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URBAN, SUBURBAN AND RURAL RED-TAILED HAWK NESTING HABITAT AND POPULATIONS IN SOUTHEAST WISCONSIN

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ABSTRACT.—Nesting Red-tailed Hawks (*Buteo jamaicensis*) are becoming increasingly common in urban environments. We described Red-tailed Hawk nesting habitat and reproductive success and compared urban, suburban, and rural nesting locations in southeast Wisconsin. Nest sites were classified as urban, suburban or rural if ≥70%, 30–70%, or ≤30% of the area (706.9 ha, 1.5-km radius) around nests was used for industrial or residential purposes, respectively. Mean success and productivity of breeding Red-tailed Hawks in the metropolitan Milwaukee area from 1989–94 (N = 426) was 81.9% (range = 75.3–92.7%) and 1.43 young/breeding pair (range = 1.13–1.91), respectively. Brood size averaged 1.75 young/successful nest (range = 1.61–2.06). Productivity was variable and was significantly higher in 1994 than each of the preceding yr ($P < 0.001$). Based on internest distances, the density of the Red-tailed Hawk nesting population for rural locations was greater than in suburban areas and lowest in urban locations. The amount of natural microhabitat cover around nests (19.6 ha, 0.25-km radius) did not differ for urban, suburban, or rural nest sites ($P = 0.967$) indicating that cover was an important component of the nesting habitat of Red-tailed Hawks. Natural cover comprised about 16% of the landscape area of urban sites and 40% of this area was wooded with the remaining 60% consisting of herbaceous cover. Urban planning should consider the amount of natural cover to allow Red-tailed Hawks and other wildlife to coexist with humans in an urban environment.

KEY WORDS: *Red-tailed Hawk*; Buteo jamaicensis; *urban*; *suburban*; *rural*; *nesting habitat*; nesting density.

Habitat de anidación urbano, suburbano y rural de *Buteo jamaicensis* en el sureste de Wisconsin

RESUMEN.—La anidación en áreas de *Buteo jamaicensis* es cada vez mas común en ambientes urbanos. Describimos el habitat de anidación de *Buteo jamaicensis* y su éxito reproductivo y comparamos las localidades urbanas, suburbanas y rurales de anidación en el sureste de Wisconsin. Los sitios de los nidos fueron clasificados como urbanos, rurales y suburbanos si ≥70%, ≤30%, y 30–70% del área (706.9 ha, 1.5 km de radio) alrededor del nido eran utilizadas para propósitos industrial o residencial (desarrollo) respectivamenmte. La media del éxito en la productividad de los nidos ocupados por *Buteo jamaicensis* en el área metropolitana de Milwakee entre 1989–94 (N = 426) fue de 81.9% (rango = 75.3–92.7%) y 1.43 juveniles/nido ocupado (rango = 1.13–1.91). Tamaño de la nidada promedio de 1.75 juveniles/nido exitoso (rango = 1.61–2.06). La productividad fue variable y significativamente mas alta en 1994 que en cada uno de los añós precedentes ($p < 0.0001$). Con base en la distancia entre nidos se observo que la densidad de la población reproductiva de las localidades rurales, fue mayor que en las áreas suburbanas y fue menor en áreas urbanas. La cantidad de cobertura de microhabitat natural alrededor de los nidos (19.6 ha, 0.25 km de radio) no fue diferente entre los sitios de los nidos urbanos, suburbanos y rurales ($P = 0.967$) lo cual indica que la cobertura es un componente importante del habitat de anidación de *Buteo jamaicensis.* La cobertura natural incluyo el 16% del microhabitat de los sitios urbanos, 40% de esta área eran bosques y el 60% restante eran cobertura de pastizales. La planeación urbana debe considerar la cantidad de cobertura natural requerida para que *Buteo jamaicensis* y la vida silvestre puedan coexistir con los humanos en un ambiente urbano.

[Traducción de César Márquez]

Red-tailed Hawks (*Buteo jamaicensis*) nest in urban environments, yet no comprehensive studies have been published on their urban nesting habitat. Two reports in Michigan document the successful nesting of red-tails in urban settings (Valentine 1978, Hull 1980), and urban nesting also has been reported in Puerto Rico (Santana et al. 1986) and New York (Minor et al. 1993).

Three studies of rural Red-tailed Hawk populations have previously been conducted in Wisconsin (Orians and Kuhlman 1956, Gates 1972, Petersen 1979). Howell et al. (1978) correlated nesting habitat structure and productivity at rural nest sites in Ohio and found that highly productive sites had more than twice as much fallow land, less than half as much cropland, and less than half the number of woodlots than did sites with low productivity. Other studies of red-tails conducted in rural areas throughout North America have described other aspects of red-tail ecology (e.g., Wiley 1975, Fitch and Bare 1978, Adamcik et al. 1979).

Our objectives were to describe Red-tailed Hawk nesting habitat and reproductive success, and to compare urban, suburban, and rural nesting locations in southeast Wisconsin. We determined relative nesting population densities for all three locations based on internest distances and identified important physical components of the nesting habitat.

STUDY AREA

Our study area covered approximately 1100 km^2 located in the metropolitan Milwaukee area in southeast Wisconsin (43°N, 88°W). It included Milwaukee county and parts of Waukesha, Washington, and Ozaukee counties. Milwaukee and Ozaukee counties are bordered by Lake Michigan to the east. Milwaukee county covers an area of 626.5 km^2. The city of Milwaukee covers an area of 248.5 km^2 with a human population of 629 554 (1994 population estimate; 2533 people per km^2). Human population density decreases radially from the city of Milwaukee to suburban communities and to rural areas. Two interstate highways transect the study area. Land use within the study area included agricultural, natural, industrial/commercial, and residential areas.

METHODS

Red-tailed Hawk nests were located from a vehicle from 1 February–30 April, 1987–94 (Craighead and Craighead 1956) and visited at least twice (once within 10 d after the onset of incubation and again when nestlings were 20–35 d of age) during each nesting season to determine productivity (Postupalsky 1974, Steenhof 1987). Woodlots that were not entirely visible from the road early in the season before leaf-out were checked by foot. A breeding pair (i.e., eggs were laid) was considered successful if ≥1 nestling survived to a bandable age (20–35 d). Intrayear internest distances for 1989 and 1990 were measured to determine the nearest breeding pair of Red-tailed Hawks (nearest neighbor; Clark and Evans 1954). These data were used as an index for population nesting density and to compare urban, suburban, and rural densities (Clark and Evans 1954, McGovern and McNurney 1986). We believe that all nests were found in urban and suburban areas and, therefore, the distances between nests in these locations are accurate.

To describe Red-tailed Hawk nesting habitat and to compare urban, suburban, and rural locations, we characterized features of 1989 and 1990 nest sites on four different spatial scales: 1) nest site, 2) habitat, 3) macrohabitat and 4) landscape (Titus and Mosher 1981, Mosher et al. 1986, 1987, Adamus 1995, Stout 1995; Table 1). The nest-site scale described the nest and nest tree and data were collected when nestlings were 20–35-d old Nest exposure (i.e., the open side of the nest) was assigned one of the following values: total access/exposure, N, NE, E, SE, S, SW, W, or NW. The nest tree was classified as being in a woodlot interior (the tree crown did not touch a woodlot edge), on the edge of an interior woodlot clearing (clearing was ≥0.1 ha), savannah (not on an edge), woodlot edge, hedgerow, lone tree, powerline tower, or billboard.

The habitat scale described vegetation within a 0.04-ha circular plot (11.3 m radius) centered on the nest tree and data were collected after fledging through September for 1989 and 1990 nest sites. Canopy, understory, shrub, ground cover, and slope of the plot were described according to Titus and Mosher (1981) and Mosher et al. (1986, 1987). Shrub structure was classified by shrub density, shrub index and density board (Mosher et al. 1986). Slope and slope aspect were determined for sites with a slope ≥2% using a compass and clinometer.

The landscape scale described land use within a 1.5-km radius (706.9 ha) of the nest tree. Data were collected for 1989 and 1990 nest sites, and used for analysis and nest site classification (i.e., as urban, suburban, or rural). The amount of land with natural, agricultural, residential, and industrial cover types within the landscape area was determined from 1990 aerial photos (1 cm = 48 m) with a compensating polar planimeter. The number of individual areas of each cover type was recorded. Natural habitat included woodlots, tree and shrub savannahs, shrublands, herbaceous cover (grasses and forbs, fallow fields, and inactive pastures), and open water. The mean area of open water was <1% (7 ha; maximum = 6.2%, 43.8 ha) and primarily consisted of pothole ponds and, therefore, was included in the natural category. For management recommendations, natural habitat was subdivided into grassland and forest habitat. Agricultural land included row crops (e.g., corn), cover crops (e.g., alfalfa and clover), actively grazed pastures, tree nurseries and orchards. Residential land included human dwellings and other buildings and land associated with them. Industrial land included nonresidential industrial and commercial buildings, pavement, roads, graded land (e.g , gravel pits), mowed land (e.g., cemeteries, airports, mowed land surrounding industrial buildings), and nonmowed land associated with human activity (e.g., freeway intersections, nonmowed land surrounding industrial buildings). Each area was measured separately and combined for analysis. Industrial and residential areas were considered developed. Natural and agricultural areas were considered undeveloped because they are devoid of any buildings or pavement. A nest site was classified as urban if ≥70% of the landscape area (706.9 ha) was developed, rural if ≤30%, and suburban if 30–70% was developed (Stout et al. 1996). Hedgerow length was measured within the landscape area. The Baxter-Wolfe interspersion index was determined from the changes in cover type along the north-south and east-west median lines within the landscape area (Baxter and Wolfe 1972, Mosher et al. 1987). The area and perimeter of woodlots containing nests were measured. Distances to the nearest residence, industrial building and road were recorded and mean distance to buildings was determined by using a point-quarter method of measuring the distance to the nearest building in each of four quadrants; a buffer area (circular area surrounding the nest without buildings) was calculated by using the mean distance to buildings as the radius of a circle (Stout 1995). The macrohabitat scale described land use within a 0.25 km radius (19.6 ha) of the nest for a comparison of land use patterns closer to the nest site. The same variables that were measured at the landscape scale also were determined at the macrohabitat scale.

Nest-site data were collected for all known breeding pairs of Red-tailed Hawks in the metropolitan Milwaukee area for 1989 and 1990. Nest sites that were used in both 1989 and 1990 (in either the same or a different nest tree or structure) were included in the analysis only once. Macrohabitat and landscape-scale data were collected on all urban sites and at least as many suburban and rural sites. According to our definitions, 15 urban nest sites were found. For the urban, suburban, and rural comparison, 22 suburban and 18 rural nest sites were identified. Nest-site and habitat data were collected for these sites where access (landowner permission) was granted.

Categorical data were tested with a Chi-square goodness of fit. Urban, suburban, and rural nest sites were compared using univariate statistics. Frequency distributions were used to determine variables with normal distributions. Log transformations were used when applicable. Quantitative variables with normal distributions were treated with parametric methods (one-way ANOVA). The TUKEY multiple range test was used to identify different groups. Nonparametric methods (Kruskal-Wallis test, Chi-square approximation; Sokal and Rohlf 1981) were used for nonparametric variables. All tests were considered significant when $P \leq 0.05$. The Statistical Package for the Social Sciences (SPSS; Nie et al. 1975) was used for statistical analyses.

RESULTS

Productivity did not differ among urban, suburban, and rural nest sites used by breeding Red-tailed Hawks (Table 1). Mean nesting success for Red-tailed Hawks in the Milwaukee metropolitan area from 1989–94 ($N = 426$) was 81.9% (range = 75.3–92.7%; Table 2). Productivity of breeding pairs for the same 6-yr period averaged 1.43 young/breeding pair (range = 1.13–1.91), and 1.75 young/successful nest (range = 1.61–2.06). Productivity was significantly higher in 1994 than each of the preceding years ($P < 0.001$). Mean internest distance for urban sites was greater than in suburban and rural sites ($P = 0.004$, $P < 0.001$, respectively), and mean internest distance was greater for suburban than rural sites ($P = 0.018$; Table 1).

In 1989 and 1990, we found 89 breeding Red-tailed Hawks nesting in 18 species of trees. Four were on high voltage transmission towers and one was on a billboard. Nests constructed in trees and on unnatural structures occurred in urban, suburban, and rural areas (Stout 1995, Stout et al. 1996). Only one nest-site variable, nest-tree height, was different for urban, suburban, and rural locations indicating behavioral consistency in nest building (Stout 1995, Table 1). Nest structures were in woodlots or on edges of woodlots more often than in hedgerows, totally exposed lone trees, or human-made structures ($\chi^2 = 23.273$, df = 2, $P < 0.001$). Nests had a northwest exposure more often than other directions ($N = 88$; Fig. 1; $\chi^2 = 35.955$, df = 8, $P < 0.001$). Sloped sites ($N = 41$) were not used more often than nonsloped sites ($N = 38$; $\chi^2 = 0.114$, df = 1, $P = 0.736$). When sloped, red-tails used a southeast slope more often than other directions (Fig. 1; $\chi^2 = 19.293$, df = 7, $P = 0.007$).

At the habitat scale, the percent slope of plots was greater for suburban sites than for rural sites, the number of shrub species at suburban sites was greater than at both urban and rural sites, and the number of small understory saplings (dbh = 1–4 cm) at suburban sites was greater than at rural sites (Table 1).

At the landscape scale, total hedgerow length within the landscape area, mean building distance, buffer area, nearest residence, industrial structure, building, road, the Baxter-Wolfe interspersion index, and the amount of natural, agricultural, industrial and residential land were different for urban, suburban, and rural sites (Table 1). At the macrohabitat scale, agricultural, industrial, and residential land use were different, but the amount of natural cover (total grassland and forest cover) did not differ among the three sites (Table 1). Natural cover within the macrohabitat area averaged 10.3 ha for all three locations while natural habitat within the larger landscape area averaged 111.3 ha

Table 1. Comparison of productivity, nest site, habitat (0.04-ha circular plot, 11.3-m radius), macrohabitat (19.6-ha, 0.25-km radius) and landscape (706.9 ha, 1.5 km radius) for urban, suburban and rural Red-tailed Hawk nest sites. Nest site and habitat results do not include nests on artificial substrates. Productivity, macrohabitat and landscape results include nests on artificial substrates.

Variable	Urban Nest Sites Mean ± SE Range (N)	Suburban Nest Sites Mean ± SE Range (N)	Rural Nest Sites Mean ± SE Range (N)	One-way ANOVA[b] Kruskal-Wallis Test[c] F/χ^2	P
Productivity	1.27 ± 0.25 0–3 (15)	1.50 ± 0.19 0–3 (22)	1.44 ± 0.22 0–3 (18)	0.593[c]	0.744
Nest Site					
Nest tree height (m)	20.09 ± 1.00[x] 14.10–26.30 (11)	23.33 ± 0.67[y] 18.50–28.96 (20)	21.09 ± 0.99[xy] 14.17–28.65 (16)	3.699[b]	0.033
Habitat (0.04-ha circular plot, 11.3-m radius)					
% Slope	2.7 ± 1.75[xy] 0–10 (7)	3.6 ± 0.86[x] 0–16 (21)	1.0 ± 0.46[y] 0–6 (15)	6.076[c]	0.048
No. shrub species	4.6 ± 0.95[x] 1–8 (7)	7.4 ± 0.56[y] 4–12 (21)	4.5 ± 0.84[x] 0–11 (15)	5.640[b]	0.007
No. small saplings	48.3 ± 9.61[xy] 0–78 (7)	72.6 ± 8.67[x] 15–183 (21)	40.9 ± 9.32[y] 0–113 (15)	6.420[c]	0.040
Macrohabitat Area (19.6-ha, 0.25-km radius)					
Grassland (ha)	4.77 ± 1.38 0.0–17.2 (15)	4.37 ± 0.76 0.0–13.3 (22)	4.53 ± 1.34 0.0–18.5 (18)	0.143[c]	0.813
Forest (ha)	4.83 ± 1.19 0.0–13.3 (15)	6.06 ± 0.72 0.0–15.2 (22)	5.91 ± 1.05 0.3–14.1 (18)	1.528[c]	0.466
Natural (ha)	9.76 ± 1.68 0.0–17.7 (15)	10.62 ± 0.97 2.6–18.8 (22)	10.44 ± 1.49 1.3–19.6 (18)	0.067[c]	0.967
Agricultural (ha)	0.17 ± 0.17[x] 0.0–2.6 (15)	3.89 ± 1.05[y] 0.0–15.6 (22)	7.76 ± 1.53[z] 0.0–18.2 (18)	21.171[c]	<0.001
Industrial (ha)	5.24 ± 1.68[x] 0.0–18.9 (15)	3.14 ± 0.96[x] 0.0–16.2 (22)	0.46 ± 0.25[y] 0.0–3.5 (18)	10.263[c]	0.006
Residential (ha)	4.43 ± 1.16[x] 0.7–19.0 (15)	1.96 ± 0.56[y] 0.0–9.1 (22)	0.93 ± 0.45[y] 0.0–6.4 (18)	15.160[c]	0.001
Landscape					
Woodlot area[a] (ha)	9.93 ± 4.19 0.3–45.4 (11)	8.53 ± 1.27 2.5–20.2 (20)	9.39 ± 2.99 0.3–39.5 (15)	0.164[b]	0.850
Woodlot perimeter[a] (m)	1550 ± 403.0 288–3936 (11)	1425 ± 137.0 768–2688 (20)	1715 ± 440.9 307–6816 (15)	0.348[b]	0.708
Mean building dis. (m)	224 ± 17.7[x] 68–341 (15)	322 ± 35.4[y] 79–759 (22)	455 ± 29.9[z] 150–692 (18)	12.607[b]	<0.001
Buffer area[a] (ha)	17.10 ± 2.35[x] 1.5–36.5 (15)	40.89 ± 8.85[x] 2.0–181.0 (22)	62.18 ± 7.27[y] 7.1–127.5 (18)	9.004[b]	<0.001
Nearest residence[a] (m)	117 ± 10.6[x] 30–178 (15)	240 ± 26.1[y] 86–533 (22)	289 ± 34.3[y] 67–571 (18)	11.327[b]	<0.001
Nearest industry[a] (m)	348 ± 69.8[x] 48–1080 (15)	397 ± 72.1[x] 62–1166 (22)	743 ± 97.2[y] 187–1375 (17)	6.915[b]	0.002
Nearest building[a] (m)	106 ± 11.3[x] 30–178 (15)	180 ± 15.0[y] 62–293 (22)	272 ± 33.0[z] 67–571 (18)	12.620[b]	<0.001
Nearest road[a] (m)	114 ± 14.9[x] 24–197 (15)	218 ± 28.5[y] 53–518 (22)	322 ± 48.5[y] 38–878 (18)	8.292[b]	0.001
Mean internest dis.[a] (m)	2743 ± 319.3[x] 1327–4968 (15)	1780 ± 120.9[y] 799–2904 (20)	1316 ± 165.5[z] 403–2246 (15)	11.322[b]	<0.001

Table 1. Continued.

VARIABLE	URBAN NEST SITES MEAN ± SE RANGE (N)	SUBURBAN NEST SITES MEAN ± SE RANGE (N)	RURAL NEST SITES MEAN ± SE RANGE (N)	ONE-WAY ANOVA[b] KRUSKAL-WALLIS TEST[c] F/χ^2	P
Landscape Area (706.9-ya, 1.5-km radius)					
Baxter-Wolfe Index	18.3 ± 1.36[x]	28.8 ± 1.03[y]	26.2 ± 1.26[z]	19.304[b]	<0.001
	8–27 (15)	21–40 (21)	19–37 (18)		
Hedgerow length (m)	7619 ± 1087[x]	10 506 ± 995[xy]	12 053 ± 981[y]	4.258[b]	0.019
	2208–16080 (15)	1920–18 432 (22)	3984–18 720 (18)		
Grassland (ha)	67.20 ± 11.14[x]	137.23 ± 8.57[y]	141.18 ± 22.77[y]	6.707[b]	0.003
	0.0–146.3 (15)	70.0–231.9 (22)	24.7–312.5 (18)		
Forest (ha)	39.30 ± 6.26[x]	77.82 ± 7.56[y]	103.80 ± 9.70[z]	14.007[b]	<0.001
	0.0–94.0 (15)	31.1–178.9 (22)	43.1–187.3 (18)		
Natural (ha)	111.27 ± 13.52[x]	221.07 ± 10.68[y]	253.11 ± 29.22[y]	13.166[b]	<0.001
	16.3–190.2 (15)	123.7–329.4 (22)	81.3–457.4 (18)		
Agricultural (ha)	11.69 ± 4.05[x]	128.05 ± 14.75[y]	309.74 ± 30.76[z]	40.587[c]	<0.001
	0.0–48.8 (15)	20.5–310.3 (22)	108.2–534.4 (18)		
Industrial (ha)	273.85 ± 35.34[x]	180.45 ± 18.94[y]	53.57 ± 9.77[z]	23.117[b]	<0.001
	56.6–499.1 (15)	39.6–354.2 (22)	0.0–123.0 (18)		
Residential[a] (ha)	310.00 ± 31.28[x]	177.27 ± 15.65[y]	90.68 ± 9.60[z]	25.905[b]	<0.001
	153.4–537.2 (15)	21.9–331.5 (22)	25.5–173.2 (18)		

[a] Variables log-transformed for one-way Analysis of Variance (one-way ANOVA).
[b] One-way ANOVA F values.
[c] Kruskal-Wallis test χ^2 values (χ^2 approximation).
[xyz] Values followed by the same superscript letter [x], [y] or [z], are not significantly different at the $P \leq 0.05$ level (TUKEY multiple range test[b] or Mann-Whitney U test[c]).

(15.7%) for urban nest sites only, and this natural habitat was interspersed among developed land in an average of 16.4 different tracts.

DISCUSSION

Reproductive success and productivity of breeding Red-tailed Hawks during our 6-yr study was comparable to that of previous studies in Wisconsin (Orians and Kuhlman 1956, Gates 1972, Peterson 1979; Table 2) and an urban/suburban area in New York (Minor et al. 1993). Red-tailed Hawk nest success estimates for North America range from 58–93% (Preston and Beane 1993).

The distance between breeding pairs of Red-tailed Hawks was used as an index of nesting density (McGovern and McNurney 1986). Our mean internest distance of 1.9 km was comparable to other studies (Fitch et al. 1946, Orians and Kuhlman 1956, Gates 1972, Petersen 1979, McGovern and McNurney 1986). Rural nests were significantly closer together than suburban and urban nests, and suburban nests were closer together than urban nests which indicated that nesting density decreased from rural to urban areas. We found rural nests adjacent to suburban nests at the perimeter of our study area. As a result, the nearest breeding pair of red-tails may not have been found in all rural areas making rural nests even closer than our data indicated. Peterson (1979) found a mean internest distance of 1.51 km in rural Wisconsin. Our mean internest distance of 1.32 km between rural nests may indicate that the density of nesting Red-tailed Hawks may have increased in rural southeast Wisconsin over the past 25 yr, possibly because of increased availability of nesting habitat resulting from changes in agricultural practices such as the conservation reserve program (CRP).

The microclimate surrounding nest structures is important in the selection of nest sites by raptors. We found Red-tailed Hawk nests had predominantly northern exposures (primarily NW and NE) and sloped sites had southeast aspects. Speiser and Bosakowski (1988) also found Red-tailed Hawk nests to have southeast facing slope exposures. They suggested that a southeast slope maximizes insulation to the nest on cold mornings and min-

Table 2. Red-tailed Hawk reproductive success from 1989–94 for the metropolitan Milwaukee, Wisconsin area.

Yr	Breeding Pairs	Nest Failures	Nest Success (%)	Young/Nest			Reproductive Success	
				1	2	3	A[a]	B[b]
1989	59	11	81.4	20	24	4	1.36	1.67
1990	85	21	75.3	19	39	6	1.35	1.80
1991	92	16	82.6	33	40	3	1.33	1.61
1992	83	9	89.2	24	45	5	1.55	1.74
1993	52	16	69.2	16	17	3	1.13	1.64
1994	55	4	92.7	13	22	16	1.91	2.06
Total	426	77	81.9	125	187	37	1.43	1.75

[a] Young/breeding pair.
[b] Young/successful nest.

imizes the possibility of heat stress in the afternoon. Southeast slopes may help to keep nestlings dry by minimizing the effects of predominantly northwest storm winds in Wisconsin while northern nest accesses may provide more shade and reduce heat stress. Several studies also found that nest sites usually have unobstructed access and a commanding view of the surrounding area (Petersen 1979, Bednarz and Dinsmore 1982, Santana et al. 1986, Speiser and Bosakowski 1988, Bechard et al. 1990, Toland 1990, Preston and Beane 1993). Sloped nest sites probably provide this type of nest orientation.

Red-tailed Hawks used similar types of nest sites in urban, suburban, and rural locations, however, suburban nest sites tended to be located on sloped sites and in wetlands, probably because upland sites are developed first. Suburban areas also had the highest land use diversity (Baxter-Wolfe interspersion index) while urban locations had the least amount of land use diversity. Woodlot area and perimeter remained relatively constant for urban,

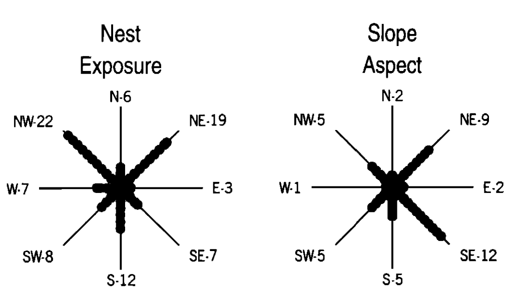

Figure 1. Nest exposure ($N = 84$) and slope aspect ($N = 41$) at Red-tailed Hawk nest sites in southeast Wisconsin. Sample size is indicated for each direction.

suburban, and rural nesting locations indicating that 9 ha may represent an ideal size woodlot for Red-tailed Hawk nesting sites. Other studies have found that red-tails selected smaller woodlots, open stands, and woodlot edges compared to larger woodlots or closed canopy woodlot interiors (Orians and Kuhlman 1956, Gates 1972, Petersen 1979). Speiser and Bosakowski (1988) found that red-tails nested closer to forest openings than random sites and Howell et al. (1978) reported that the most productive pairs of Red-tailed Hawks used small woodlots.

Landscape variables (e.g., nearest road, industry, residence) varied significantly and increased from urban to suburban and rural areas. The amount of natural and agricultural land within the landscape scale decreased as the amount of industrial and residential land increased. While the amount of agricultural land increased and residential and industrial land decreased at the macrohabitat scale from rural through suburban and urban areas, the amount of natural cover within the macrohabitat remained consistent for all three areas averaging 10.3 ha indicating that natural cover constitutes an important nesting habitat component for Red-tailed Hawks.

For the purposes of urban planning and development, we believe that managing for important habitat components such as natural cover will enhance the availability of nesting habitat for Red-tailed Hawks in urban areas. Based on our findings, we recommend that at least 16% of urban land be left in natural habitat with approximately 40% wooded and 60% herbaceous cover. This natural habitat should be distributed among residential and industrial land in approximately 16 separate tracts within the landscape area (706.9 ha). Wooded areas should be approximately 9 ha to provide suitable nesting woodlots.

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LITERATURE CITED

ADAMCIK, R.S., A.W. TODD AND L.B. KEITH. 1979. Demographic and dietary responses of Red-tailed Hawks during a snowshoe hare fluctuation. *Can. Field-Nat.* 93: 16–27.

ADAMUS, P.R. 1995. Validating a habitat evaluation method for predicting avian richness. *Wildl. Soc. Bull.* 23: 743–749.

BAXTER, W.L. AND C.W. WOLFE. 1972. The interspersion index as a technique for evaluation of Bobwhite Quail habitat. Pages 158–165 *in* J.A. Morrison and J.C. Lewis [EDS.], Proc. First Natl. Bobwhite Quail Symp. Okla. State Univ., Res. Found. Stillwater, OK U.S.A.

BECHARD, M.J., R.L. KNIGHT, D.G. SMITH AND R.E. FITZNER. 1990. Nest sites and habitats of sympatric hawks (*Buteo* spp.) in Washington. *J. Field Ornithol.* 61:159–170.

BEDNARZ, J.C. AND J.J. DINSMORE. 1982. Nest sites and habitat of Red-shouldered and Red-tailed Hawks in Iowa. *Wilson Bull.* 94:31–45.

CLARK, P.J. AND F.C. EVANS. 1954. Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology* 35:445–453.

CRAIGHEAD, J.J. AND F.C. CRAIGHEAD. 1956. Hawks owls and wildlife. The Stackpole Co., Harrisburg, PA and Wildlife Manage. Inst., Washington DC U.S.A.

FITCH, H.S., F. SWENSON AND D.F. TILLOTSON. 1946. Behavior and food habits of the Red-tailed Hawk. *Condor* 48:205–257.

——— AND R.O. BARE. 1978. A field study of the Red-tailed Hawk in eastern Kansas. *Trans. Kansas Acad. Sci.* 81:1–13.

GATES, J.M. 1972. Red-tailed Hawk populations and ecology in east-central Wisconsin. *Wilson Bull.* 84:421–433.

HOWELL, J., B. SMITH, J.B. HOLT AND D.R. OSBORNE. 1978. Habitat structure and productivity in the Red-tailed Hawk. *Bird Banding* 49:162–171.

HULL, C.N. 1980. Additional successful nesting of a Red-tailed Hawk in an urban subdivision. *Jack Pine Warbler* 58:30.

MCGOVERN, M. AND J.M. MCNURNEY. 1986. Densities of Red-tailed Hawk nests in aspen stands in the Piceance Basin, Colorado. *J. Raptor Res.* 20:43–45.

MINOR, W.F., M. MINOR AND M.F. INGRALDI. 1993. Nesting of Red-tailed Hawks and Great Horned Owls in a central New York urban/suburban area. *J. Field Ornithol.* 64:433–439.

MOSHER, J.A., K. TITUS AND M.R. FULLER. 1986. Developing a practical model to predict nesting habitat of woodland hawks. Pages 31–35 *in* J. Verner, M.L. Morrison and C.J. Ralph [EDS.], Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Univ. of Wisconsin Press, Madison, WI U.S.A.

———, ——— and ———. 1987. Habitat sampling, measurement and evaluation. Pages 81–97 *in* B.A. Giron Pendleton, B.A. Millsap, K.W. Cline and D.M. Bird [EDS.], Raptor management techniques manual. Nat. Wildl. Fed., Washington, DC U.S.A.

NIE, N.H., C.H. HULL, J.G. JENKINS, K. STEINBRENNER AND D.H. BENT [EDS.]. 1975. Statistical package for the social sciences. McGraw Hill, Inc., New York, NY U.S.A.

ORIANS, G. AND F. KUHLMAN. 1956. Red-tailed Hawk and horned owl populations in Wisconsin. *Condor* 58:371–385.

PETERSON, L. 1979. Ecology of Great Horned Owls and Red-tailed Hawks in southeastern Wisconsin. Wis. Dept. Nat. Res. Tech. Bull. No. 111, Madison, WI U.S.A.

POSTUPALSKY, S. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology. Pages 21–31 *in* F.N. Hamerstrom, B.E. Harrell and R.R. Olendorff [EDS.], Management of raptors. Raptor Res. Rep. 2.

PRESTON, C.R. AND R.D. BEANE. 1993. Red-tailed Hawk (*Buteo jamaicensis*). *In* A. Poole and F. Gill [EDS.], The birds of North America., No. 52. Philadelphia: Acad Nat. Sci.; Am. Ornithol. Union, Washington, DC U.S.A.

SANTANA, E.C., E.N. LABOY, J.A. MOSHER AND S.A. TEMPLE. 1986. Red-tailed Hawk nest sites in Puerto Rico. *Wilson Bull.* 98:561–570.

SOKAL, R.R. AND F.J. ROHLF. 1981. Biometry. W.H. Freeman and Co., New York, NY U.S.A.

SPEISER, R. AND T. BOSAKOWSKI. 1988. Nest site preferences of Red-tailed Hawks in the highlands of southeastern New York and northern New Jersey. *J. Field Ornithol.* 59:361–368.

STEENHOF, K. 1987. Assessing raptor reproductive success and productivity. Pages 157–170 *in* B.A. Giron Pendleton, B.A. Milsap, K.W. Cline, D.M. Bird [EDS.], Raptor management techniques manual. Natl. Wildl. Fed., Washington, DC U.S.A.

STOUT, W.E. 1995. An urban, suburban, rural Red-tailed Hawk nesting habitat comparison in southeast Wisconsin. M.S. thesis, Univ. Wisconsin, Stevens Point, WI U.S.A.

———, R.K. ANDERSON AND J.M. PAPP. 1996. Red-tailed Hawks nesting on man-made and natural structures in southeast Wisconsin. Pages 77–86 *in* D.M. Bird, D.E. Varland and J.J. Negro [EDS.], Raptors in human landscapes. Academic Press, London, U.K.

TITUS, K. AND J.A. MOSHER. 1981. Nest-site habitat selected by woodland hawks in the central Appalachians. *Auk* 98:270–281.

TOLAND, B.R. 1990. Nesting ecology of Red-tailed Hawks in central Missouri. *Trans. Miss. Acad. Sci.* 24:1–16.

VALENTINE, A.E. 1978. The successful nesting of a Red-tailed Hawk in an urban subdivision. *Jack Pine Warbler* 56:209–210.

WILEY, J.W. 1975. Nesting and reproductive success of Red-tailed Hawks and Red-shouldered Hawks in Orange County, California, 1973. *Condor* 77:133–139.

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