BIODIVERSITY OF OPEN SPACE GRASSLANDS AT A SUBURBAN/AGRICULTURAL INTERFACE

PART III

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

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Abstract: We conducted point counts of diurnal raptors on Boulder, Colorado, Open Space grasslands for three winters and three summers (1993-1996), and compared results to landscape features of the count areas. Four species were particularly 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 (*Buteo 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*). Historical records suggest that Bald Eagles and Ferruginous Hawks have increased over the past century in the Boulder Valley, perhaps because of reduced human persecution of their prairie dog prey. Three species were more abundant on plots dominated by lowland hayfields and tallgrass prairies, as opposed to upland mixed and shortgrass prairies: Swainson's Hawk (*Buteo swainsoni*), Red-tailed Hawk (*Buteo jamaicensis*), and American Kestrel (*Falco sparverius*). The Red-tailed Hawk was the most abundant raptor in the study area. Its numbers were negatively correlated with urbanization in the count areas, but in a linear rather than a threshold fashion. We conclude that urbanization represented simple habitat loss to this adaptable species, whereas even small amounts of urbanization usually rendered whole landscapes unacceptable to Bald Eagles, Ferruginous Hawks, Rough-legged Hawks, and Prairie Falcons.

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

INTRODUCTION

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.

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 (e.g., Marion and Ryder 1975, Schmutz et al. 1980, Woffinden and Murphy 1983, Janes 1985, Preston 1990). Urban and suburban 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).

There is increasing evidence that abundances of animal populations can be influenced by the landscape setting and spatial arrangement of their habitats, especially in places where these habitats are fragmented by human activities (Soulé 1986, Hansen and di Castri 1992, Andren 1994, Wiens 1995). This should be the case particularly for birds of prey, given their low densities, large home ranges, and the resulting scale at which they operate. Conservation of most raptorial birds therefore could benefit from

landscape approaches to both analysis and management of their habitats (e.g., Olendorff 1984).

Most studies of the responses of terrestrial vertebrates to habitat fragmentation have focused on forests and woodlands (Andren 1994, Robinson et al. 1995). Relatively little is known about the impacts of fragmentation on grassland communities (but see Herkert 1994, Vickery et al. 1994). The city of Boulder, Colorado, owns and manages over 10,000 ha of Open Space (City of Boulder 1995; Fig. 1), the majority of which is grassland. It is the largest per capita municipally-owned greenbelt system in the United States (J. Crain, pers. comm.). To the west of the city, Boulder Open Space includes coniferous forests and shrublands at the base of the Front Range of the Rocky Mountains (Fig. 1). However, most parcels of Boulder Open Space include short, mixed, and tallgrass prairies and hayfields around its northern, eastern, and southern perimeters, where the present study took place.

Boulder Open Space grasslands do not exist as isolated patches embedded in urban landscapes, but as part of a belt of largely agricultural and grazing land enclosing the city. Therefore, metrics derived from island biogeographic theory and frequently applied to fragmented mainland habitats , namely patch size and isolation (e.g., Bolger et al. 1997), cannot be applied readily to Boulder Open Space. While 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 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 34 600-m diameter plots in Boulder Open Space that differed in terms of 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, mixed and shortgrass prairies on upland slopes and benches, all against a montane backdrop of saxicoline shrublands and 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, while colonies of black-tailed prairie dogs (*Cynomys ludovicianus*) were scattered through upland grasslands (personal observations).

In the fall of 1993, we established 66 sampling points spaced widely across Boulder Open Space, and placed to include replicates of the various grassland habitats and the maximum available range of

urban landscape settings. We used these points to conduct fixed-distance counts of songbirds as well as raptors, and initially intended each count circle to be 200-m in diameter (Bock et al. 1995). However, numbers of raptors detected at this scale were too few for meaningful analyses. Therefore, we expanded the count circles for raptors to 600-m in diameter. At this scale, many pairs of plots overlapped or were too close to be considered independent. To address this problem, the 66 points were pooled into 34 non-overlapping study plots, each separated by at least 500-m, and each including one (n = 9), two (n = 20), three (n = 3), or four (n = 2) of the original 66 sampling points. A single value was computed for each raptor and each landscape variable on each of the 34 study plots, by averaging when necessary, so that n = 34 for all of our analyses. We averaged landscape data, rather than re-calculating new landscape measures for the 34 study plots, in order to hold spatial sampling scale constant around each raptor count point, regardless of how many points were included in each plot.

POINT COUNTS

We counted raptors between November and March for the winters of 1993-1994, 1994-1995, and 1995-1996, completing four ten-minute 300-m radius fixed-distance point counts (Ralph et al., 1995) per year at each of the 66 points. Breeding season raptors were counted between late May and mid-July, with four counts in 1994 and three each in 1995 and 1996. Total field sampling time over the 22 counts on the 66 plots was 242 hr.

We divided the number of raptor observations per pooled plot by the number of counts conducted, to yield detections per count as a metric of relative abundance among plots. For species present exclusively or predominantly within a single season (winter or summer), we only included counts from the appropriate season. Certain raptors (e.g., Bald Eagle) doubtless were detectable at greater distances than others (e.g., American Kestrel). However, we used count data only for intra-specific comparisons. Observability was similar at all 66 points, because each was centered in an open grassland landscape.

LANDSCAPE DESCRIPTION

We defined the landscape study area to include grasslands that are part of City 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 georectified in State Plane coordinate system (GRS 1980, Zone -501/3451, North American Datum 83), and re-sampled to 90 x 90-ft 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 on ground truth information from the 66 bird count points, our general familiarity with the study area, and review by employees of the Boulder Open Space Department.

Locations of the 66 sampling points were determined with Global Positioning Systems. We then described the rectangular landscape setting of each point at the scale of 23 x 23 cells (appr. 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.

We also described larger landscapes centered on count points (up to 420 ha), with the goal of determining whether landscape features at larger scales affected raptor counts, perhaps independent of features of the count plots themselves. However, percentage compositions of the larger landscapes were so highly positively correlated with those at the 40-ha scale, including amounts of urbanization, that we were unable to test for scale effects (Wiens 1989).

Prairie dog towns in the study area were digitized by the City of 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(Table 1), 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 on post-plague distributions in 1996, which approximated the conditions during the majority of our study.

STATISTICAL ANALYSES

We compared raptor detections per count with landscape variables on each of the 34 study plots using the Spearman rank correlation coefficient ($P < 0.05$).

RESULTS

On average, 91.3% of the 40-ha landscape rectangle enclosing each count point consisted of three habitats: urban development, upland grasslands, and lowland grasslands (Table 1). The urban category included both developed areas (pavement, buildings) and urban vegetation. Upland grasslands dominated 17 of the 34 plots, and included several categories of short and mixed-grass prairie (Bennett 1997). Lowland grasslands were the most abundant habitat on the remaining 17 plots, and included both tallgrass prairies and hayfields, which were not readily distinguishable using the Landsat data.

We counted 465 diurnal raptors of eleven species during the three winter and three summer seasons (Table 2). Counts of seven species were significantly correlated with at least one landscape variable (Table 3).

Bald Eagles were detected only in winter, usually in areas with little urban habitat (Fig. 2), and most frequently on plots near prairie dog towns (Fig. 3). Their avoidance of urban landscapes was particularly striking, as only 1 of 15 plots where this species occurred included >5% urban environments.

We counted Swainson's Hawks only in summer, and then only 15 times on 10 plots. Their numbers were uncorrelated with

urbanization, and positively correlated with % lowland grasslands (Fig. 4).

The Red-tailed Hawk was present year-round, was the most frequently-counted species in winter (Table 2), and occurred on 26 of 34 plots. Detections were much more common in landscapes dominated by lowland grasslands (Table 3, Fig. 4). Across all plots, Red-tailed Hawk numbers were uncorrelated with urbanization. However, there was a significant negative correlation between Red-tailed Hawk detections and urbanization among the 17 plots dominated by lowland grasslands, where this species was most abundant (Table 3, Fig. 2).

Both Ferruginous and Rough-legged Hawks were present almost exclusively in winter, and, like Bald Eagles, they avoided urbanized landscapes and aggregated near prairie dog towns (Table 3, Figs. 2 and 3). Also like the Bald Eagle, these hawks appeared to have a low threshold of tolerance for amount of urban landscape in the count circles. 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 than the Bald Eagle, Rough-legged Hawk, or Prairie Falcon.

The American Kestrel was common year-round (Table 2), and occurred on 26 plots. Its numbers were uncorrelated with the amount of urban habitat (Table 3, Fig. 2), and positively correlated with the percentage of lowland tallgrass prairies and hayfields in the landscape (Fig. 4).

The Prairie Falcon was seen only twice in three summers. The 11 winter detections were negatively correlated with % urbanization (Table 3), and this species was never seen on a plot that was >5% urbanized (Fig. 2).

Counts of Turkey Vultures, Northern Harriers, Golden Eagles, and Merlins were not significantly correlated with any environmental variables.

DISCUSSION

EFFECTS OF URBANIZATION

Diurnal birds of prey responded in three distinctly different ways to urban development in the Boulder Valley. First, there were raptors that appeared indifferent to the presence of urban and suburban landscapes, at least to the degree they occurred on our study plots (up to 30% of the count circles). The species most clearly fitting this category was the American Kestrel, one of the most abundant raptors in our study area. 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).

Other species whose counts were not correlated with landscape urbanization were the Turkey Vulture, Northern Harrier, Swainson's Hawk, and Golden Eagle. We are unwilling to conclude that these species were insensitive to urban development, for two reasons. First, the lack of significant correlations could be artifacts of relatively small numbers of detections overall, and second, other studies suggest at least some of these species may be negatively

affected by urbanization elsewhere (Horak 1986, England et al. 1995).

The second pattern of response to urban landscapes is illustrated by the Red-tailed Hawk. This abundant species, along with the Swainson's Hawk, usually hunted over lowland hayfields, where the most abundant prey was the prairie vole (*Microtus ochrogaster*; personal observation), where mowed vegetation probably made prey conspicuous, and where nearby riparian woodlands provided both nest and perch sites (see Preston 1990, and England et al. 1997). In these landscapes, counts of Red-tailed Hawks were negatively correlated with urbanization, but in an essentially linear fashion (Figure 2). We interpret this to mean that urbanization represented simple habitat loss to Red-tailed Hawks, rather than any particular intolerance for the proximity of urban landscapes. Interestingly, we rarely observed Red-tailed Hawks in upland grasslands, except in the least urbanized of our plots (Fig. 2). This suggests that the Red-tailed Hawk may be more tolerant of urban development near high-quality habitats (as suggested by Preston and Beane 1996), but such a hypothesis clearly requires additional testing. Overall, our data are consistent with a variety of studies of Red-tailed Hawks documenting their abundance in heterogeneous rural and agricultural landscapes across much of North America (Bock and Lepthien 1976, Preston and Beane 1993).

Finally, there were those species that appeared generally intolerant of even small amounts of urban development in our study area: the Bald Eagle, Rough-legged Hawk, Prairie Falcon, and, perhaps to a lesser degree, the Ferruginous Hawk. For these raptors, it seems

clear that urbanization represented a critical landscape threshold or "transition range" (Turner and Gardner 1991, With and Crist 1995), whose upper bound may have been as little as 5-7%. Below this range of urbanization, counts were highly variable (Fig. 2). These patterns are consistent with the hypothesis that urbanization represented a limiting factor to abundances of these species (Terrell et al. 1996, Schroeder and Vangilder 1997).

There have been few other 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 through a 40-yr 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 (Sodhia et al. 1993).

Smallwood et al. (1996) found that accipitrine 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; Plimpton 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. Ferruginous Hawks declined on Boulder Open Space following a plague outbreak among prairie dogs in 1994, as they have in the past (Jones 1989).

Bald Eagles avoided urban landscapes in the Boulder Valley, and have been found to be highly 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 explains its avoidance of the generally-wooded urban landscapes in the Boulder Valley (Fig. 2).

Our study was designed to reveal patterns of raptor habitat use in relation to urbanization, and we can only speculate about the causal relationships behind those patterns. Raptors have proven sensitive to human disturbance in a variety of circumstances (Knight and Knight 1984, Knight and Gutzwiller 1995, Preston and Beane 1996, 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 further research.

HISTORICAL CHANGES

Early published descriptions of the birds of Boulder County were little more than annotated checklists (Henderson 1909, Betts 1913). Nevertheless, it is interesting to compare the current status of raptors on Boulder Open Space with descriptions of their occurrence in the same region nearly a century ago.

With the exception of the Peregrine Falcon (*Falco peregrinus*), which apparently has always been scarce in Boulder County, we found all species of diurnal raptors that have been associated with grasslands of the Boulder Valley since the early 1900's. In this sense, Boulder Open Space clearly serves as a valued biodiversity reserve, since by now the whole place would be covered in suburban sprawl were it not for this effort. Indeed, comparison of our results with the early accounts suggests that contemporary open space grasslands may support more of certain raptors, especially in winter, than they once did.

Henderson, Betts, and more recently Alexander (1937) all described the Bald Eagle as a rare transient in Boulder County, and the Ferruginous Hawk as rare or absent in winter. By contrast, we found both species to be frequent winter residents, as have others in recent decades (Jones 1989). An explanation may lie in these

species' dependence upon black-tailed prairie dogs as winter prey (Jones 1989, Manci 1992, Bechard & Schmutz 1995, Preston and Beane 1996). While prairie dogs were present in the Boulder Valley a century ago (Armstrong 1972), 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 1900's (Miller et al. 1994).

The Rough-legged Hawk has long been a common winter resident of Boulder Valley grasslands (Betts 1913), as it was in our study in non-urbanized landscapes. This species is not known as a prairie dog predator, and its association with the vicinity of prairie dog towns (Fig. 3), while less striking than that of the Bald Eagle or Ferruginous Hawk, is puzzling. One possibility is that Rough-legged Hawks may have preferred to hunt prairie dog towns because other prey were more conspicuous in the sparse vegetation around prairie dog burrows. We also frequently observed Rough-legged Hawks hunting lowland hayfields that had been mowed.

Red-tailed Hawks and American Kestrels were common breeding birds in the Boulder Valley in the early 1900's, but apparently were uncommon in winter (Henderson 1909, Betts 1913). Today, both are common winter residents, and our winter counts exceeded summer counts for both species (Table 2). The reasons for these winter season increases are unclear. One possible explanation is that changing agricultural practices (e.g., more irrigated hayfields) may

have increased availability of winter-active prey such as voles and deer mice (*Peromyscus maniculatus*).

Finally, abundances of Northern Harriers may have declined in the Boulder Valley over the past century. Betts (1913) described the harrier as "common on the plains," while Alexander (1937) considered it an "infrequent to common summer resident." We counted only one harrier in summer on Boulder Open Space, and found it on only 12 of 34 plots in winter. Loss of wetlands likely has contributed to the decline of the Northern Harrier in the Boulder Valley, as it has elsewhere (MacWhirter and Bildstein 1996).

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, especially any remaining larger areas with little urban or suburban development. Our study should be replicated elsewhere, to determine if the apparent critical landscape threshold of 5-7% urbanization is generally true, and to search for possible causes of this relationship.

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Figure Legends

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.

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

FIGURE 3. Detections per point count of three raptor species in relation to distance to the nearest prairie dog town from the center points of 34 study plots in the Boulder Valley.

FIGURE 4. Detections per point count of three raptor species in relation to lowland grasslands as percent of the landscape on 34 study plots in the Boulder Valley.

Fig. 1

Berry

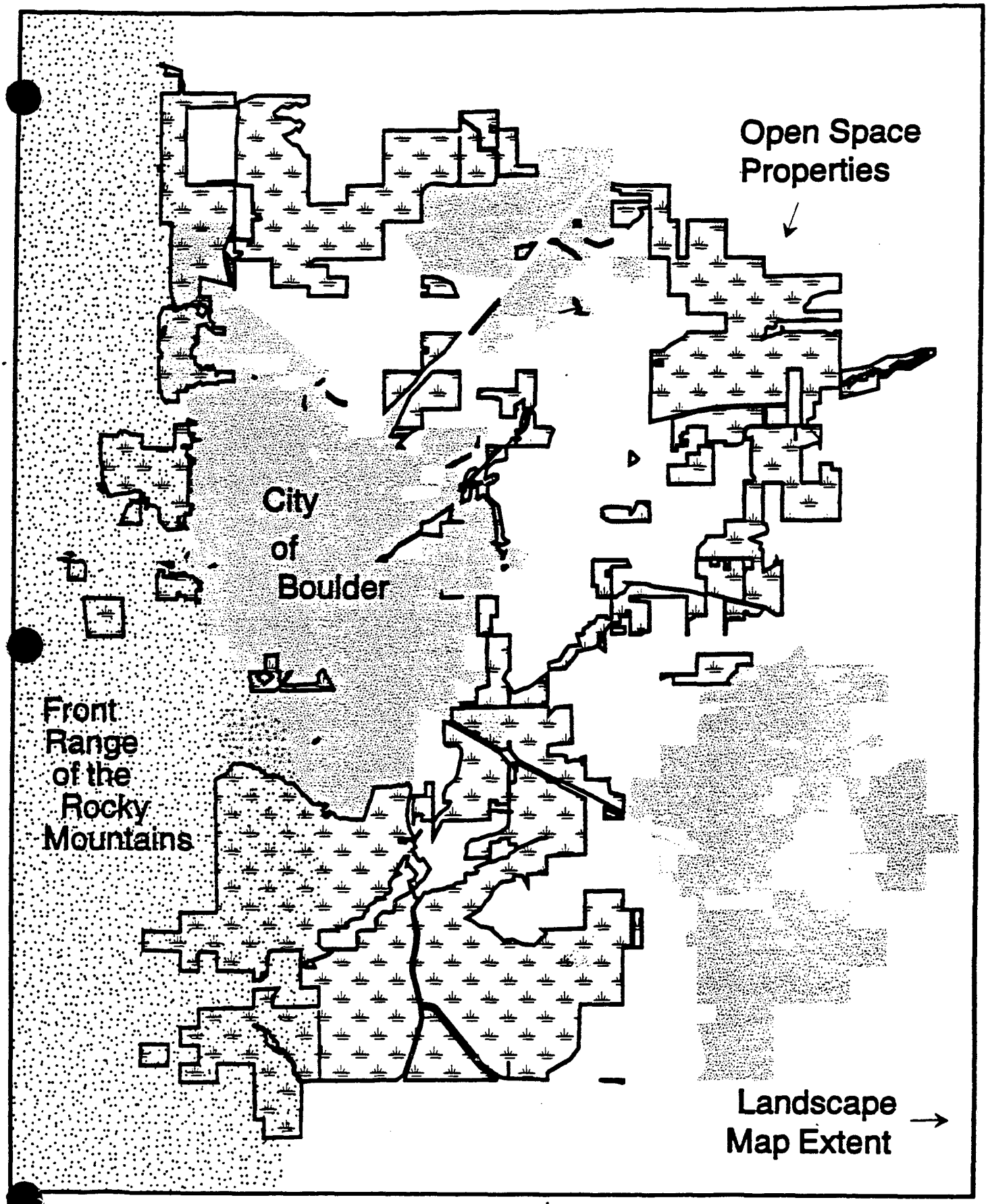
Open Space Properties
City of Boulder
Front Range of the Rocky Mountains
Landscape Map Extent
KILOMETERS
1 0 1 2 3 4 5 6
1 0 1 2 3 4
MILES
Colorado

Fig. 2a

Benny

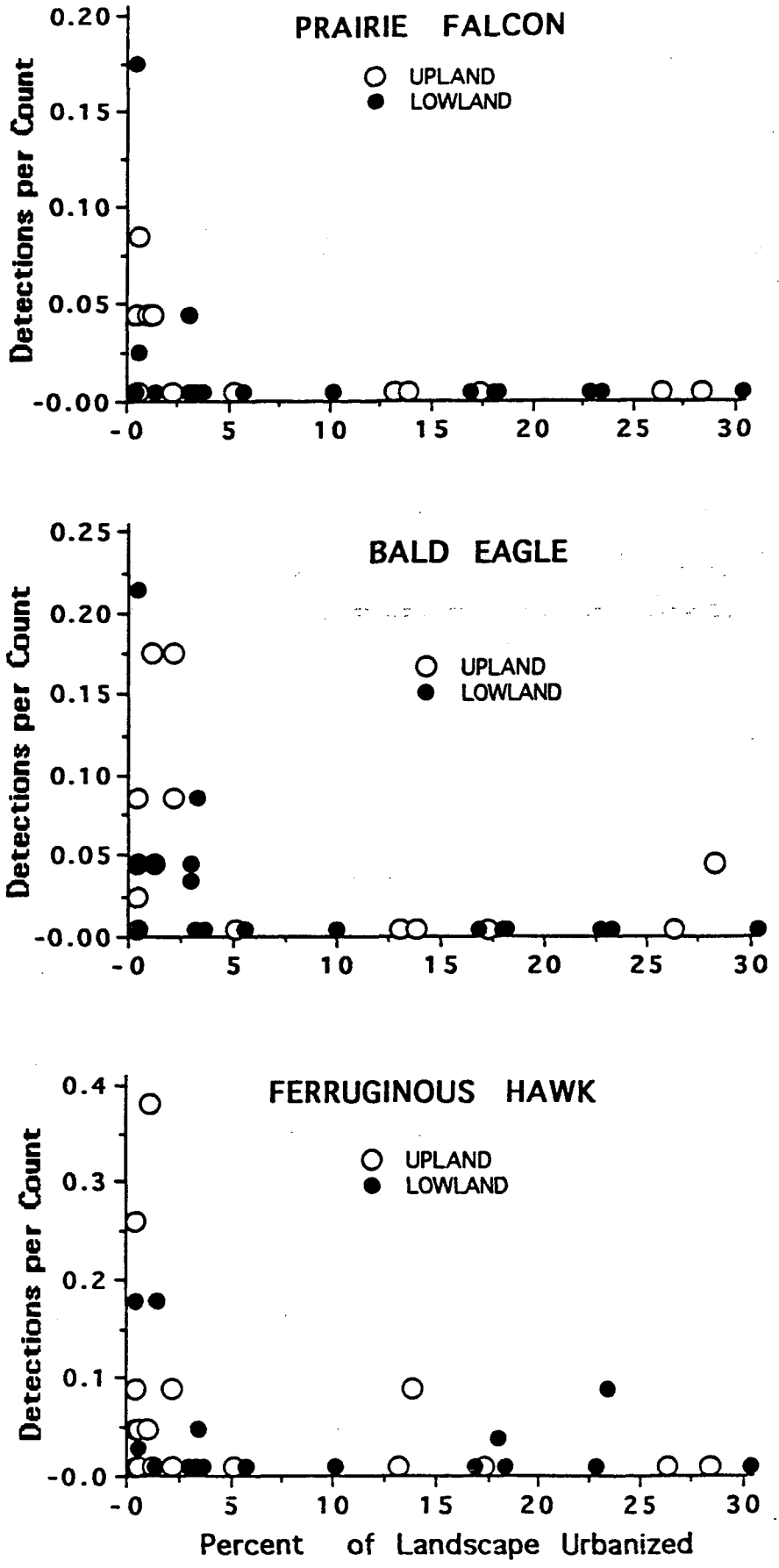
PRAIRIE FALCON
UPLAND
LOWLAND
Detections per Count
0.20
0.15
0.10
0.05
-0.00
-0 5 10 15 20 25 30
BALD EAGLE
UPLAND
LOWLAND
Detections per Count
0.25
0.20
0.15
0.10
0.05
-0.00
-0 5 10 15 20 25 30
FERRUGINOUS HAWK
UPLAND
LOWLAND
Detections per Count
0.4
0.3
0.2
0.1
-0.0
-0 5 10 15 20 25 30
Percent of Landscape Urbanized

Fig. 2b

Berry

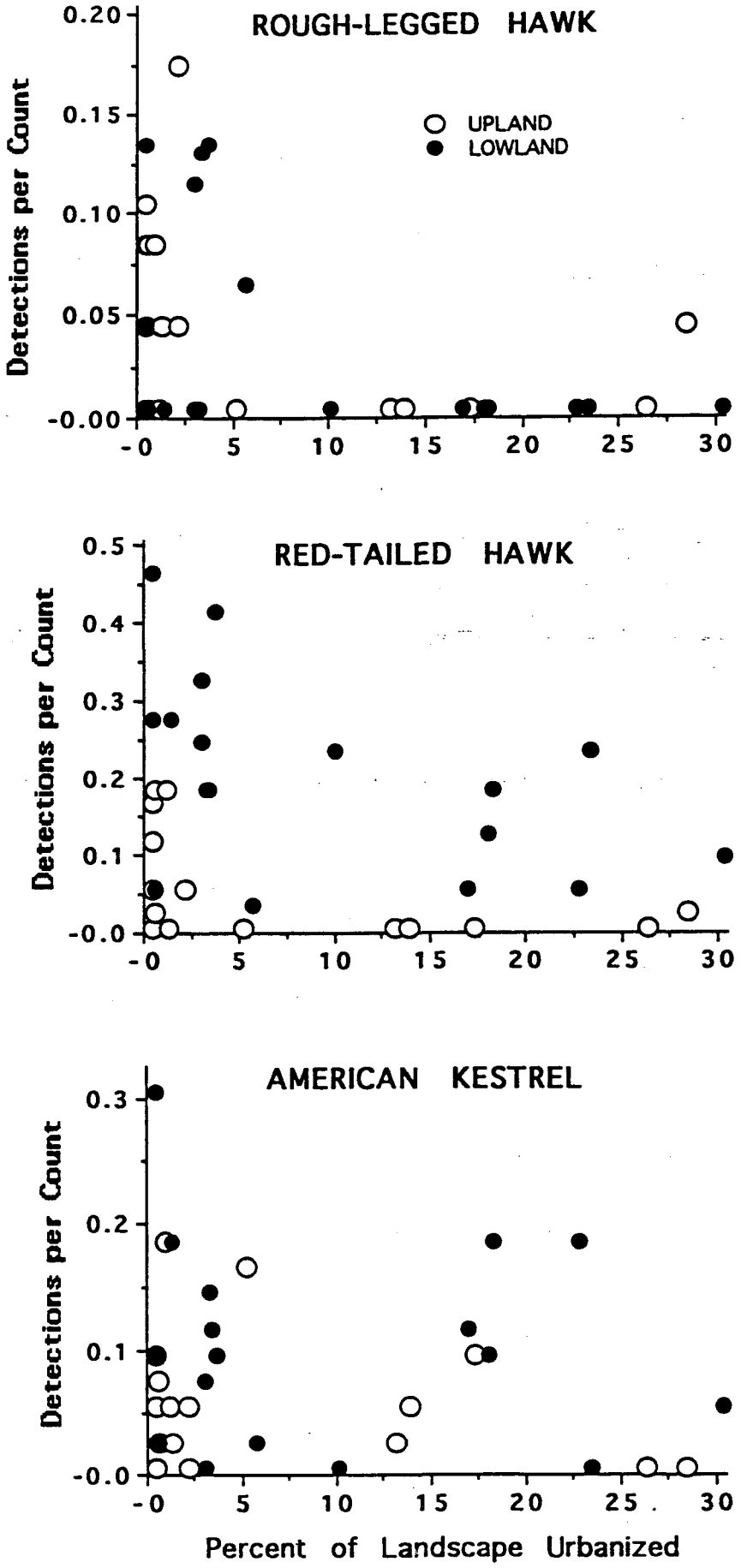
ROUGH-LEGGED HAWK
UPLAND
LOWLAND
Detections per Count
0.20
0.15
0.10
0.05
-0.00
-0 5 10 15 20 25 30
RED-TAILED HAWK
Detections per Count
0.5
0.4
0.3
0.2
0.1
-0.0
-0 5 10 15 20 25 30
AMERICAN KESTREL
Detections per Count
0.3
0.2
0.1
-0.0
-0 5 10 15 20 25 30
Percent of Landscape Urbanized

Fig. 3

Beny

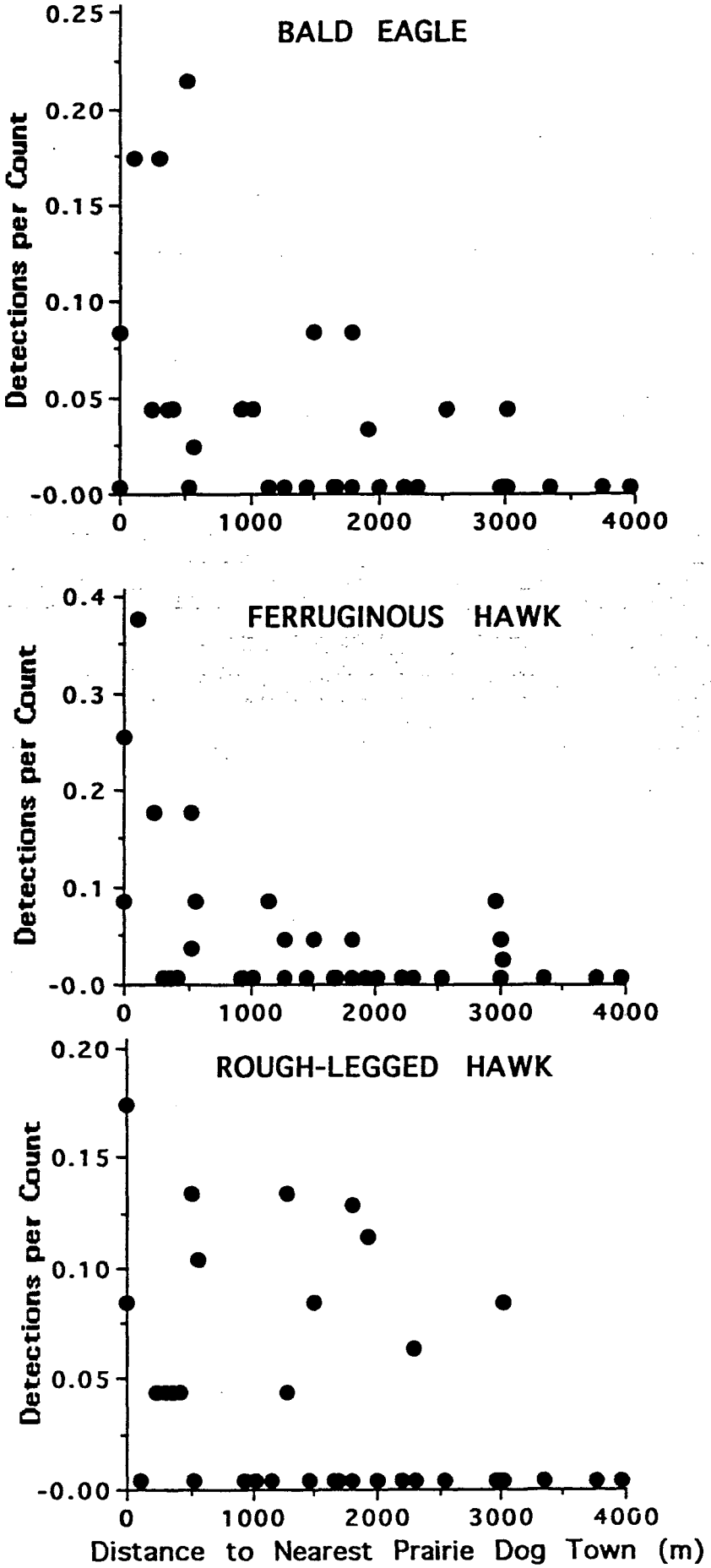
BALD EAGLE
Detections per Count
0.25
0.20
0.15
0.10
0.05
-0.00
0
1000
2000
3000
4000
FERRUGINOUS HAWK
Detections per Count
0.4
0.3
0.2
0.1
-0.0
0
1000
2000
3000
4000
ROUGH-LEGGED HAWK
Detections per Count
0.20
0.15
0.10
0.05
-0.00
0
1000
2000
3000
4000
Distance to Nearest Prairie Dog Town (m)

Fig. 4

Berry

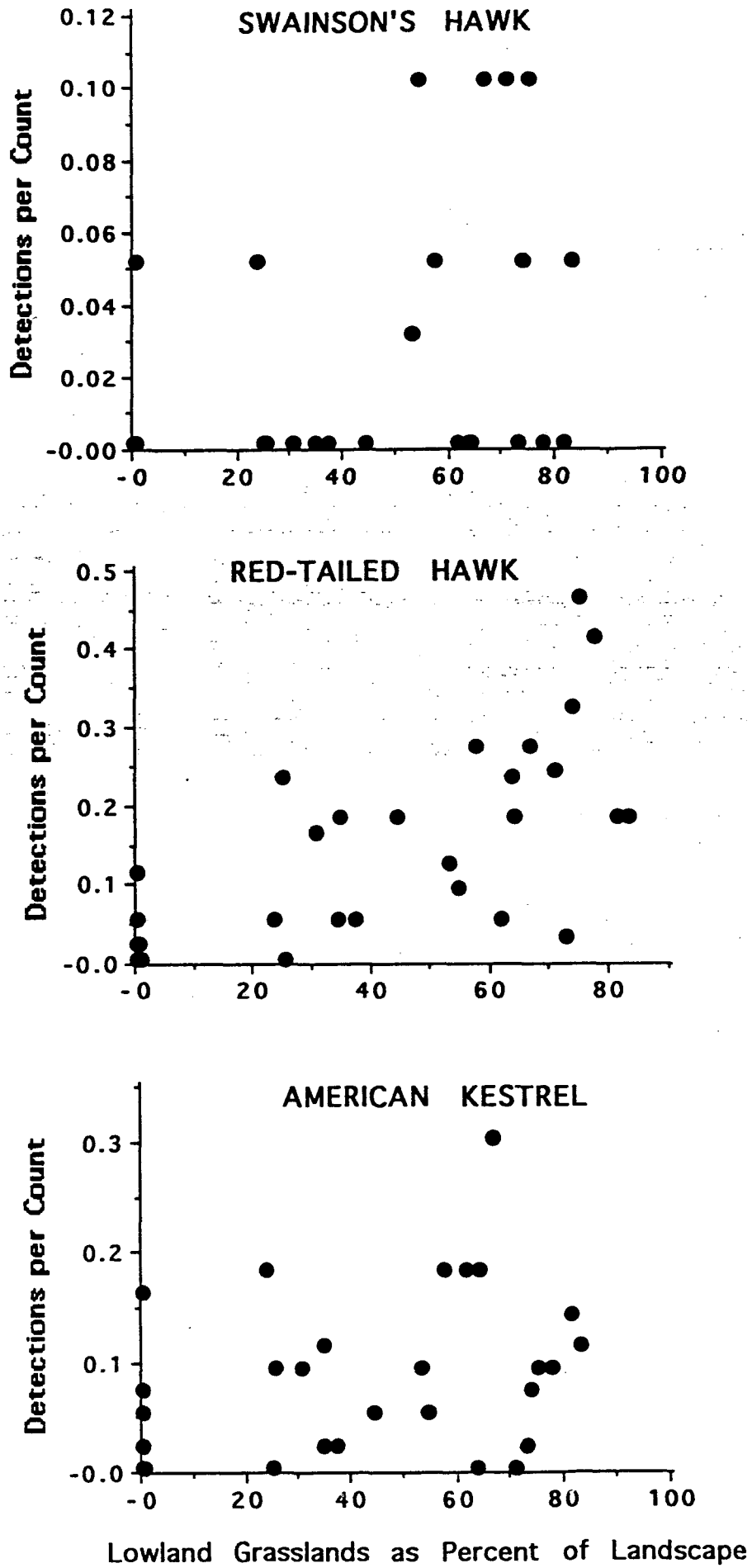
SWAINSON'S HAWK
Detections per Count
0.12
0.10
0.08
0.06
0.04
0.02
-0.00
-0
20
40
60
80
100
RED-TAILED HAWK
Detections per Count
0.5
0.4
0.3
0.2
0.1
-0.0
-0
20
40
60
80
AMERICAN KESTREL
Detections per Count
0.3
0.2
0.1
-0.0
-0
20
40
60
80
100
Lowland Grasslands as Percent of Landscape

TABLE 1. Environmental variables quantified on 34 study plots used in analyses of raptor abundance on Boulder Open Space.

Variable	Mean	Standard Deviation	Range
Percent urban development	7.7	9.6	0 - 29.9
Percent upland grassland	48.2	32.3	4.9 - 94.1
Percent lowland grassland	35.4	30.9	0 - 82.9
Distance to prairie dog town (m)	1,615	1,131	0 - 3,963

TABLE 2. 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*	21
Bald Eagle (*Haliaeetus leucocephalus*)	27	0
Northern Harrier (*Circus cyaneus*)	23	1*
Swainson's Hawk (*Buteo swainsoni*)	0	15
Red-tailed Hawk (*Buteo jamaicensis*)	157	22
Ferruginous Hawk (*Buteo regalis*)	33	1*
Rough-legged Hawk (*Buteo lagopus*)	32	0
Golden Eagle (*Aquila chrysaetos*)	15	4*
American Kestrel (*Falco sparverius*)	61	35
Merlin[1] (*Falco columbarius*)	2	0
Prairie Falcon (*Falco mexicanus*)	11	2*

* Data from this season not used in landscape analysis for this species.

[1] Landscape associations not analyzed, given paucity of data.

TABLE 3. 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.

	Correlation with landscape variable[1]		
Species	% urbanized	% lowland grassland[2]	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[3]			
- all data	-0.15	*0.76*	-0.22
- lowlands only	-0.51		
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

[1] Underlined values statistically significant at the $P < 0.05$ level; underlined and italicized values significant at the $P < 0.01$ level.

[2] Correlations with % upland grassland are not shown, because this variable was strongly correlated with % lowland grassland (Rho = -0.92). The three species positively correlated with % lowland grassland were the only ones signficantly correlated (all negatively) with % uplands.

Table 3 (continued)

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[3] Data for Red-tailed Hawks were analyzed for lowland plots alone (n = 17), because of their association with these habitats, and to test significance of apparent negative relationship to urbanization in lowland landscapes (see Figs. 2 and 3).