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Source: Journal of Raptor Research, 40(3) : 181-192

Published By: Raptor Research Foundation

URL: https://doi.org/10.3356/0892-1016(2006)40[181:LFORHN]2.0.CO;2

THE JOURNAL OF RAPTOR RESEARCH

A QUARTERLY PUBLICATION OF THE RAPTOR RESEARCH FOUNDATION, INC.

VOL. 40 SEPTEMBER 2006 NO. 3

*J. Raptor Res.* 40(3):181–192


# LANDSCAPE FEATURES OF RED-TAILED HAWK NESTING HABITAT IN AN URBAN/SUBURBAN ENVIRONMENT

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ABSTRACT.—We described urban/suburban Red-tailed Hawk (*Buteo jamaicensis*) nesting habitat and compared nesting habitat to unused habitat based on presence and absence of Red-tailed Hawks. We developed a landscape-scale logistic model of nesting habitat occupancy, then applied it to other locations to determine whether unoccupied patches of Red-tailed Hawk nesting habitat existed in urban locations. Red-tailed Hawk nesting habitat in urban/suburban Milwaukee usually included large areas of grassland and other herbaceous cover types. Urban/suburban Red-tailed Hawk nesting habitat was comprised of more than three times as much grasslands and woodlands, and had greater land-cover diversity and patch richness than unused habitat. Characteristics of unused habitat indicated that Red-tailed Hawks avoided areas of heaviest urbanization, perhaps because of insufficient hunting habitat. The logistic regression model developed from our data demonstrated that suitable, unoccupied nesting habitat existed in this urban area. As the Red-tailed Hawk population expanded into urban locations in this study area, the birds apparently were adjusting well to urbanization. Additional studies of urban raptor populations may provide valuable insight into future management considerations for wildlife in human-influenced landscapes.

KEY WORDS: Buteo jamaicensis; *Red-tailed Hawk*; *human-influenced landscapes*; *land-use planning*; *urban/suburban habitat.*

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CARACTERÍSTICAS A ESCALA DE PAISAJE DEL HÁBITAT DE NIDIFICACIÓN DE *BUTEO JAMAICENSIS* EN AMBIENTES URBANOS Y SUBURBANOS

RESUMEN.—Describimos el hábitat de nidificación urbano y suburbano de *Buteo jamaicensis* y comparamos el hábitat de nidificación con ambientes no usados basándonos en la presencia y ausencia de *B. jamaicensis.* Desarrollamos un modelo logístico de ocupación de hábitat de nidificación a escala de paisaje y luego lo aplicamos a otros lugares para determinar si existían parches desocupados de hábitat de nidificación de *B. jamaicensis* en lugares urbanos. Los ambientes de nidificación de *B. jamaicensis* en sitios urbanos y suburbanos de Milwaukee usualmente incluyeron grandes áreas de pastizales y otros tipos de cobertura herbácea. Los ambientes de nidificación de *B. jamaicensis* en sitios urbanos y suburbanos estuvieron conformados por tres veces más de hábitat de pastizal y bosque, y presentaron una mayor diversidad de coberturas y riqueza de parches que los ambientes no usados. Las características de los ambientes no usados indicaron que *B. jamaicensis* evita las áreas más urbanizadas, debido tal vez a la falta de hábitat para cazar. El modelo de regresión logística desarrollado con nuestros datos demostró que existe hábitat adecuado no ocupado en esta área urbana. A medida que las poblaciones de *B. jamaicensis* se expanden hacia lugares urbanos en esta área de estudio, las aves aparentemente se ajustan bien a la urbanización. Estudios adicionales de las

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poblaciones urbanas de rapaces podrían aportar información importante para los planes de manejo de vida silvestre en paisajes con influencia humana.

[Traducción del equipo editorial]

Habitats provide basic resource requirements such as food, cover, and other resources for wildlife. For raptors, including Red-tailed Hawks (*Buteo jamaicensis*), nest-site availability, and prey abundance and availability may be the major habitat components that influence populations (Janes 1984, Preston and Beane 1993, Newton 1998). Although Red-tailed Hawk habitat has been described repeatedly for rural locations throughout North America (Titus and Mosher 1981, Bednarz and Dinsmore 1982, Speiser and Bosakowski 1988), the results of these studies may not be applicable to Red-tailed Hawk habitat in urban locations.

Several raptor studies documented high population densities and survival rates for a number of species in urban locations (Oliphant et al. 1993, Bloom and McCrary 1996, Botelho and Arrowood 1996, Gehlbach 1996, Rosenfield et al. 1996). The Red-tailed Hawk population in southeast Wisconsin has been increasing and expanding into more urbanized landscapes over the past 15 years; evidently, urban landscape characteristics did not adversely affect habitat quality or reproductive success (Stout 2004, Stout et al. 2006). However, these studies did not differentiate between nesting habitat and unused habitat in urban locations. It remains unclear whether landscape-scale habitat features important in rural areas also are important in urban areas, or whether Red-tailed Hawks avoid particular urban landscape features. A better understanding of nesting habitat in urban/suburban locations will provide a basis for determining whether suitable habitat exists in urban areas where Red-tailed Hawks are not present.

We studied an urban/suburban Red-tailed Hawk population in the metropolitan Milwaukee area over a 15-yr period, 1988–2002. The objectives of this study were to describe urban/suburban Red-tailed Hawk nesting habitat, to compare nesting habitat and unused habitat in an urban/suburban landscape, and to determine whether unoccupied patches of Red-tailed Hawk nesting habitat existed in urban locations.

## METHODS

**Study Area.** The Metropolitan Milwaukee Study Area (MMSA) covered 631 km$^2$ in southeast Wisconsin (43° N, 88° W), and included parts of Milwaukee, Waukesha, and Washington counties (Fig. 1). Milwaukee County was bordered on the east by Lake Michigan. Human population density in urban locations within the study area averaged 2399.5/km$^2$; the city of Milwaukee covered an area of 251.0 km$^2$ with a human population of 596 974 (U.S. Census Bureau 2000). Landscape composition included urban and suburban areas. Human population density and land-use intensity decreased radially from the urban center of Milwaukee. Human density in suburban parts of the MMSA was less than 10% of urban density. Interstate 43 and Interstate 94 transect the MMSA.

Curtis (1959) described vegetation, physiography, and soil for the study area. Remnants of historical vegetation that were marginally impacted by development were sparsely scattered throughout the study area; the size and abundance of these remnants increased farther from the urban center (Matthiae and Stearns 1981).

**MMSA Land Cover.** Land cover within the MMSA included agricultural, natural, industrial/commercial, and residential areas. To compare Red-tailed Hawk nesting habitat to unused habitat and to develop a nesting habitat prediction model, we used the Southeast Wisconsin Regional Planning Commission's (SEWRPC) 1995 land-cover data set (SEWRPC 1995). Every five years SEWRPC flew aerial surveys and documented land cover through aerial photography. These aerial photos were produced at a 1:4800 scale, and were digitized into ortho photos and a vector-based GIS land-cover database. The grain of these ortho photos was less than 0.3 m. We used the 1995 SEWRPC data set because it represented land cover from approximately the midpoint of our study. SEWRPC classified land cover into 104 different categories (SEWRPC 2000). For the purposes of this study, we combined the 104 different SEWRPC categories into the following 12 land-cover classes: high-density urban, low-density urban, roads, parking, recreational, graded, cropland, pasture, grassland, woodland, wetland, and water. High-density urban land consisted of land-uses such as medium to high-density residential, commercial, and industrial land-use; low-density urban land consisted of land-uses such as low-density and suburban-density residential, commercial, and industrial land-use; recreational land consisted of land-uses such as city and county parks (excluding wooded areas), golf courses, soccer fields, and baseball parks; graded land consisted of land-uses such as gravel pits and landfills (all as defined by SEWRPC 2000).

**Nest Surveys.** The MMSA was surveyed consistently for Red-tailed Hawk nests during the 15 yr, 1988–2002. We located Red-tailed Hawk nests from a vehicle (Craighead and Craighead 1956) between 1 February and 30 April each year by driving major roads systematically so that we could view all suitable nest substrates before visibility was obscured by foliage. Woodlots that were not entirely visible from the road were checked by researchers on foot. Each nest was visited at least twice during each nesting season (once at an early stage of incubation and again when the young were at an advanced nestling age [average age = 28 d, based on Bechard et al. 1985]) to determine reproductive success (Postupalsky 1974). We followed Newton

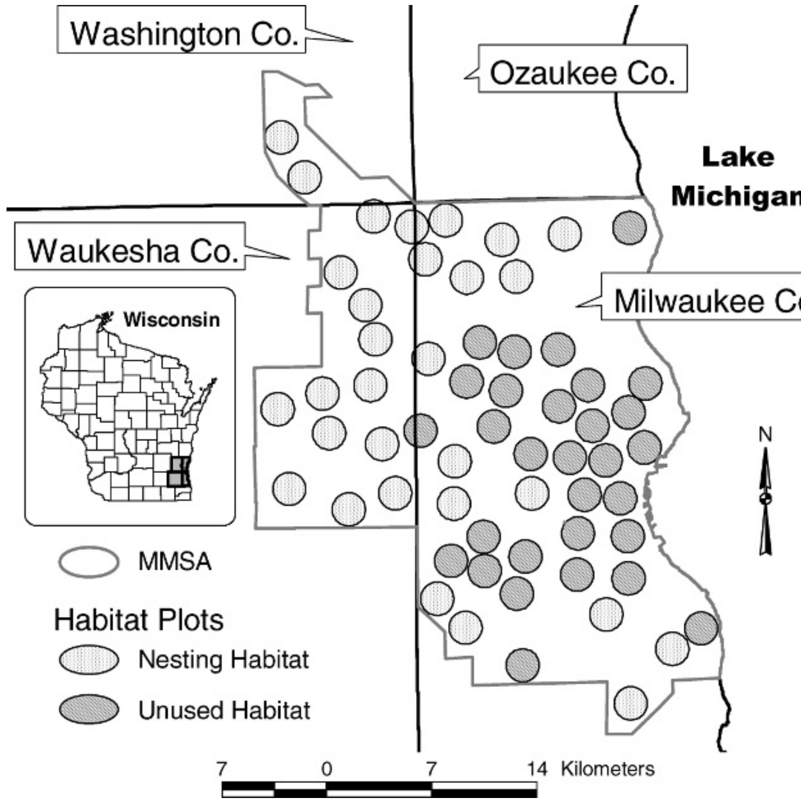


Figure 1. The Metropolitan Milwaukee Study Area (MMSA), and urban/suburban Red-tailed Hawk nesting habitat and unused habitat. Nesting habitat was defined as habitat where laying pairs were present, and was described within a 1000-m-radius (314.2 ha) circular plot centered on the nest tree for nests of different Red-tailed Hawk territories. Unused habitat was described in 314.2 ha randomly-selected, nonoverlapping circular plots where Red-tailed Hawks were absent. The 314.2 ha nesting habitat approximates Red-tailed Hawk home range size.

(1979 and Steenhof and Newton 2007) in defining: a laying pair as a mated pair of birds that laid eggs thereby initiating a nesting attempt; a nesting territory as an area that contains one or more nests within the home range of a mated pair of birds; and an occupied territory (or habitat) as a nesting territory in which one or more adults were engaged in courtship, reproductive activity, nest defense, or nest affinity.

**Nesting Habitat and Unused Habitat.** We defined Red-tailed Hawk nesting habitat as habitat where laying pairs were present. Habitat that was not occupied by Red-tailed Hawks was considered unused habitat. Locations of nests of laying pairs were mapped in a Geographic Information System (GIS). A circular plot with a radius of 1000 m (314.2 ha), centered on the nest tree, was used to describe Red-tailed Hawk nesting habitat at the landscape scale. This spatial scale approximated Red-tailed Hawk home range size (Craighead and Craighead 1956, Petersen 1979, Mosher et al. 1987, Preston and Beane 1993, Smith et al. 2003). The SEWRPC land-cover data were merged with the landscape-scale nesting habitat plots in the GIS.

Thirty Red-tailed Hawk nests were selected from 573 nesting attempts (18–53, annually) in approximately 74 different nesting territories that occurred from 1988–2002 within the MMSA (Stout et al. 2006) such that the nesting habitat plots were completely within the MMSA and did not overlap, and each of the 30 nests was from a different nesting territory. Land cover within these nesting habitat plots was compared to land cover in 30 randomly-generated, nonoverlapping 1000-m-radius circular plots located in unused habitat within the MMSA (Fig. 1). The SEWRPC land-cover data were merged with the unused habitat plots in the GIS. The 30 nesting habitat plots (9426 ha) and 30 unused habitat plots (9426 ha) comprised approximately 30% (18 852 ha) of the MMSA. Thirty sample plots provided the maximum number of nonoverlapping plots for unused habitat; an equal number of nesting habitat plots was used.

**Habitat Model and Hexagons.** To determine if unoccupied Red-tailed Hawk nesting habitat existed in urban locations, we developed a landscape-scale logistic model of nesting habitat occupancy. A nonoverlapping coverage of 234 contiguous 314.1 ha hexagons was produced in a GIS to completely cover the MMSA. The 314.1 ha hexagons (Spence and White 1992, White et al. 1992, White 2000) were used to approximate the 314.2 ha landscape areas used for Red-tailed Hawk nesting habitat analysis. Hexagons were also used because (1) hexagons produce a complete, nonoverlapping coverage and (2) hexagons produced through a random initial base point minimize and may eliminate biases that result from land-use planning and development of townships (e.g., some roads in urban and suburban locations typically follow section lines). The SEWRPC land-cover data were merged with the hexagon coverage for analyses. Hexagons were classified as Red-tailed Hawk nesting habitat if their centers were within 1000 m of any nesting attempt (1988–2002). All other hexagons were classified as unused habitat.

**GIS Software.** We used ArcView GIS version 3.3 (ESRI 2002) for GIS procedures and analyses. We used FRAGSTATS class and landscape metrics as defined and described in McGarigal and Marks (1995) to describe Red-tailed Hawk nesting habitat and unused habitat, and to describe the habitat of hexagons for the nesting habitat model. We compared the area (ha), perimeter (m), and number of patches for each of the 12 land-cover classes (36 FRAGSTATS class metrics), and 18 FRAGSTATS landscape metrics within nesting habitat and unused habitat. FRAGSTATS landscape metrics provide measures of patch configuration (e.g., mean patch fractal dimension: a perimeter/area ratio that provide an index of average patch shape complexity), diversity, density, and richness across the entire landscape (McGarigal and Marks 1995). FRAGSTATS for ArcView version 1.0 (Space Imaging 2000) was used to calculate FRAGSTATS metrics. The Animal Movement Extension to ArcView version 1.1 was used to select nest sites (for nesting habitat) and to generate unused habitat locations within the specified parameters, and to randomly select hexagons for a logistic regression model (Hooge and Eichenlaub 1997).

**Statistical Analyses.** Red-tailed Hawk nesting habitat was compared to unused habitat using univariate statistics (Sokal and Rohlf 1981). A Kolmogorov-Smirnov test was used to determine variables with normal distributions (Sheskin 2000). Square root and common logarithmic transformations were used when applicable. Two-sample $t$-tests were used to compare normally distributed variables and Mann-Whitney $U$ tests were used to compare variables that did not form normal distributions (Snedecor and Cochran 1989). All tests were considered significant when $P \leq 0.05$. SYSTAT (SPSS 2000) was used for all statistical analyses.

Logistic regression was used to develop a model for predicting the probability of Red-tailed Hawk nesting habitat occupancy for hexagons. Class and landscape metrics that were significantly different for Red-tailed Hawk nesting habitat and unused habitat were included in the analysis. One hundred hexagons were randomly selected from the MMSA to estimate the parameters of the probability of occupancy. Nesting habitat ($N = 54$) and unused habitat ($N = 46$) hexagons used to develop the model were unequal because they were randomly selected (Hooge and Eichenlaub 1997) and nesting habitat was slightly more common. A Pearson correlation was used to identify and eliminate correlated variables ($r \geq 0.2$). A Pearson correlation coefficient of 0.2 was used for reducing the number of variables available for the logistic regression model to maximize the possibility of independence of variables and, thus, to improve the validity of the model. We entered correlated variables into forward stepwise logistic regression analyses in a pair-wise process to determine which of the correlated variables best explained the difference between nesting habitat and unused habitat. The variables that best explained the difference between nesting habitat and unused habitat and were not intercorrelated were used to develop a nesting habitat occupancy model. We compared all possible models using the remaining variables and determined the best model using Akaike Information Criterion (AIC). To determine if unoccupied nesting habitat existed within the MMSA, we applied the best model to 136 hexagons (72 Red-tailed Hawk nesting habitat and 64 unused habitat hexagons based on Red-tailed Hawk presence and absence observations) from the MMSA that were not used to develop the logistic regression model.

## RESULTS

**Urban/suburban Nesting Habitat and Unused Habitat.** Urban/suburban Red-tailed Hawk nesting habitat in the MMSA averaged 58.7% highly-developed land-cover types (high-density urban, low-density urban, roads, parking, recreational, and graded) and 41.3% less-developed land cover types (grassland, cropland, pasture, woodland, wetland, and water). Unused habitat averaged 91.7% highly-developed land-cover types and 8.3% less-developed land cover types (Fig. 2).

**Nesting Habitat and Unused Habitat Comparisons.** Thirty of 36 FRAGSTATS class metrics and 16 of 18 FRAGSTATS landscape metrics were significantly different for Red-tailed Hawk nesting habitat compared to unused habitat (Appendix). The three area class metrics (parking, recreational, and graded land) that did not differ for nesting habitat and unused habitat, averaged approximately 10% of the landscape in total, for both nesting habitat and unused habitat (Fig. 2).

**Habitat Model and Predictions.** Of 236 hexagons across the MMSA, 126 were classified as Red-tailed Hawk nesting habitat and 110 were unused habitat based on the presence and absence of Red-tailed Hawks. Of 100 randomly selected hexagons used for a multivariate logistic regression analysis, 54 were nesting habitat and 46 were unused habitat. Three variables (road perimeter, water area, and double log fractal dimension) had Pearson correlation coefficients <0.2. Double log fractal dimension (FRAGSTATS metric: DLFD), which ranges from 1–2, approaches 1 for shapes with very simple perimeters such as circles or squares and approaches 2 for highly convoluted shapes; DLFD is a function of area to perimeter ratios (McGarigal and Marks

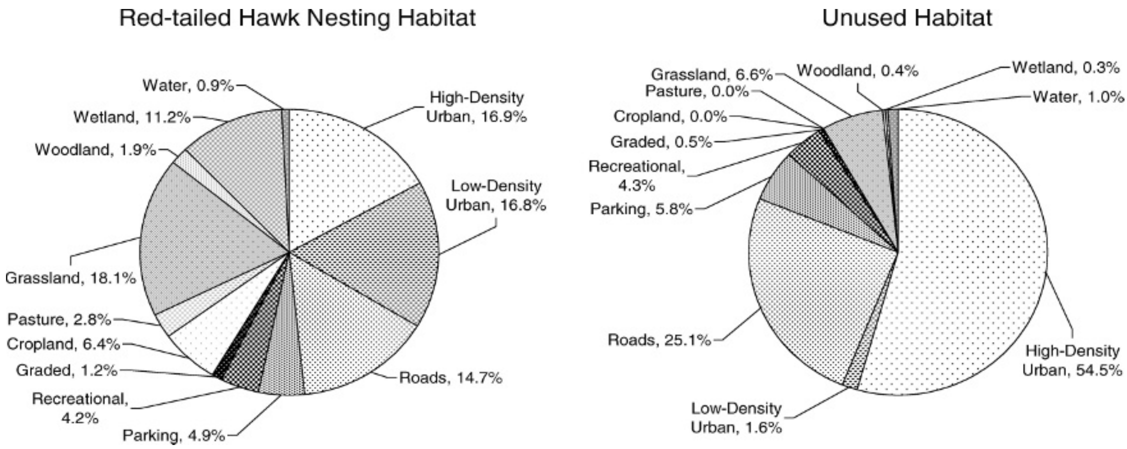


Figure 2. Land-cover composition for urban/suburban Red-tailed Hawk nesting habitat and unused habitat within the Metropolitan Milwaukee Study Area (MMSA).

1995). Seven logistic regression models were possible using these three variables (Table 1). Based on AIC, the following model provided the simplest and best fit model to distinguish between nesting habitat and unused habitat:

$$\text{Model Score} = 7.550 + (\text{road perimeter} \times -0.000152) + (\text{water area} \times -0.056).$$

When applied to the hexagons used to develop the model, 88.9% of nesting habitat hexagons and 82.6% of unused hexagons were consistent with observed presence and absence data (combined average: 85.7%; Table 2).

To predict whether unoccupied Red-tailed Hawk nesting habitat existed within the MMSA, we applied the regression model to the 136 hexagons that were not used in building the model. From the

Table 1. Summary of logistic regression models for predicting Red-tailed Hawk nesting habitat and unused habitat. Based on AIC, model 4 provided the simplest and best fit model to distinguish between nesting habitat and unused habitat.

| | PARAMETERS IN MODEL | ESTIMATE | SE | $t$ | $P$ | AIC |
|---|---|---|---|---|---|---|
| Model 1 | Constant | 6.791 | 1.378 | 4.927 | <0.001 | 72.32 |
| | Road perimeter | −0.000141 | 0.000029 | −4.924 | <0.001 | |
| Model 2 | Constant | 0.276 | 0.217 | 1.273 | 0.203 | 139.31 |
| | Water area | −0.030 | 0.025 | −1.188 | 0.235 | |
| Model 3 | Constant | 4.662 | 17.871 | 0.261 | 0.794 | 141.93 |
| | Double log fractal dimension | −3.213 | 12.753 | −0.252 | 0.801 | |
| Model 4 | Constant | 7.550 | 1.556 | 4.852 | <0.001 | 68.96 |
| | Road perimeter | −0.000152 | 0.000032 | −4.809 | <0.001 | |
| | Water area | −0.056 | 0.040 | −1.426 | 0.154 | |
| Model 5 | Constant | −28.582 | 32.590 | −0.877 | 0.380 | 73.08 |
| | Road perimeter | −0.000142 | 0.000028 | −5.043 | <0.001 | |
| | Double log fractal dimension | 25.323 | 23.423 | 1.081 | 0.280 | |
| Model 6 | Constant | 3.223 | 17.984 | 0.179 | 0.858 | 141.28 |
| | Water area | −0.030 | 0.025 | −1.183 | 0.237 | |
| | Double log fractal dimension | −2.104 | 12.836 | −0.164 | 0.870 | |
| Model 7 | Constant | −36.350 | 35.541 | −1.023 | 0.306 | 69.33 |
| | Road perimeter | 0.000153 | 0.000031 | −4.906 | <0.001 | |
| | Water area | −0.059 | 0.041 | −1.432 | 0.152 | |
| | Double log fractal dimension | 31.466 | 25.612 | 1.229 | 0.219 | |

Table 2. Predictions of the logistic regression model for Red-tailed Hawk nesting habitat and unused habitat in southeast Wisconsin, 1988–2002.

| | Model Prediction | | |
|---|---|---|---|
| | Nesting Habitat | Unused Habitat | Total |
| **Model hexagons (reclassification)** | | | |
| Observed (count) | | | |
| Nesting habitat | 48 | 6 | 54 |
| Unused habitat | 8 | 38 | 46 |
| Observed (percent) | | | |
| Nesting habitat | 88.9 | 11.1 | 100.0 |
| Unused habitat | 17.4 | 82.6 | 100.0 |
| Total consistent with observed | 85.7 | | |
| **Prediction hexagons** | | | |
| Observed (count) | | | |
| Nesting habitat | 64 | 8 | 72 |
| Unused habitat | 10 | 54 | 64 |
| Observed (percent) | | | |
| Nesting habitat | 88.9 | 11.1 | 100.0 |
| Unused habitat | 15.6 | 84.4 | 100.0 |
| Total consistent with observed | 86.6 | | |

Table 3. Probability of occupancy for habitat of prediction hexagons based on the logistic regression model.

| Probability of Occupancy | Nesting Habitat | Unused Habitat | % Observed Occupied |
|---|---|---|---|
| 0–0.1 | 1 | 34 | 2.9 |
| 0.1–0.2 | 0 | 4 | 0.0 |
| 0.2–0.3 | 3 | 6 | 33.3 |
| 0.3–0.4 | 3 | 4 | 42.9 |
| 0.4–0.5 | 1 | 6 | 14.3 |
| 0.5–0.6 | 2 | 3 | 40.0 |
| 0.6–0.7 | 5 | 2 | 71.4 |
| 0.7–0.8 | 7 | 1 | 87.5 |
| 0.8–0.9 | 14 | 4 | 77.8 |
| 0.9–1.0 | 36 | 0 | 100.0 |
| Total | 72 | 64 | |

model score we calculated the probability of occupancy:

$$e^{\text{model score}}/\left(1 + e^{\text{model score}}\right).$$

Based on the model, 88.9% of hexagons where Red-tailed Hawks were observed nesting (i.e., occupied nesting habitat) had a probability of occupancy >0.5 (Table 2). In some cases, habitat with a low probability of occupancy (<0.2) was actually occupied (1 of 39 hexagons, 2.6%), and habitat with a high probability of occupancy (>0.8) remained unoccupied (4 of 54 hexagons, 7.4%; Table 3, Fig. 3). Ten of 64 (15.6%) hexagons in which Red-tailed Hawks were absent had >0.5 probability of occupancy (Table 2, Fig. 4).

## Discussion

Our results indicated that Red-tailed Hawk nesting habitat in the urban/suburban metropolitan Milwaukee area usually consisted of large areas of grassland and other herbaceous cover types. Urban/suburban Red-tailed Hawk nesting habitat was comprised of relatively large amounts of less-developed land cover types (grassland, woodland, wetland, pasture and cropland) compared to unused habitat, and had greater land-cover diversity and patch richness than unused habitat. Characteristics of unused habitat indicated that Red-tailed Hawks avoided areas of heaviest urbanization, perhaps because of insufficient hunting habitat and possibly unsuitable nesting locations.

**Urban/suburban Nesting Habitat.** Large circular plots are often used to approximate home ranges and to describe habitat at a landscape scale (Mosher et al. 1987). Several studies determined home range size for Red-tailed Hawks (Preston and Beane 1993). Smith et al. (2003) determined that home range size for seven male Red-tailed Hawks in northwestern Wyoming averaged 241 ha (range: 181–480 ha) during the breeding season (i.e., March to August). Petersen (1979) studied a rural Red-tailed Hawk population in southern Wisconsin and determined home range size for each of the four seasons. He found that seasonal Red-tailed Hawk home ranges averaged 141 ha (range: 31–390 ha, $N = 27$; males: $\bar{x} = 186$ ha, 117–390 ha, $N = 7$; females: $\bar{x} = 125$ ha, 31–344 ha, $N = 20$); only two birds had seasonal home ranges larger than 314.2 ha (1 winter: 344 ha, 1 fall: 390 ha). For his study, spring home ranges (April–June) during the nesting period averaged 104 ha (range: 31–179 ha, $N = 8$; males: $\bar{x} = 163$ ha, 147 and 179 ha, $N = 2$; females: $\bar{x} = 85$ ha, 31–144 ha, $N = 6$). Additionally, the 314.2 ha nesting habitat areas for adjacent occupied territories in this study area had substantial overlap (e.g., for 2002, the two nearest nests of different territories for laying pairs were 250 m apart, resulting in approximately 84% overlap of these two nesting hab-

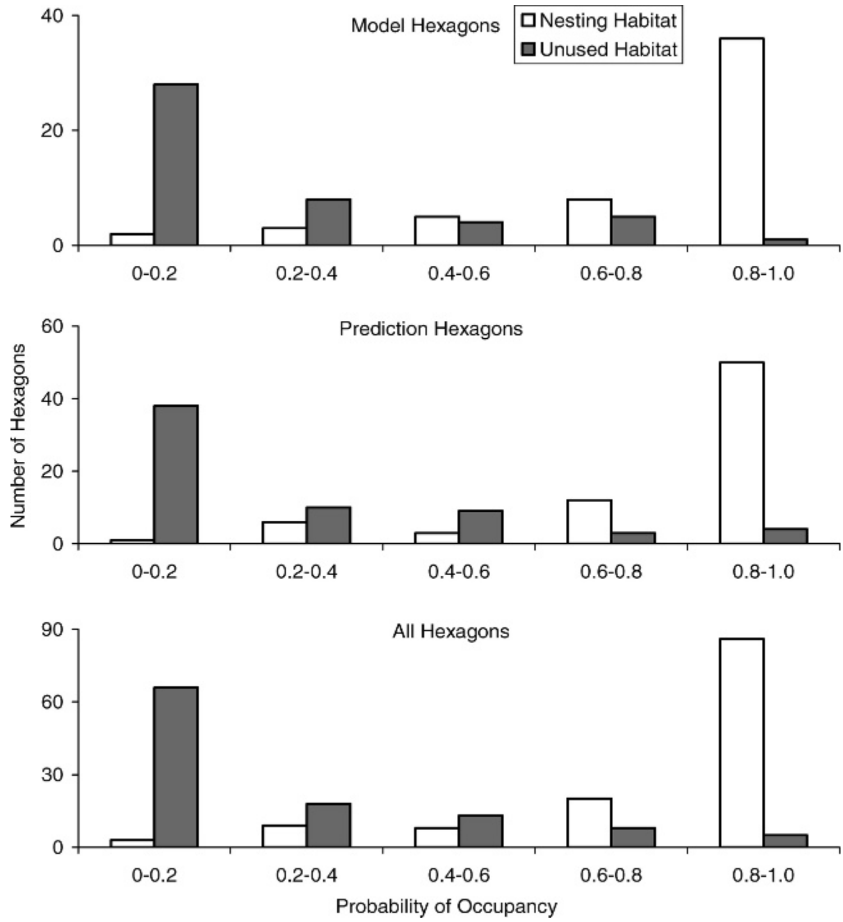


Figure 3. Probability of Red-tailed Hawk occupancy for model hexagons, prediction hexagons, and all hexagons based on the logistic regression model.

itat areas; Stout 2004, Stout et al. 2006). Therefore, we suggest that, at least for our study area in southeast Wisconsin, the 314.2 ha nesting habitat area encompassed the majority, if not all, of the typical home range and, therefore, hunting habitat, for laying pairs of Red-tailed Hawks for the nesting period.

Nest-site availability and hunting habitat (i.e., prey abundance and availability) are often the external limiting factors that have the greatest impact on Red-tailed Hawk reproductive rates as well as those of other raptors (Preston and Beane 1993, Newton 1998). Our study underscored the importance of adequate hunting habitat for Red-tailed Hawks. A large part of the nesting habitat area for this study included grassland and other herbaceous cover types. Some types of roads such as freeways and the large intersections associated with them may provide suitable hunting habitat. Airports, cemeteries, and recreational areas such as golf courses and parks also may provide hunting and nesting habitat in urban locations. In southern Wisconsin, Petersen (1979) found that 71.5% of the habitats used by Red-tailed Hawks during the nesting season were cropland, pastures, and grasslands, habitats Red-tailed Hawks typically use for hunting. Availability of adequate hunting habitat may affect Red-tailed Hawk reproductive success (Stout et al. 2006). Howell et al. (1978) compared landscape features to productivity for rural Red-tailed Hawk nest sites in Ohio, and reported that high-productivity sites had more than twice as much fallow land and less than half as much cropland and woodland than did low-productivity sites. In another study, hunting perch density near nest sites was positively

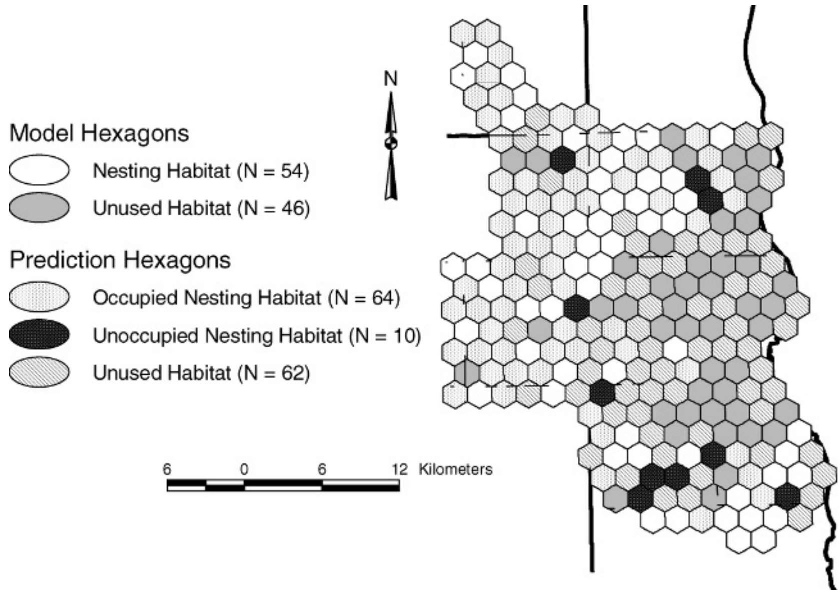


Figure 4. Predictions of the Red-tailed Hawk nesting habitat model.

correlated with reproductive success (Janes 1984). In southeast Wisconsin, Red-tailed Hawks nesting on human-made structures had higher reproductive success than those nesting in trees (Stout et al. 1996, 2006). As Red-tailed Hawks continue to nest on and hunt from human-made structures in urban areas, the amount of woodland area available to them may be becoming less important than in rural locations.

**Nesting Habitat and Unused Habitat Comparisons.** Landscape-scale characteristics of nesting habitat suggested that Red-tailed Hawks avoided areas of heaviest urbanization within the MMSA probably because of insufficient hunting habitat and possibly unsuitable nesting locations. Landscape characteristics indicated that unused habitat was more homogeneous, containing more patches of fewer land-cover classes (i.e., lower patch richness and higher number of patches), and had less patch diversity. These characteristics are consistent with heavily developed urban areas. Conversely, nesting habitat was more heterogeneous and had greater patch diversity, characteristics more typical of suburbia.

**Habitat Model and Predictions.** The road class metric, road perimeter, was the major parameter used in the logistic regression model to distinguish between nesting habitat and unused habitat; roads may be a good measure for various aspects of nesting habitat in this urban environment. In another study, we used productivity (the average number of young produced per laying pair) as an index to habitat quality and fitness for this same population and developed a discriminant function model to distinguish between high-quality habitat and low-quality habitat (Stout et al. 2006). We found that another road class metric, road area, was the major discriminant function parameter for habitat quality.

The probability of occupancy determined by the logistic model may provide an index of habitat quality. Relatively high-quality habitat may have a higher probability of occupancy whereas marginal habitat may have a relatively low probability of occupancy. Consequently, the majority of hexagons with relatively high-quality habitat were occupied and a small percentage of hexagons with marginal habitat were occupied. However, some hexagons with relatively high-quality habitat remained unoccupied.

Results from our logistic model indicated that suitable, unoccupied nesting habitat existed in this urban area. This is consistent with other studies of this Red-tailed Hawk population. Stout (2004) determined that the density of this population increased from 18 to 48 laying pairs (32 to 72 territorial pairs) between 1988 and 2002, and that the birds expanded into more urbanized landscapes. Additionally, high-productivity nesting territories (likely indicative of high-quality habitat) in southeast Wisconsin were comprised of more urban land-cover area than were low-productivity nesting territories, and nesting attempts on human-made structures increased in urban locations and had relatively high productivity (Stout et al. 1996, 2006). These studies indicated that urban landscapes did not adversely affect reproductive success. Results from the logistic regression model that we developed, in conjunction with these other studies, suggested that urban/suburban Red-tailed Hawks likely adapted well to new habitat conditions in the MMSA.

**Urban Land-use Planning Considerations.** Blum (1989) suggested that maintaining biological diversity within urban environments may be the best attainable goal for urban land-use planners. Determining how wildlife species respond to human disturbance such as continued sprawl in urban, suburban, and rural landscapes is important for future wildlife management in urban locations. Top predators, avian species, and species that occupy large home ranges such as Red-tailed Hawks are sometimes used as flagship, focal, or target species for land-use planning purposes (Hildebrandt and Yarchin 1999, Ranta et al. 1999). In addition to qualifying as this type of focal species, raptors also appear to be adapting to urban environments (Bird et al. 1996) and, therefore, warrant continued study in urban locations. Additional studies of urban raptor populations may provide valuable insight into future management considerations for wildlife in human-influenced landscapes.

## Acknowledgements

J.M. Papp and W.G. Holton provided field assistance. This research has been supported in part by a grant from the U.S. Environmental Protection Agency's Science to Achieve Results (STAR) program (grant U915758). The research described in this article has not been subjected to any EPA review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred. The Zoological Society of Milwaukee provided partial funding through the Wildlife Conservation Grants for Graduate Student Research program. C.L. McIntyre and two anonymous referees provided many suggestions that improved this paper.

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Received 2 August 2005; accepted 26 April 2006

Appendix. We compared the area (ha), perimeter (m), and number of patches (FRAGSTATS class metrics) for each of 12 land-cover classes and 18 FRAGSTATS landscape metrics within urban/suburban Red-tailed Hawk nesting habitat and unused habitat in southeast Wisconsin. Land-cover for nesting habitat was measured within 1000-m-radius (314.2 ha) circular plots centered on the nest trees of nests of laying pairs. Unused habitat was measured within similar plots where Red-tailed Hawks were absent. FRAGSTATS landscape metrics provide measures of patch configuration (e.g., mean patch fractal dimension: a perimeter/area ratio that provide an index of average patch shape complexity), diversity, density, and richness across the entire landscape (McGarigal and Marks 1995).

| | Nesting Habitat ($N$ = 30) | | | | Unused Habitat ($N$ = 30) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variables | Mean | SE | Min | Max | Mean | SE | Min | Max | $t/\chi^2$ | $P$ |
| **Class metrics** | | | | | | | | | | |
| High density urban area | 52.8 | 7.2 | 0.9 | 125.8 | 170.3 | 5.7 | 112.6 | 212.3 | −12.794[c] | <0.001 |
| High density urban perimeter | 21083.7 | 2765.9 | 639.3 | 50521.2 | 72856.0 | 2533.5 | 40622.1 | 102004.6 | −13.803[c] | <0.001 |
| High density urban no. of patches | 42.9 | 5.1 | 2.0 | 105.0 | 158.3 | 8.6 | 74.0 | 263.0 | −11.493[c] | <0.001 |
| Low density urban area | 52.4 | 10.3 | 0.0 | 180.3 | 4.9 | 3.4 | 0.0 | 86.1 | 28.655[d] | <0.001 |
| Low density urban perimeter | 16745.3 | 3042.7 | 0.0 | 52796.8 | 1434.1 | 990.0 | 0.0 | 24626.3 | 29.173[d] | <0.001 |
| Low density urban no. of patches | 24.7 | 3.8 | 0.0 | 70.0 | 1.9 | 1.3 | 0.0 | 32.0 | 30.053[d] | <0.001 |
| Road area | 46.0 | 3.4 | 16.0 | 84.6 | 78.3 | 1.9 | 59.1 | 113.1 | −8.209[c] | <0.001 |
| Road perimeter | 32797.1 | 2169.2 | 9051.2 | 56660.0 | 71240.6 | 2082.8 | 55761.4 | 93690.8 | −12.784[c] | <0.001 |
| Road no. of patches | 13.0 | 1.2 | 3.0 | 28.0 | 27.2 | 2.5 | 9.0 | 63.0 | −5.144[c] | <0.001 |
| Parking area | 15.2 | 2.2 | 0.2 | 42.6 | 18.1 | 2.0 | 5.1 | 43.2 | −0.954[c] | 0.344 |
| Parking perimeter | 9729.1 | 1270.2 | 191.4 | 26939.1 | 15991.3 | 1351.8 | 5891.4 | 37059.9 | −3.376[c] | 0.001 |
| Parking no. of patches | 26.3 | 3.5 | 1.0 | 72.0 | 74.6 | 6.4 | 19.0 | 177.0 | −6.617[c] | <0.001 |
| Recreational area[a] | 13.0 | 4.0 | 0.0 | 83.3 | 13.5 | 1.8 | 0.0 | 34.6 | −1.472[c] | 0.146 |
| Recreational perimeter[a] | 2693.1 | 698.6 | 0.0 | 15100.5 | 3841.9 | 524.2 | 0.0 | 9355.5 | −2.229[c] | 0.030 |
| Recreational no. of patches[a] | 2.3 | 0.6 | 0.0 | 13.0 | 5.2 | 0.8 | 0.0 | 18.0 | −3.624[c] | 0.001 |
| Graded area | 3.9 | 1.6 | 0.0 | 45.1 | 1.5 | 0.5 | 0.0 | 11.2 | 2.613[d] | 0.106 |
| Graded perimeter[a] | 1350.3 | 284.6 | 0.0 | 6435.5 | 2645.9 | 957.0 | 0.0 | 22787.8 | −0.715[c] | 0.477 |
| Graded no. of patches | 4.3 | 0.8 | 0.0 | 18.0 | 23.7 | 8.8 | 0.0 | 222.0 | 2.532[d] | 0.112 |
| Cropland area | 20.0 | 4.8 | 0.0 | 91.9 | 0.0 | 0.0 | 0.0 | 0.0 | 24.250[d] | <0.001 |
| Cropland perimeter | 3270.4 | 730.7 | 0.0 | 12243.7 | 0.0 | 0.0 | 0.0 | 0.0 | 24.250[d] | <0.001 |
| Cropland no. of patches | 2.5 | 0.5 | 0.0 | 12.0 | 0.0 | 0.0 | 0.0 | 0.0 | 24.271[d] | <0.001 |
| Pasture area | 8.9 | 2.5 | 0.0 | 57.2 | 0.0 | 0.0 | 0.0 | 0.0 | 22.489[d] | <0.001 |
| Pasture perimeter | 2273.0 | 611.5 | 0.0 | 12765.7 | 0.0 | 0.0 | 0.0 | 0.0 | 22.489[d] | <0.001 |
| Pasture no. of patches | 2.4 | 0.7 | 0.0 | 14.0 | 0.0 | 0.0 | 0.0 | 0.0 | 22.523[d] | <0.001 |
| Grassland area | 56.5 | 5.1 | 15.8 | 112.9 | 20.6 | 2.9 | 2.0 | 61.2 | 6.173[c] | <0.001 |
| Grassland perimeter | 16704.7 | 1152.7 | 4978.5 | 29191.2 | 9153.8 | 1011.4 | 1902.5 | 20488.1 | 4.924[c] | <0.001 |
| Grassland no. of patches[b] | 19.8 | 1.4 | 8.0 | 36.0 | 25.6 | 4.1 | 4.0 | 98.0 | −0.088[c] | 0.930 |
| Woodland area | 6.0 | 1.3 | 0.0 | 29.1 | 1.3 | 0.9 | 0.0 | 27.4 | 25.224[d] | <0.001 |
| Woodland perimeter | 1849.2 | 314.8 | 0.0 | 5910.8 | 465.0 | 278.9 | 0.0 | 8084.4 | 22.929[d] | <0.001 |
| Woodland no. of patches | 2.8 | 0.4 | 0.0 | 9.0 | 0.6 | 0.3 | 0.0 | 9.0 | 25.406[d] | <0.001 |
| Wetland area | 35.1 | 8.4 | 0.0 | 195.3 | 0.8 | 0.4 | 0.0 | 8.7 | 33.994[d] | <0.001 |
| Wetland perimeter | 6472.3 | 987.4 | 0.0 | 21006.5 | 418.6 | 192.8 | 0.0 | 4775.1 | 33.815[d] | <0.001 |
| Wetland no. of patches | 5.8 | 0.7 | 0.0 | 14.0 | 0.5 | 0.3 | 0.0 | 7.0 | 34.808[d] | <0.001 |
| Water area | 2.7 | 0.7 | 0.0 | 17.4 | 3.2 | 1.3 | 0.0 | 26.8 | 7.325[d] | 0.007 |
| Water perimeter | 1632.7 | 392.8 | 0.0 | 9144.2 | 1316.0 | 495.4 | 0.0 | 10444.1 | 7.657[d] | 0.006 |
| Water no. of patches | 2.5 | 0.5 | 0.0 | 11.0 | 1.9 | 0.6 | 0.0 | 13.0 | 6.294[d] | 0.012 |

Appendix. Continued.

| Variables | Nesting Habitat ($N$ = 30) Mean | SE | Min | Max | Unused Habitat ($N$ = 30) Mean | SE | Min | Max | $t/\chi^2$ | $P$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Landscape metrics** | | | | | | | | | | |
| Number of patches | 149.17 | 7.59 | 58.00 | 219.00 | 319.43 | 24.90 | 164.00 | 645.00 | −6.541[c] | <0.001 |
| Mean patch size | 2.31 | 0.16 | 1.43 | 5.39 | 1.13 | 0.07 | 0.48 | 1.91 | 6.803[c] | <0.001 |
| Mean shape index (MSI) | 1.70 | 0.01 | 1.54 | 1.84 | 1.61 | 0.01 | 1.50 | 1.79 | 4.162[c] | <0.001 |
| Mean patch fractal dimension (MPFD) | 1.41 | 0.01 | 1.26 | 1.58 | 1.44 | 0.01 | 1.35 | 1.57 | −1.672[c] | 0.100 |
| Patch size standard deviation[b] | 5.24 | 0.48 | 2.58 | 14.24 | 2.35 | 0.13 | 1.34 | 3.84 | 7.816[c] | <0.001 |
| Largest patch index[b] | 13.62 | 1.43 | 5.15 | 33.14 | 7.91 | 0.38 | 4.23 | 14.32 | 4.009[c] | <0.001 |
| Patch density | 47.72 | 2.43 | 18.56 | 70.07 | 102.20 | 7.97 | 52.47 | 206.36 | −6.541[c] | <0.001 |
| Patch size coefficient of variation | 225.01 | 11.39 | 125.80 | 375.64 | 219.26 | 9.97 | 158.59 | 374.38 | 0.380[c] | 0.705 |
| Area-weighted MSI | 2.40 | 0.05 | 1.88 | 3.21 | 3.24 | 0.07 | 2.35 | 3.87 | −9.467[c] | <0.001 |
| Double log fractal dimension (×100) | 139.74 | 0.30 | 137.25 | 143.65 | 141.06 | 0.40 | 136.76 | 145.92 | −2.651[c] | 0.010 |
| Area-weighted MPFD (×100) | 136.00 | 0.37 | 131.57 | 138.38 | 139.94 | 0.24 | 137.97 | 143.07 | −8.879[c] | <0.001 |
| Shannon's diversity index | 1.74 | 0.04 | 1.37 | 2.14 | 1.21 | 0.04 | 0.89 | 1.61 | 9.428[c] | <0.001 |
| Simpson's diversity index | 0.77 | 0.01 | 0.58 | 0.87 | 0.61 | 0.02 | 0.48 | 0.77 | 7.798[c] | <0.001 |
| Modified Simpson's diversity index | 1.51 | 0.05 | 0.88 | 2.02 | 0.97 | 0.04 | 0.66 | 1.47 | 8.060[c] | <0.001 |
| Shannon's evenness index | 0.75 | 0.01 | 0.59 | 0.89 | 0.64 | 0.02 | 0.50 | 0.83 | 5.006[c] | <0.001 |
| Simpson's evenness index | 0.86 | 0.01 | 0.65 | 0.95 | 0.72 | 0.02 | 0.58 | 0.90 | 6.133[c] | <0.001 |
| Modified Simpson's evenness index | 0.65 | 0.02 | 0.38 | 0.82 | 0.51 | 0.02 | 0.37 | 0.75 | 4.890[c] | <0.001 |
| Patch richness | 10.20 | 0.24 | 7.00 | 12.00 | 6.70 | 0.17 | 5.00 | 8.00 | 11.913[c] | <0.001 |

[a] Square root-transformed for $t$-test.
[b] Log-transformed for $t$-test.
[c] $t$-statistic.
[d] $\chi^2$ value.