent. Further, Marti et al. (1993) note that wintering Red-tailed Hawks in Michigan remained dependent upon voles despite variable presence of Rough-legged Hawks between years, implying that prey selection of Red-tailed Hawks is independent of Rough-legged Hawks, even though the species are potential competitors.

In a study of raptor guilds in Alberta, Phelan and Robertson (1978) found that both Red-tailed and Rough-legged Hawks exhibited strong numerical responses to vole density changes. Additionally, this study found that voles comprised between 50 and 70 percent of the biomass of each of these raptor species during two winter field seasons. Bart (1977) found Red-tailed Hawk densities to be highly correlated with both high quality vole habitat and number of vole runways within the habitat. Gates (1972) found that microtine species comprised 16.5 percent of prey remains collected at Red-tailed Hawk nests in east-central Wisconsin, making voles the second most common food source for this population. Platt (1971) found *Microtus* remains in eight out of 18 cast pellets collected in the Curlew Valley on the Utah-Idaho border, making voles the most common prey for this population. In a study at Rocky Mountain Arsenal National Wildlife Refuge, Colorado, Seery and Matiatos (2000) found that Rough-legged and Red-tailed Hawk abundances and habitat selection were not related to plague epizootics in prairie dogs, and hypothesized that both of these birds responded primarily to small mammal availability. Preston (1990) found that 82 percent of 102 Red-tailed Hawk pellets were comprised of small mammals, and that Red-tailed Hawks were selecting habitat based primarily upon prey density and perch availability. Baker and Brooks (1981) found that both Red-tailed Hawk and Rough-legged Hawk abundances tracked vole densities. In Boulder County Blumstein (1986) found that cast pellets from beneath seven of eight Red-tailed Hawk nests contained remains of at least one *Microtus* species. All nests showed at least some usage of small mammals for prey, including *Peromyscus* species. Finally, Hogan (1983) documented an instance of interspecific food piracy of a Rough-legged Hawk stealing food from a Red-tailed Hawk.

In summary, aside from the Red-tailed Hawk's ability to take a broader variety of prey (Preston and Beane 1993) there is an extensive amount of dietary overlap between these two species. Given the fact that both species are responsive to prey densities, it is logical to conclude that any differences in habitat associations are due primarily to the way these raptors select habitat.

Statement of Purpose

The objective of this study was to further document avoidance of urbanized areas by the Rough-legged Hawk, and to investigate whether such avoidance is a primary effect attributable to the bird's habitat selection or a secondary effect attributable to the way prey species respond to urbanized areas. In an attempt to separate these factors I also examined habitat selection of the Red-tailed Hawk. Because these two raptors both prey on voles, differences in habitat selection with regard to urbanization can be attributable to the bird's behavioral response to urbanizing landscapes and to their possible interspecific interactions. During the winters of 1999-2000, 2000-20001, and 2001-2002, I conducted roadside surveys throughout eastern Boulder County and compared Rough-legged Hawk and Red-tailed Hawk habitats with respect to amount of urbanization at various scales, presence of vole activity, and associations with grassland habitat. Additionally, I examined the National Audubon Society's Christmas Bird Count data for the Rough-legged Hawk from 1980 – 2001 for 15 counts from both rural and urbanized areas across eastern Colorado to document any declines in abundances.

METHODS

Study Area

The plains of eastern Boulder County include narrow riparian corridors along streams, tall and shortgrass prairies, agricultural hayfields in lowland floodplains, mixed grasslands on upland plateaus to the west, and tilled agricultural land to the east. Tallgrass stands consist of big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and Indian grass (*Sorhastrum nutans*), and are grazed in fall and winter (Bock et al. 1999).

Agricultural hayfields around Boulder support mixtures of alfalfa (*Medicago sativa*), sedges (*Carex* spp.), and non-native pasture grasses, such as smooth brome (*Bromus inermis*), meadow fescue (*Festuca pratensis*), orchard-grass (*Dactylis glomerata*), and timothy (*Pheleum pratense*). These areas are flood-irrigated in spring and early summer, mowed in July, and sometimes grazed in fall and winter (Bock et al. 1999).

Upland habitats in the Boulder Valley support both mixed and shortgrass prairies where dominant grasses include blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), buffalograss (*Buchloë dactyloides*), needle grasses (*Stipa* spp.), and two exotics, Japanese brome (*Bromus japonicus*), and cheatgrass (*B. tectorum*). Yucca (*Yucca glauca*) and prickly pear cactus (*Oputina* spp.) are common in some areas (Marr 1964). All upland sites have a history of livestock grazing, although some areas have gone ungrazed recently.

The landscape is dotted with small farms and ranchettes between larger cities such as Boulder and Longmont. Lands protected by City of Boulder Open Space and Boulder County Parks and Open Space comprise the majority of relatively unaltered grassland. Cottonwoods (*Populus* spp.) and willows (*Salix fragilis*) are associated primarily with riparian areas as well as with some urban developments. Prairie dog (*Cynomys ludovicianus*) towns are scattered throughout the landscape as well.

Field Methods

This study used a bird-centered approach to quantifying habitat associations (Larson and Bock 1986). Systematic driving surveys of eastern Boulder County were conducted from November 1st through March 31st 1999-2000 and 2000-2001, and from November 1st 2001 to February 15th 2002, encompassing an area approximately 750 km^2. Surveys were conducted 2 to 3 times each week, usually lasting from 4 to 6 hours. Surveys were conducted at varying times of the day and under viariable wind conditions, though usually on clear days when visibility was high.

When a Rough-legged or Red-tailed Hawk was sighted the following data were recorded: type and height of perch used, number of perch opportunities greater than three m high within a 100 m radius circle of the sighting, an estimate of the percentage of tree canopy cover and developed land in this area, the length of all roads in this area, and length of all riparian strips and trails within the 100 m radius. I also recorded the number of prairie dog mounds within 100 m of the sighting. When a bird in flight was sighted I observed the bird until it perched, and then collected all measurements from that perch. If the bird did not perch and left the area I used the point below where I had first seen the bird for all measurements. To ensure that sightings were statistically independent, I noted the color phase of each bird, and if a hawk with a similar color phase (Clark 1987) was seen within 1 km of that area during the same winter, the data from both points were averaged, and these averaged data were used for all analyses. This method prevented pseudoreplication of hawk centered data.

Where I was able to gain access to the land, I recorded vegetation height and type at 10 m intervals along four 100 m transects running along the cardinal directions away from the center of the plot. I recorded the presence or absence of vole trails (Fitzgerald et al. 1994) at 10 m intervals along these transects as well. Similar methodology has been used in the past to determine relative vole densities (Bart 1977). The number of 10 m intervals in which I found vole activity was averaged for each point to produce an Index of Vole Activity.

At the landscape level I recorded the distances from the center of each plot (within 500 m) to the nearest development, road, trail, riparian zone, and prairie dog colony, using a Bushnell YardagePro 600 Laser Rangefinder in eight directions (N, NE, E, SE, S, SW, W, and NW). If the measured variable did not exist within the 500 m radius, 500 was recorded. These data were then converted to an index of proximity by using:

Individual Proximity Index = 1 - (Measured Distance / 500m)

These eight Individual Proximity Indices were then averaged to create a single Proximity Index for each variable measured at each plot. This variable has a range from 0 to 1, with values of 1 being the plot center itself, and 0 being no presence within the 500 m radius.

I also sketched a map of the landscape within a 500 m radius circle of the sighting, making special note of urban developments, roadways, riparian zones, lakes and ponds, tilled agricultural land, and grassland / hayfields. These maps were then used to estimate the percentage of cover of each of the noted landscape types by placing a transparent grid over the map and assigning each grid square to one of the landscape types and dividing the number of each type by the total squares possible. Roadways and riparian strips were analyzed using the lengths of these variables within the 500 m plots.

Control plots were determined by generating random coordinates and locating the points on a map of eastern Boulder County. I then traveled to these random plots and located the nearest perching opportunity (usually a power pole, tree or fencepost) and made this perch the center of a Control plot. If there was no perching opportunity within 100 m of the random point, I used the random point itself, and recorded no perch height information. I recorded the same data on Control plots as on hawk plots. If an area was entirely urban or fell outside of the area of my roadside surveys, I disregarded the plot in favor of a new one.

Statistical Analyses of Habitat and Landscape Data

Because the majority of the data violated the assumptions for ANOVA (Zar 1999), I used Kruskal-Wallis tests followed by individual Mann Whitney – U comparisons to determine which means were significantly different between plot types (Welkowitz et al. 1991) for all variables measured.

Christmas Bird Count Analyses

I compiled the National Audubon Society's Christmas Bird Count Rough-legged Hawk data from the past 20 years (winter of 1980 / 1981 to the winter of 2000 / 2001) from 15 locations across eastern Colorado. I classified counts from Boulder, Longmont, Denver, Fort Collins, Colorado Springs, and Pueblo as urban. All urban areas conducted 21 counts between 1980-2001, except Boulder and Colorado Springs, which conducted 20 and 19 counts, respectively. Areas that I classified as rural contained variable numbers counts: Nunn (21 counts), Barr Lake, and Fort Morgan (20 counts each), Greeley (19 counts), Holly (7 counts), Rocky Ford (6 counts), Crook (4 counts), Bonny (3 counts), and Walsenburg (1 count). Numbers from each year were averaged within the two types, and I used these averaged data to regress abundance against year. To investigate trends unique to the Boulder area, I isolated the Boulder data from the other urban areas and again conducted linear regressions followed by a t-test comparison of the two slopes (Zar 1999).

RESULTS

Christmas Bird Count Analyses

Rough-legged hawk numbers appear to have declined in Colorado since 1980 (Figure 1), but this decline was significant only for counts in urbanizing areas (Adjusted $r^2 = 0.36$, $F = 12.27$, $P = 0.0024$). The decline in Boulder County has been especially steep (Adjusted $r^2 = 0.56$, $F = 25.51$, $P < 0.0001$) compared to the average of other urban counts (Adjusted $r^2 = 0.26$, $F = 8.00$, $P = 0.0108$), and the two slopes are significantly different ($\nu = 37$, $t = 2.82$, $P < 0.01$; Figure 2).

Rough-legged and Red-tailed Hawk Habitat Selection

During November through February 1999-2000, 2000-2001, and 2001-2002 (three winter field seasons), I observed 49 Rough-legged Hawks representing at least 35 individuals, and during the final field season data on 20 individual Red-tailed Hawks were recorded. Data were also taken from 35 Control plots. Of these plots I was able to obtain permission from landowners to take vegetation measurements on 16 Rough-legged Hawk plots, eight Control plots, and four Red-tailed Hawk plots.

Mean vegetation height, Index of Vole Activity, number of perches over three m, percentage of tree canopy cover, meters of riparian strip, meters of road, and meters of trail within 100 m of the hawk did not differ between Rough-legged Hawk, Red-tailed Hawk and the Control plots (Table 1). At the landscape scale (within a

Figure 1. Mean Rough-legged Hawk abundances for urban and rural Christmas Bird Counts and their associated linear regressions.

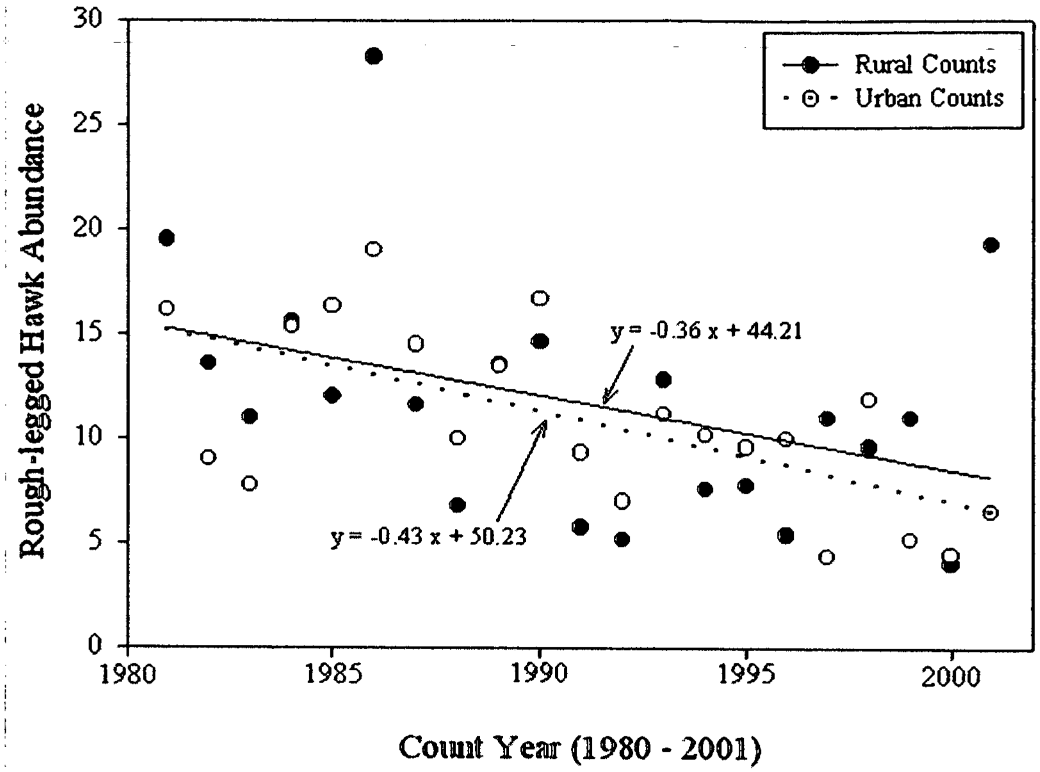

Figure 2. Mean Rough-legged Hawk abundances for Boulder and other urban Christmas Bird Counts and their associated linear regressions.

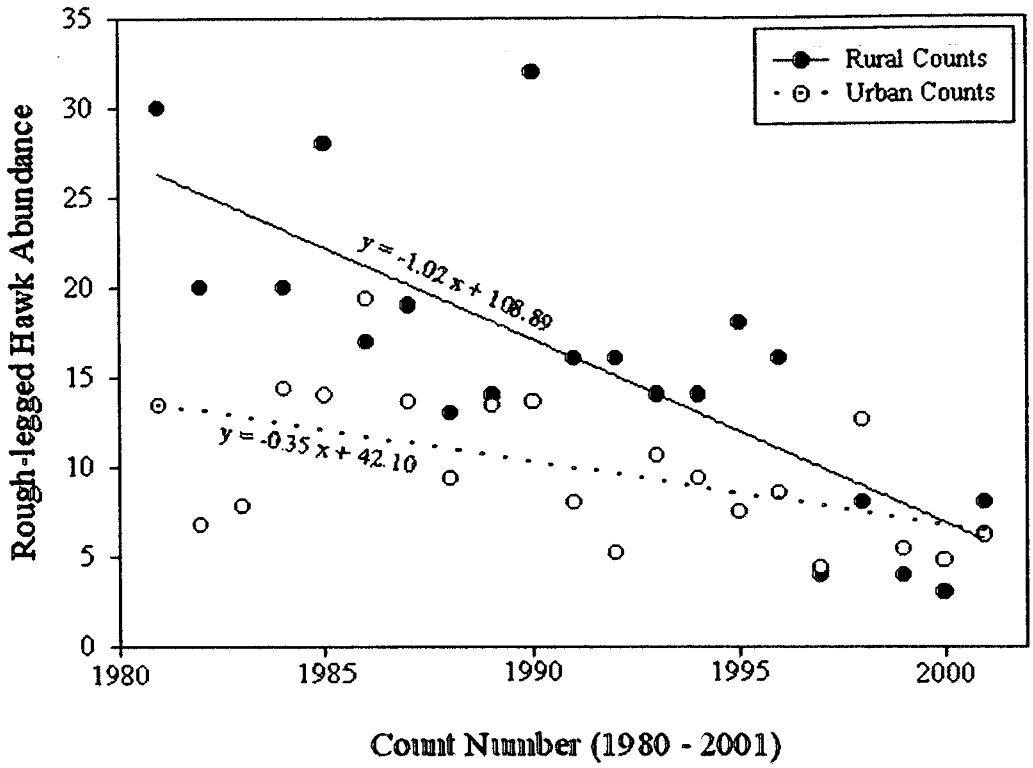

Table 1. Attributes (Mean, S. E.) of 100 m radius (habitat) plots centered on individual Red- tailed Hawks, Rough-legged Hawks and random (Control) points, in Boulder County, Colorado (n = 35 for all Rough-legged Hawk, Red-tailed Hawk and Control categories, except for Mean Perch Height [$n_{Rough\text{-}legged}$=28, $n_{Red\text{-}tailed}$ = 17, and $n_{Control}$ = 32]). Values with shared superscript letters indicate homogeneous subsets revealed by *post hoc* Kruskal-Wallis and Mann Whitney U tests.

Variable	Rough-legged Hawk	Red-tailed Hawk	Control Plot	Kruskal-Wallis H^2	P Value
Mean Perch Height (m)	10.29 (1.21)[a]	16.88 (1.56)[b]	10.81 (1.00)[a]	11.28	0.0036
Mean Number of Perches > 3 m	6.56 (1.72)	8.65 (2.11)	9.91 (2.25)	2.42	
% Tree canopy cover w/in 100 m of Perch	3.75 (1.56)	8.20 (2.12)	6.80 (1.93)	3.22	
m of Riparian Strip	66.80 (14.09)	36.25 (12.76)	44.57 (13.04)	2.23	
Number of Prairie Dog Mounds w/in 100 m of Perch	1.66 (1.29)[a]	8.25 (3.60)[b]	0.29 (0.29)[a]	8.78	0.0124
m of Road w/in 100 m of Perch	106.12 (15.12)	68.4 (16.71)	88.71 (18.22)	5.47	
m of Trail w/in 100 m of Perch	1.43 (1.01)	0.75 (0.75)	0 (0)	1.98	
% Developed w/in 100 m of Perch	1.89 (0.84)[a]	22.00 (5.24)[b]	8.71 (2.71)[c]	17.13	0.0002
% Developed w/in 100 m of Perch (Excludes Five Red-tailed Hawks associated w/ prairie dogs)	1.89 (0.84)[a]	16.07 (5.06)[b]	8.71 (2.71)[c]	9.78	.0075

Table 1. Continued.

Variable	Rough-legged Hawk	Red-tailed Hawk	Control Plot	Kruskal-Wallis H^2	P Value
Mean Vegetation Height (cm)	20.49 (3.44)	26.05 (2.71)	17.08 (5.70)	2.93	
Mean Index of Vole Presence	0.06 (0.01)	0.11 (0.4)	0.05 (0.04)	5.10	

500 m radius from the center of the plot) length of riparian strips, percent water and agricultural land as well as proximity to nearest road, riparian zone, prairie dog colony, and trail did not differ between plot types (Table 2). However, several other variables did differ among plot types at both habitat (100 m) and landscape (500 m) scales.

Mean perch height was greater for Red-tailed Hawks than for either Rough-legged Hawks or Control plots. Additionally, Red-tailed Hawk plots had significantly more prairie dog mounds within 100 m of the perch than did Rough-legged Hawk or Control plots. Rough-legged Hawk plots contained the least amount of developed land within a 100 m radius of the center point, while Red Tailed Hawk plots contained the most. Control plots were intermediate between the two (Table 1). This pattern was echoed at the landscape (500 m) scale, with Rough-legged Hawk plots includes significantly less development than either Red-tailed Hawk or Control plots. Conversely, Rough-legged Hawk plots encompassed more open grasslands/hayfields than any other plot type. Red-tailed Hawk plots included more km of road than any other type of plot. Finally, Rough-legged Hawks were found farther away from developed structures than Red-tailed Hawks. Again Control plots were intermediate between the two (Table 2).

Table 2. Attributes (Mean, S. E.) of 500 m (landscape) plots centered on individual Red-tailed Hawks, Rough-legged Hawks and random (Control) points, in Boulder County, Colorado (n = 35 for all Rough-legged, Red-tailed Hawk and Control categories. Values with shared superscript letters indicate homogeneous subsets revealed by *post hoc* Kruskal-Wallis and Mann Whitney U tests.

Variable	Rough-legged Hawk	Red-tailed Hawk	Control Plot	Kruskal-Wallis H^2	P Value
% Developed w/in 500 m of Perch	4.27 (0.97)[a]	26.89 (3.96)[b]	20.20 (2.53)[b]	34.87	<0.0001
km Roadways w/in 500 m of Perch	0.82 (0.04)[a]	1.44 (0.38)[b]	0.77 (0.07)[a]	35.39	<0.0001
km Riparian Strip w/in 500 m of Perch	0.43 (0.09)	0.68 (0.16)	0.45 (0.18)	3.01	
% Water w/in 500 m of Perch	2.59 (1.01)	1.06 (0.94)	1.92 (1.09)	1.65	
% Tilled Agricultural Land w/in 500 m of Perch	5.38 (1.85)	0.81 (0.69)	14.01 (4.46)	4.19	
% Grassland w/in 500 m of Perch	75.26 (2.53)[a]	56.07 (3.64)[b]	49.82 (4.66)[b]	22.03	<0.0001
Proximity Index to Nearest Developed Area	0.0950 (0.03)[a]	0.42 (0.03)[b]	0.21 (0.03)[c]	38.05	<0.0001
Proximity Index to Nearest Road	0.34 (0.03)	0.35 (0.03)	0.31 (0.03)	1.44	

Table 2. Continued.

Variable	Rough-legged Hawk	Red-tailed Hawk	Control Plot	Kruskal-Wallis H^2	P Value
Proximity Index to Nearest Riparian Zone	0.21 (0.05)	0.18 (0.05)	0.16 (0.04)	0.87	
Proximity Index to Nearest Prairie Dog Colony	0.03 (0.01)	0.08 (0.04)	0.04 (0.02)	0.50	
Proximity Index to Nearest Trail	0.001 (0.003)	0.01 (0.01)	0.0 (0.0)	4.21	

DISCUSSION

Rough-legged Hawks preferred open grasslands (including hayfields), and avoided developed lands, at both the habitat (< 100 m) and landscape (< 500 m) scales. Rough-legged Hawks perched farther from urban edges than would have been predicted randomly. These findings seem consistent with the fact that the Rough-legged Hawk spends its breeding season in the Arctic tundra, where three-dimensional habitat heterogeneity is a rarity (Brown and Amadon 1968). Overall, my results are in agreement with those of Berry et al. (1998), who found an avoidance of landscapes with greater than 5-10 percent urbanization by Rough-legged Hawks. This figure closely matches that found by the present study, as mean percent urbanization of Rough-legged Hawk plots (at the landscape level) was just above 4 percent.

This avoidance of urbanized areas is likely attributable to actual avoidance of developments rather than prey availability, as Red-tailed Hawks did not show this pattern, thus indicating that sufficient prey were likely present in areas near developments. The presence of Red-tailed Hawks has been shown to be an indicator of prey populations in the past (Gates 1972, McInvaille and Keith 1974, Bart 1977, Phelan and Robertson 1978, Adamcik et al. 1979, Baker and Brooks 1981, and Marti and Kochert 1995,). Rather than avoiding urbanized areas, Red-tailed Hawks preferred them at the habitat scale. This preference is likely due to the increased availability of perching opportunities around urban areas. Preston (1990) found that Red-tailed Hawks responded to both the presence of prey in the area and perch availability, and Janes (1985) found Red-tailed Hawks to prefer areas with greater perch densities than other raptors. Janes (1985) attributed this difference in habitat selection to morphological characteristics of the Red-tailed Hawk. Because of the bird's relatively low wing aspect ratio, the Red-tailed Hawk is less adapted to aerial foraging, and therefore hunts mostly from a perch (Preston and Beane 1993). However, the Rough-legged Hawk is better adapted to hunting on the wing (Schnell 1968), and therefore is able to exploit prey populations in areas where Red-tailed Hawks hunt less frequently. The fact that Red-tailed Hawks perched higher than Rough-legged Hawks supports these findings, as a higher perch would allow for a better vantage point from which to hunt. Additionally, the Red-tailed Hawk was associated with greater road lengths than either of the other plot types at the landscape scale. This association is likely a function of the hawk's habit of perching on power and telephone lines near urbanized areas.

Rough-legged Hawks showed no association with prairie dog towns, in contrast to the findings of Berry et al. (1998). During the time Berry et al. (1998) conducted their study in Boulder County, there was a sylvatic plague epidemic that dramatically reduced prairie dog numbers. This reduction in prairie dog abundances may have reduced competition for smaller mammals. This factor, in combination with the lower stature grasslands of prairie dog towns may have attracted hawks to the abandoned towns. When the present study occurred prairie dog populations had rebounded, and prairie dogs may have again been excluding smaller rodents, leaving no reason for a Rough-legged Hawk association with prairie dog towns to persist. Red-tailed Hawks did show an association with prairie dogs at the habitat level, though this was primarily driven by large numbers of prairie dog mounds present in a small fraction of Red-tailed hawk plots (five of 20 plots). Red-tailed Hawk plots that did not include prairie dog towns were 16.07 percent urbanized at the habitat level, a figure well above the same value for Rough-legged Hawks (1.89 percent; Table 1). Thus, it is clear that even in the absence of prairie dogs Red-tailed Hawks associated with urbanized areas to a greater degree than Rough-legged Hawks. Some association between the Red-tailed Hawk and prairie dogs is not surprising, as Red-tailed Hawks have been documented to eat prairie dogs (Cully 1991).

Rough-legged Hawks appear highly sensitive to urban encroachment and land alteration in eastern Boulder County, avoiding not only urban edges but entire landscapes > 4 percent urbanized. This sensitivity likely arises from an innate preference for open spaces where the raptor can hunt on the wing as is its habit on its arctic nesting grounds. In contrast, the Red-tailed Hawk is relatively insensitive to some urban intrusion, and it apparently thrives in the edge habitat created by the urban-grassland interface. While these habitat selection differences do exist, it remains unknown to what extent competitive exclusion may be occurring between these two species. Given the similarity in diets between these hawks, the possibility that Red-tailed Hawks exclude Rough-legged Hawks from urban boundaries or Rough-legged Hawks exclude Red-tailed Hawks from open areas are both plausible explanations for these birds' habitat complimentarity. However, given the morphological and behavioral differences between these birds, it is more likely that differential habitat selection, rather than competition is driving the patterns I observed.

These findings agree with the analyses of the Christmas Bird Count data from eastern Colorado. Rough-legged Hawk abundances have declined across eastern Colorado during the past 20 years, though these declines were statistically significant only in urban areas. The reason for declines in rural areas is unknown. Abundances of Rough-legged Hawks around Boulder declined much more rapidly than in other urbanizing areas. This pattern could be explained by the crossing of a critical threshold (With and Crist 1995) of urbanization, beyond which the Rough-legged Hawk can no longer find landscapes with enough open habitat to persist. Because the Boulder area has several open space agencies working to preserve land, it is possible that these efforts have conserved enough land to allow the Rough-legged Hawk to winter in the Boulder area longer than in other urbanizing areas over the past 20 years. However, growth near Boulder may have finally proceeded to the point beyond which the Rough-legged Hawk can no longer find suitable habitat.

Lande (1987) investigated such extinction thresholds with mathematical models and found that sensitive species are unlikely to persist in landscapes that have undergone as little as 20 percent alteration. Hansen and Urban (1992) noted that a species' life history should be examined in attempting to determine its vulnerability to urbanization and fragmentation processes. Clearly the Rough-legged Hawk's rigidity with regard to habitat selection behaviors places it among species which are sensitive to slight landscape changes. To better understand the impact of small landscape changes, future research should look at effects of low density exurban development and community dynamics along wildland to exurban gradients (Miller et al. 2001).

Future conservation efforts for the Rough-legged Hawk in Boulder County should focus on preserving or restoring broad areas of undeveloped grassland. Such efforts would not only benefit the Rough-legged Hawk, but would also conserve a variety of grassland communities that are increasingly under the threat of destruction through urban expansion.

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Habitat Selection of the Rough-legged Hawk in an Urbanizing Landscape: Boulder, CO
Data Analysis Supplementary Report
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The following are preliminary quantitative results of data analysis on data collected during the winter field season of 1999 – 2000.

Over 20 sightings of 9 individual Rough-legged Hawks were recorded from November 1, 1999 to March 31, 2000. For each sighting data was recorded regarding:

Habitat Characteristics: (Data taken within 200 m diameter of Perch)
Perch Height, Number of Perches over 3 m Tall, m of Riparian Strip, Number of Prairie Dog Mounds, m of Road, m of trail, Area (m^2) of tree cover, Area (m^2) of urbanization (Including structures, yards, sidewalks, etc.), Vegetation height and type (40 samples)

Landscape Characteristics: (Data taken within 1000 m diameter of Perch)
Distance to nearest: House, Road, Trail, Riparian Zone, Prairie Dog Town in 4 directions (N, E, S, W), and approximate area (based off of sketches of the landscape) of: Area of urbanization, road, riparian zone, water, tilled agricultural land, and undisturbed grassland.

Unless noted otherwise, all analyses compared data from Random points in Boulder with data taken from Hawk centered points using One Way ANOVA (Comparison of Means).

Preliminary Results:

Note that P values in RED are significant, P values in **BLUE** are not significant after 1 year of data, but I feel there is likely a trend which will become significant with more data.

Habitat Characteristics:

Perch Height	n	mean	S.D.	P
Hawk Data:	9	12.8 m	2.53 m	.2251
Random Data:	19	9.7 m	1.2 m	

# Perches over 3 m in Height	n	mean	S.D.	P
Hawk Data:	9	14.9	11.13	.2592
Random Data:	19	9.21	11.41	

m Riparian Strip				
	n	mean	S.D.	P
Hawk Data:	9	109.78 m	31.6 m	.0746
Random Data:	19	47.37 m	17.71 m	

# of Prairie Dog Mounds				
	n	mean	S.D.	P
Hawk Data:	9	1	3	.6477
Random Data:	19	.52632	2.29	

m of Road				
	n	mean	S.D.	P
Hawk Data:	9	134.9 m	75.86 m	.6753
Random Data:	19	123.9 m	114.53 m	

m Trail				
	n	mean	S.D.	P
Hawk Data:	9	5.55 m	11.3 m	.0416 *
Random Data:	19	0 m	0 m	

* Note Variances were not Equal for this test… Non-Parametric procedures used.

Area of Tree Cover (m^2)				
	n	mean	S.D.	P
Hawk Data:	9	3062.1 m^2	4167.8 m^2	.4143
Random Data:	19	1784.8 m^2	3631.8 m^2	

Area of Urbanized Cover (m^2)				
	n	mean	S.D.	P
Hawk Data:	9	1605.5 m^2	2009.4 m^2	.35
Random Data:	19	3470.5 m^2	5722.8 m^2	

Vegetation Height (cm)				
	n	mean	S.D.	P
Hawk Data:	5	21.5 cm	14.33 cm	.5439
Random Data:	3	29.6 cm	21.7 cm	

Landscape Characteristics:

Note that several of the following results use a "Relative Proximity Measure." Distances to the nearest object being measured were taken in 8 directions (N, NE, E, SE, S, SW, W, NW) and data recorded. If no object occurred in that direction the number 500 was recorded. Each measure was then converted using:

$$\text{Relative Proximity Measure} = 1 - \frac{\text{Measured Value}}{500}$$

Such that objects immediately at the perch site measure a 1 (Close to Perch) and objects at 500 measure a 0 (Or not Present). This measure was useful because it avoids results which would indicate that objects exist at 500 m, even if there are none. The Relative Proximity Measures were then analyzed using standard ANOVA.

Relative Proximity Measure to Urban Area				
	n	mean	S.D.	P
Hawk Data:	9	.156624	.122120	.3373
Random Data:	19	.219053	.17324	

Relative Proximity Measure to Road				
	n	mean	S.D.	P
Hawk Data:	9	.397807	.187432	.5506
Random Data:	19	.351039	.192733	

Relative Proximity Measure to Trail				
	n	mean	S.D.	P
Hawk Data:	9	.017002	.026623	.0103 *
Random Data:	19	0	0	

* Note Variances were not Equal for this test… Non-Parametric procedures used.

Relative Proximity Measure to Riparian Zone				
	n	mean	S.D.	P
Hawk Data:	9	.429103	.343803	.1135
Random Data:	19	.220421	.301145	

Relative Proximity Measure to Prairie Dog Town				
	n	mean	S.D.	P
Hawk Data:	9	.039750	.107092	.5766
Random Data:	19	.073118	.160044	

Area of Urbanization				
	n	mean	S.D.	P
Hawk Data:	9	58439 m^2	20354 m^2	.0161
Random Data:	19	176832 m^2	29927 m^2	

Area of Road				
	n	mean	S.D.	P
Hawk Data:	9	20687 m^2	6896 m^2	.2842
Random Data:	19	30984 m^2	7108 m^2	

Area of Riparian Zone				
	n	mean	S.D.	P
Hawk Data:	9	40994 m^2	32551 m^2	.9386
Random Data:	19	38837 m^2	79431 m^2	

Area of Water				
	n	mean	S.D.	P
Hawk Data:	9	46228 m^2	64904 m^2	.0713
Random Data:	19	10329 m^2	36638 m^2	

Area of Tilled Agricultural Land				
	n	mean	S.D.	P
Hawk Data:	9	0 m^2	0 m^2	.0694 *
Random Data:	19	138408 m^2	235837 m^2	

* Note Variances were not Equal for this test… Non-Parametric procedures used.

Area of Grassland				
	n	mean	S.D.	P
Hawk Data:	9	550372 m^2	40715 m^2	.0263
Random Data:	19	359447 m^2	51986 m^2	

Summary of Results to Date:

Differences Found between Random and Hawk Data at Habitat Level:

- Significantly more meters of Trail exist in Hawk centered points. This is likely a function of the hawk preferring areas with less development, and trail construction also corresponding to similar patterns.

- Though not significant, there seems to be a trend for an association between the hawk and greater amount of riparian areas at the habitat scale. This may be a result of the bird preferring riparian areas (and especially cottonwood trees) to perch.

Differences Found Between Random and Hawk Data at Landscape Scale:

- Hawks were associated with significantly less urbanized landscape cover than were random points.
- Hawks were associated with significantly more undisturbed grasslands than were random points.
- Hawks were found significantly closer to trails than were random points. Again, this is likely a function of the hawk preferring areas with less development, and trail construction also corresponding to similar patterns.

- Though not significant, there seems to be a trend for Hawks to be found closer to riparian areas at a landscape level than random.
- Additionally, there seems to be a trend (though not yet significant) for hawks to be found in areas near water more often than random points.
- Finally, there may also be a trend for hawks to avoid tilled agricultural land when compared to random points, presumably due to a lack of food in such areas.

Prospects for Future Data:

It is important to keep in mind that the results herein are presented as a work in progress, and represent only the initial season of this study. Thus far during the second field season Rough-legged Hawk sightings are up from last year (15 confirmed individuals) and several weeks still remain in the field season. I feel confident that the data presented herein clearly indicates a pattern in this bird's habitat selection, and it is likely that with greater sample size I will be able to better distinguish between Hawk and Random points based on several of the variables I am looking at.