

# Nest selection by red-headed woodpeckers across three spatial scales in an urban environment

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**Abstract** Forest habitat is important for a variety of woodpecker species, and is under pressure from urbanization. Red-headed Woodpeckers (*Melanerpes erythrocephalus*; RHW) were once abundant across Eastern North America, and their populations have been declining since the 1960s. Their distribution encompasses urban centers, and since urban habitats differ from natural forest areas, our goal was to understand RHW nest-site selection in an urban context. We addressed two main questions 1) what are the characteristics of RHW nest selection across multiple spatial scales and 2) how do RHW nest tree characteristics in city parks compare to those in forest preserves? This work was done in Cook County, IL, which includes Chicago, the third-largest city in the USA by population. We examined 34 RHW nest trees used between 2010 and 2013, their surrounding habitat, and the landscape within a 1 km radius. Used trees and habitats were compared to paired unused trees and habitats, and landscape-scale characteristics were compared to random locations. Advanced decay of the nest tree, low canopy cover and increased presence of fungus on trees in the surrounding habitat were the best predictors of RHW nesting in the area. Nests were most commonly found in forested areas outside of dense urban areas. However, we did not detect significant differences in the characteristics of the nest trees located in forest preserves and city parks. Our findings are consistent with nest selection studies in rural and natural areas, suggesting that forest habitats in metropolitan landscapes can support RHW nesting.

**Keywords** Red-headed woodpecker · Urbanization · Nest selection · Chicago · Forest preserves

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## Introduction

Woodpeckers and other primary excavators have the unique ability to excavate tree cavities, which persist in the environment for long periods of time (Cockle et al. 2011; Edworthy et al. 2012). While relatively few species create tree cavities, in North America, over 89 species are known to utilize tree cavities, including birds, reptiles, and mammals (Titus 1983). Conserving species of primary excavators therefore has implications not only for woodpecker species themselves, but also for communities that rely on these “keystone vegetative structures” as habitat (Tews et al. 2004). Woodpeckers are an easily recognizable guild, but there tends to a low diversity and abundance of woodpeckers in urban areas because most depend on snags (standing dead trees) and decaying wood for nesting, roosting, and foraging (Thomas et al. 1976; DeGraff and Wentworth 1986; Bull et al. 1997) which are less available in urbanized habitats (LaMontagne et al. 2015). Woodpecker species are also a reliable indicator for woodland bird species abundance and richness at several different spatial scales (Landres et al. 1988, Thompson et al. 2005, Drever et al. 2008).

One woodpecker species of particular recent interest is the Red-headed Woodpecker (*Melanerpes erythrocephalus*, RHW), which was once abundant in temperate woodlands and savannas across the eastern and central United States but over the past half-century RHW population sizes have decreased by 60 % across this range (Sauer et al. 2008). RHW have been classified as a “common species in steep decline” (Rich et al. 2004), and their decline is a conservation concern (Illinois Department of Natural Resources 2005; National Audubon Society 2008; Sauer et al. 2008; US Fish and Wildlife Service 2008). Several studies have evaluated RHW nest site selection in natural forest habitats (e.g. Vierling and Lentile 2006; King et al. 2007; Waldstein 2012; Frei et al. 2013; Hudson and Bollinger 2013). In these natural habitats, RHW have shown preferences at a range of hierarchical spatial scales (sensu Johnson 1980), from the nest tree to the landscape scale. RHW selected for nest sites that were snag trees with a large diameter at breast height (DBH), the habitat surrounding the nest had nearly twice as many dead trees as random sites (Smith et al. 2000; King et al. 2007, Hudson and Bollinger 2013), and they occurred in landscapes with open areas and therefore a lower percentage of canopy cover (Graber et al. 1977).

Here, we focus on RHW habitat selection in an urban area. Their distribution spans from east of the Rocky Mountains to the Atlantic Coast, and from the southern areas of Manitoba and Saskatchewan, Canada, through Texas and Louisiana in the United States (Smith et al. 2000). The large range of the RHW encompasses ten large cities (greater than one million inhabitants), and while they were once common in urban areas their pattern of decline has also been noted in cities in Illinois (Graber et al. 1977) and Texas (Pulich 1988). In general, habitats in urban areas are considerably different in structure and function than those in natural and rural woodlands (e.g. Tweit and Tweit 1986, Germaine et al. 1998, Marzluff et al. 1998; Garaffa et al. 2009). For instance, urban habitats generally are more fragmented and contain less dead wood than natural and rural woodlands, which may affect the availability of nesting habitat. Determining whether or not there are differences in habitat selection by RHW between natural and urban areas may fill an important gap in our understanding the ecology of this native species in urban areas. As far as we know, no research to date has evaluated RHW nest selection at multiple spatial scales in an urban environment.

Our study took place in a heterogeneous forest-urban landscape in and around the city of Chicago, Illinois, USA and our objectives were to 1) identify the characteristics of nest sites selected by RHW across three spatial scales (the individual cavity tree, the habitat

immediately surrounding the cavity tree, and the broader landscape), and 2) compare characteristics of nest trees found in large city parks and those found in forest preserves. Because RHWO preferentially excavate cavities in softened wood (Smith et al. 2000), we predicted that RHWO nest trees would be larger and more decayed than unused trees (Kilgo and Vukovich 2011). We also predicted that the selection of nest sites would depend on the surrounding habitat, specifically that RHWO nest sites would have lower canopy cover to aid in flycatching behavior (Beal 1911; Venables and Collopy 1989; Smith et al. 2000), as well as a higher density of mast-producing trees (oaks, walnuts, beeches, hickories, etc.; Smith and Scarlett 1987; Doherty et al. 1996) which provide cacheable food sources. We predicted that the landscapes surrounding nests would have a larger forested-land area and a smaller area of urban development compared to landscapes around randomly selected points. Across an urban gradient woodpecker-excavated cavities are significantly more common in forest preserves than in large city parks or residential areas (LaMontagne et al. 2015), therefore we predicted that RHWO nests would be less common in city parks than in forested areas, and that RHWO nest cavities found in city parks will be in large living trees with less surrounding decay, as trees in city parks are managed to remove dead and decaying wood (Carpaneto et al. 2010).

## Methods

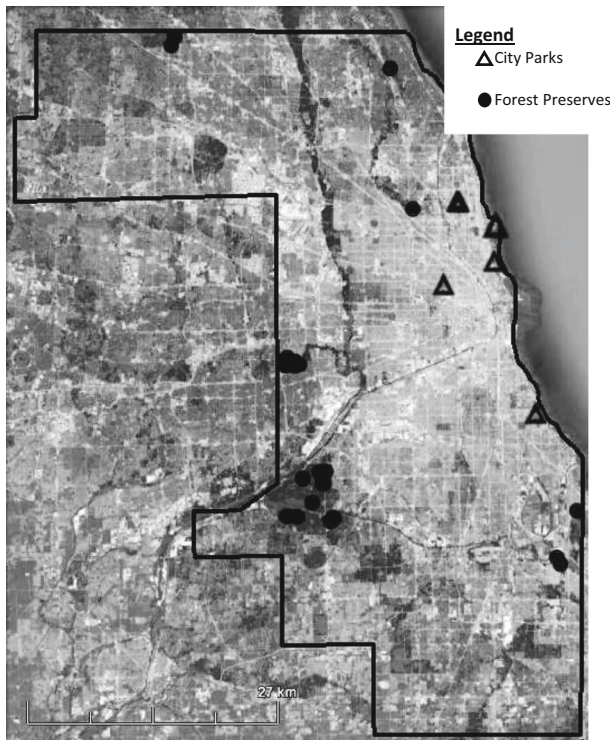
### Study area

Our study took place within Cook County, IL, USA (Fig. 1) which includes Chicago (41° 53' N, 87° 38' W) the third largest city in the United States by population (US Census Bureau 2010). Cook County is approximately 423,500 ha, and urbanization within and surrounding Chicago has resulted in a built area of over 195,000 ha within our study area (US Census Bureau 2010). Cook County contains a vast network of Forest Preserve sites, which encompass 27,518 ha (~11 %) of county land, and Chicago Park District properties include another 3237 ha, and include approximately 7.6 % of the city's tree population (Nowak et al. 2010).

We used reports from the Bird Conservation Network (BCN) and the Audubon Society Chicago Region to identify the locations of RHWO nest trees that were active during at least one breeding season between 2010 and 2013. An active nest status was defined either by sighting reports that contained details of nesting behavior, or by four independent reports of RHWO sightings at the same site within a 1-month time frame during the breeding season which we assumed indicated an active nest. We excluded reports made during the fall and spring migrations (Thorne Smith 1972). Habitat assessments were conducted between April and October 2013. We conducted site visits to determine precise locations of cavities, and quantified tree and habitat characteristics. We excluded three sites from the BCN database because we could not find the reported cavity based on the provided GPS coordinates, and we did not want to confound RHWO cavities with cavities of other excavators. Overall, we identified and measured tree, habitat, and landscape characteristics at 34 RHWO nest sites, and compared these to random trees, sites, and landscapes (see below).

### Landscape selection

At the broadest scale of selection, we compared the landscape composition around RHWO nests to points randomly selected from Cook County using the 'Create Random Points' tool in



**Fig. 1** Map of study sites located within Cook County, IL. The thick outer border is the Cook County limit and the boundary of our study

Data Management of ArcMap 10.2. Our landscape classifications of interest were modified slightly from Blewett and Marzluff (2005) to include forest (mesic, dry mesic, and savannah), high density urban (all/nearly all covered by manmade structures), medium density urban (50–80 % covered by manmade structures), low density urban ( $\leq 50$  % of land covered by manmade structures), and urban open space (parks and yards, Illinois Natural History Survey 2003). GIS data layers were obtained from the collections at the Urban Wildlife Institute of Lincoln Park Zoo and included vector data for road class and density from the Illinois Department of Transportation (IL DOT 2012) and vector data from the Illinois Department of Natural Resources ([dnr.state.il.us](http://dnr.state.il.us)) for streams. We used raster data of 30 m spatial resolution of land use from Illinois Gap Analysis Project (IL-GAP 2012) through the Illinois Natural History Survey (2012) and used a Zonal Analysis to determine the land use within a 1 km radius buffer centered around each nest tree ( $n=34$ ) and random point ( $n=34$ ) following Blewett and Marzluff (2005), Vierling and Lentile (2006), Frei et al. (2013), and LaMontagne et al. (2015).

We also measured the distance from each RHWO nest location to roads, streams, and the city center of Chicago because these risks and resources have been previously demonstrated to impact wildlife distributions in an urban context (e.g. Loss et al. 2009; Gehrt et al. 2009; Magle et al. 2010). We calculated Euclidian distances from both our nest trees and random points to the nearest stream and the nearest road of class 1–7, which includes major interstates, highways, two-lane roads, and busy residential streets but excludes low-traffic (<50 km per

hour roads) or unpaved streets (IL DOT 2012). We also calculated the Euclidian distance from each nest and randomly generated point to the city center of Chicago.

### Tree-level selection

We conducted fieldwork to assess the characteristics for selection of nest trees. Each nest tree was paired with six random control trees which were located at least 100 m from the nest tree (Doherty et al. 1996; Vierling and Lentile 2006) in a randomly selected direction and did not contain any excavated cavities. Henceforth, this collective set of individual trees will be referred to as focal trees. While most studies match a nest tree with one random tree for comparison (e.g. King et al. 2007; Waldstein 2012), we chose to use the mean characteristics based on six random trees in order to remove the influence of selecting a single random tree that was not reflective of the trees available within the habitat. We set a minimum diameter breast height (DBH) of 40 cm for control trees based on literature values (Ingold 1994; Smith et al. 2000), but adjusted our threshold to 20 cm DBH at four sites where the nest tree was smaller than our original cutoff. For each focal tree, we measured DBH, identified tree species, determined presence or absence of visible fungal growth, and classified decay based on a modified Maser et al. (1979) scale. For the decay classification, we classified trees from 1 to 5 based on how much of the tree was alive (1=100 % living, 2=<50 % dead, 3=51–99 % dead, 4=100 % dead, 5=snag (LaMontagne et al. 2015)). If a tree had one or more cavities, we estimated the cavity height, recorded the orientation (based on cardinal directions), location on the tree (trunk, primary branch, or secondary branch), and whether there was visible fungal growth within one meter of the cavity opening.

### Surrounding habitat-level selection

We also assessed selection based on the habitat surrounding nest trees. Two of our control focal trees per site were designated as full-plot control trees, meaning we measured surrounding habitat variables in addition to tree characteristics. We opted to use two surrounding habitat plots and average their measurements to avoid biases in our measurements due to undersampling at a specific site. At nest trees and full-plot control trees, we measured an 11.3 m radius and constructed a 0.04 ha circular plot centered on the focal tree (Martin et al. 1997; Vierling and Lentile 2006; Norris and Martin 2008; Cooke and Hannon 2012). For each tree >10 cm DBH within the plot, we identified the genus, measured DBH, classified decay (see above), and noted whether there was visible fungal growth on the tree. From this data, we calculated tree density, basal area density, dead-tree density (trees in decay class 4 and 5), snag density (class 5 only) and mast-tree density based on living oaks (*Quercus* spp), chestnuts (*Aesculus* ssp), hickories (*Carya* ssp), walnuts (*Juglands* ssp), and buckeyes (*Aesculus* ssp). For percent canopy cover, we looked upwards through a vertical tube 4 cm in diameter and 12 cm in length and estimated cover to the nearest 5 % at 5 points along the radius of the plot in each cardinal direction, and averaged these 20 measurements across the 0.04 ha plot (Conner and Saenz 1996). To describe woody growth <10 cm DBH, we estimated an overall percent coverage of the shrub layer on a 0–10 scale, where “0” had no shrub growth, “5” had shrub growth across 50 % of the 0.04 ha plot, “10” was dense shrub growth across the entire 0.04 ha plot.

## Analysis

We conducted analyses to address RHWO habitat use at three spatial scales: the landscape, the habitat surrounding nest trees, and the nest trees themselves. All analyses were done in R version 3.0.0, and means $\pm$ SE are shown throughout. To determine if the landscape in a 1 km radius (314.16 ha) area surrounding our nest sites was different from that around ArcMAP-generated random location points, we used a logistic regression which included terms for the land-area (in ha) for the following land uses and habitat types: forest, high density urban, medium density urban, low density urban, and urban open space. We tested a full generalized linear model that included all combinations of the above terms and selected the strongest models discerning a binary response variable—that of random sites and RHWO nest sites—using an Akaike information criterion model selection adjusted for small sample sizes ( $AIC_c$ ; Burnham and Anderson 1998; see below). We also compared landscape measurements for distance to roads, streams, and city center of nest sites and randomly generated points using two-sample t-tests (Zar 1999) to obtain a brief description of the risks and resources near RHWO nests.

In order to determine what characteristics were the most important for nest-site selection at the individual tree level and the surrounding habitat (0.04 ha) level, we combined the field data from these two spatial scales into a candidate model set to assess which variables are important for RHWO selection, and whether there is a scale that shows stronger selection than the other. For all surrounding habitat-level variables, the information from the two full-plot controls corresponding to each nest site were averaged and included as a single term that was paired with the focal trees, as described above. Also, the average characteristics based on six control trees was included for focal-tree level variables. We used a generalized linear mixed effects model with a binomial response variable representing used and control nest sites, and  $AIC_c$  with subsequent model averaging to determine a best model. We constructed a full model set that included decay class of the focal trees, and the percent canopy cover, proportion of trees with visible fungal growth, basal area of mast trees, and the decay of surrounding trees within the 0.04 ha habitat plot. We restricted the full candidate model to include these five variables to avoid an overly complex full model and because they are all factors hypothesized to strongly influence RHWO habitat selection. In order to account for nest trees and control trees being paired within sites, we included nest site as a random effect in order to mitigate the effects of different sites across our study area (Sadoti 2012).  $AIC_c$  values were generated from the 32 possible subsets of our full model and parameter values were averaged from the 90 % confidence set of model weights using the MuMIN package in R. We did not include landscape scale data in this analysis because there was a distance of  $\sim$ 100 m between nest trees and control trees, meaning that they occurred in the same landscape by our definition.

For all generalized linear regression models, we used  $AIC$  model selection to find the most parsimonious models that best fit the pattern of RHWO nest site selection (Burnham and Anderson 1998). To compare the performance of the logistic regression models, we used Akaike weights based on Akaike information criterion corrected for small sample size ( $AIC_c$ ) values (Hurvich and Tsai 1989). Also, differences in  $AIC_c$  values between the best model and another model that are  $<2$  indicate that there is substantial support for both models, if the difference is between 4 and 7, there is considerably less support for the other model, and differences  $>10$  indicate essentially no support for the other model (Burnham and Anderson 1998). Estimates of the relative importance of predictor variables (variable importance weights) were calculated by summing the Akaike weights across the models in the confidence

set (Burnham and Anderson 1998). Variables tending to be in all of the top models will have a summed Akaike weight / total confidence set weight closer to 1 (Symonds and Moussalli 2011). For our analyses, we assumed that the factors that separated out nest and control (or random) tree, surrounding habitats, and landscapes, indicated a preference—and therefore selection—for particular habitat characteristics by RHWO.

We analyzed additional data collected from the focal tree and the surrounding habitat that were not included in our full model (tree density in plot, basal area of trees in plot, dead-tree density, snag density, mast-tree density, and shrub layer) using paired sample t-tests. This was done to elucidate any differences between nest trees and control trees in variables that we did not consider to be highly predictive a priori, but that may merit further evaluation. We  $\log(x+1)$  transformed the measurements for dead-tree density, snag density, and mast-tree density and arcsine square root transformed the values for the shrub layer to meet the assumptions of homoscedasticity and normality (Zar 1999). We used a Fisher's Exact Test to determine whether there was an effect of tree genus on selection of nest trees. For this test, we considered trees with no identifiable bark to be their own classification ("Unidentifiable", Conway and Martin 1993), although it is highly probable that they were oaks based on the prevalence of oaks in the surrounding tree communities so we also ran a second analysis assuming that the unidentifiable trees were oaks.

To analyze whether there were differences in nest trees found in city parks compared to forest preserves we used two-sample t-tests to evaluate differences in DBH, focal tree decay, percent canopy cover, surrounding tree density, surrounding dead-tree density, and surrounding mast-tree density. We arcsine square-root transformed values for percent canopy cover to better meet the assumptions of equal variance (Zar 1999). These variables were suggested by LaMontagne et al. (2015) to be different between city parks and forest preserves, and our goal was to determine if any of these variables impacted selection of nest trees in these two different habitat types by RHWO. We did not perform a generalized linear model on these data for two reasons, 1) they both included areas selected by RHWO, and 2) sample sizes for nests in parks were small.

## Results

### RHWO nest site selection in the landscape

The amount of urban area as well as urban open space and forest surrounding nest sites and randomly selected points were the most important variables in the model selection at the landscape scale differentiating locations used by RHWO from random locations (Table 1). High, medium, and low density urban areas appeared in eight, seven, and nine of the 13 models in the 90 % confidence set with variable importance weights of 0.79, 0.52, and 0.98, respectively. Urban open space and forest appeared in five and six models with variable importance weights of 0.76 and 0.29, respectively. The model-averaged parameter estimates indicated a negative effect of all urban-type areas (high, medium, and low density) on the presence of RHWO nests, and a negative impact of urban open space (Table 2; Fig. 2). Forested area within a 1-km radius area was not shown to be a variable that strongly differentiated nest sites and random points, showing up in only five models in the 90 % confidence model set, and only once in the four top models that made up 65 % of the  $AIC_c$  weight ( $\Delta AIC_c < 2.0$ ; Tables 1 and 2). However, the landscapes surrounding RHWO nests were comprised on average of nearly 75 %

of various forest types (mesic, dry mesic, and savannah) while a much lower area surrounding randomly generated points was forested (40 %) (Fig. 2a). The inability of a model based on forested area to differentiate between landscapes surrounding RHWO nests and random points could be due to the higher variance of forest area in our buffer zones around RHWO nests compared to that of our random points (F test,  $df=66$ ,  $F=0.0001$ ,  $p<0.0001$ ). In describing the location of nests compared to random points, RHWO nests were significantly farther from the city center ( $23.76\pm 1.55$  vs  $29.22\pm 1.94$  km, respectively; two sample  $t$ -test,  $t=2.20$ ,  $df=66$ ,  $p=0.031$ ), and significantly nearer to streams ( $245.32\pm 37.02$  vs  $770.15\pm 48.49$  m), respectively; two sample  $t$ -test,  $t=3.42$ ,  $df=66$ ,  $p=0.001$ ), while there was no significant difference in the proximity to roads of RHWO nests ( $415.02\pm 39.83$  m and random points ( $407.78\pm 52.29$  m; two sample  $t$ -test,  $t=0.11$ ,  $df=66$ ,  $p=0.912$ ).

### RHWO nest site selection – trees and surrounding habitat

The 90 % confidence set of models differentiating RHWO nest sites and unused (control) sites contained 10 models, all of which contained the decay class of the individual nest tree, with a variable importance weight of 1.00 (Table 3). The top three models ( $\Delta AIC_c < 2.0$ ) had  $AIC_c$  weights totaling 0.62, and all contained terms for percent canopy cover and the percentage of trees in the surrounding habitat with visible fungal growth, with variable importance weights of 0.90 and 0.74, respectively. Decay of surrounding trees and the basal area of mast trees in the surrounding habitat were included in four models each in the confidence set, and were only moderately important in explaining nest site selection by RHWO, with variable importance weights of 0.37 and 0.26, respectively. Model averaged odds ratios show that substantially lower canopy cover, higher nest tree decay, and higher percentage of surrounding trees with visible fungal growth increase in the likelihood of a tree being a RHWO nest tree (Table 4).

On average, there was almost 1.5 times more canopy cover in control plots than in RHWO nest plots (Fig. 2c), despite that both the density of trees and basal area of trees were similar

**Table 1** Ninety percent confidence model set for a generalized linear model of landscape variables measured around a binary response variable of RHWO nest trees (success) and randomly selected points (failure)

Model terms	K	$\Delta AIC_c$	$w_i$
High Density Urban + Low Density Urban + Urban Open Space	5	0.00	0.26
High Density Urban + Low Density Urban + Urban Open Space + Medium Density Urban	6	0.74	0.18
High Density Urban + Low Density Urban + Urban Open Space + Forest	6	1.65	0.11
Low Density Urban + Urban Open Space + Medium Density Urban	5	1.95	0.10
High Density Urban + Low Density Urban	4	2.40	0.08
High Density Urban + Low Density Urban + Urban Open Space + Medium Density Urban + Forest	7	2.92	0.06
High Density Urban + Low Density Urban + Medium Density Urban	5	3.04	0.06
Low Density Urban + Urban Open Space + Medium Density Urban + Forest	6	3.46	0.05
Low Density Urban + Medium Density Urban	4	3.89	0.04
High Density Urban + Low Density Urban + Forest	5	4.00	0.03
High Density Urban + Low Density Urban + Medium Density Urban + Forest	6	5.15	0.02
Low Density Urban + Medium Density Urban + Forest	5	5.50	0.02
Urban Open Space + Medium Density Urban	4	5.54	0.02



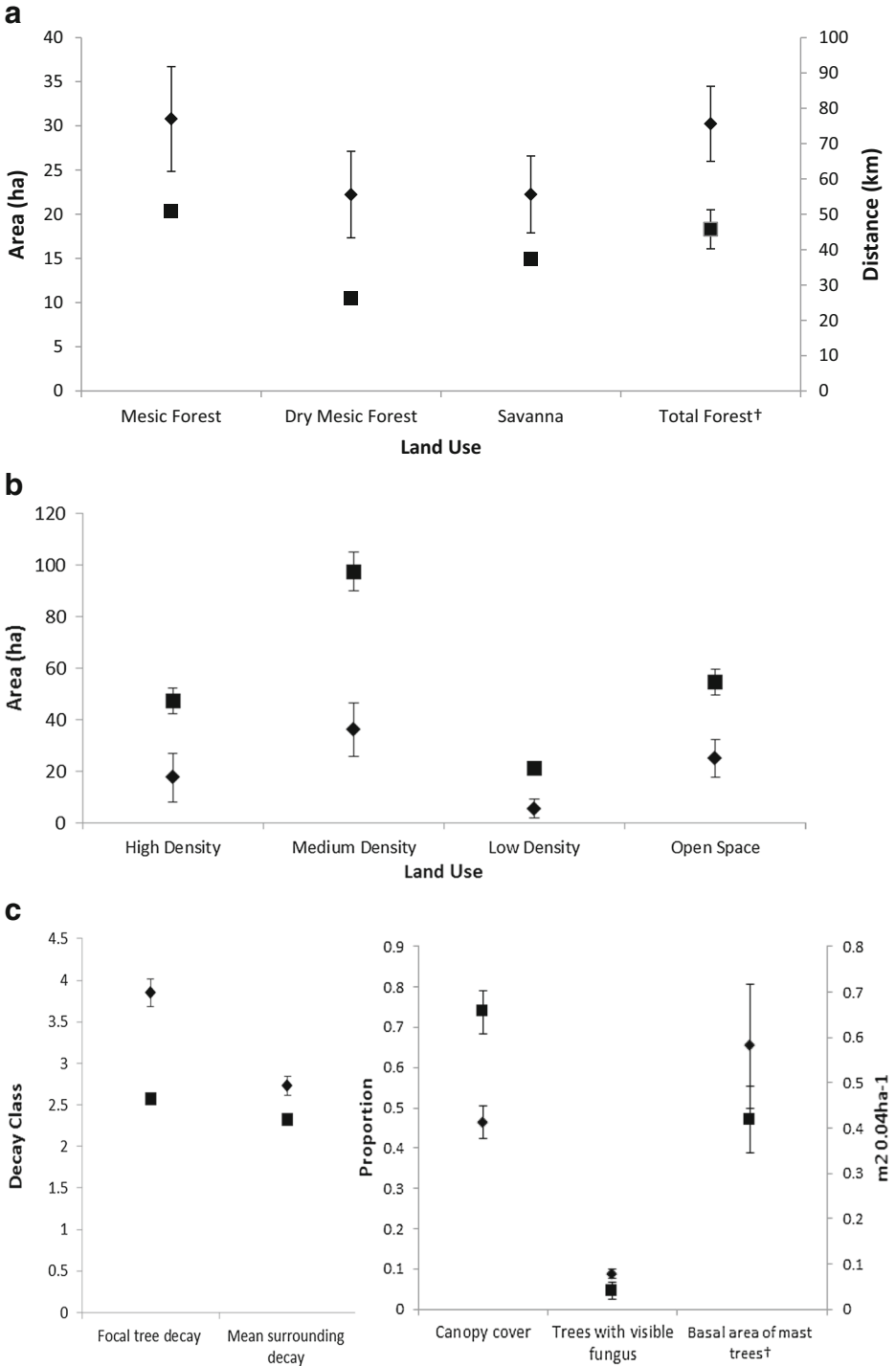
**Table 2** Model-averaged odds ratios and 95 % confidence intervals from the variables included in the 90 % confidence models set for landscape analysis surrounding nest trees (success) and randomly selected points (failure)

Variable	Odds ratio	95 % CI	Variable importance weight
Low density urban	0.90	0.83–0.98	0.98
High density urban	0.98	0.96–0.99	0.79
Urban open space	0.98	0.96–1.00	0.76
Medium density urban	0.98	0.97–1.00	0.52
Forest	1.00	0.99–1.01	0.29

between nest and control plots (Table 5). However, the mean dead-tree density (number of trees in decay class 4 and 5) in RHWO nest plots was 1.7 times greater than in control plots, and there was also a higher, but not significant, density of snags around RHWO nests (Table 5). The higher densities of dead trees, is consistent with the mean surrounding decay (average decay of all trees in plot) being higher around RHWO nests. More than 60 % of our nest trees were in decay class 4 or 5, meaning that they were completely dead, but either with branches still intact (decay class 4) or snags (decay class 5; Appendix A). Conversely, only 4.48 % of random control trees were decay class 4 or 5. There were no RHWO nests in 100 % living trees (decay class 1), even though 7.96 % of controls had no decay. Nest trees were frequently located in oak trees (14/34 nests, 41.18 %), although this estimate may be conservative because 6 nest trees (17.65 %) were unidentifiable because they were in decay class 5 and did not have any intact bark for identification; they may have been oaks as well because that was the most common genus found in our study area (Appendix A). The DBH of nest trees ( $57.37 \pm 3.79$  cm) and the control trees included in our sample ( $58.19 \pm 1.47$  cm) were similar. There was no significant difference between the genus of nest trees and random trees, both when unidentifiable trees were considered a separate category and when they were clustered with the other oak species (Fisher's exact test, separate  $p=0.240$ , clustered  $p=0.219$ ). However, the density of mast trees around RHWO nest trees was almost 20 trees  $\text{ha}^{-1}$  greater than around control trees (Table 5). The shrub layer cover did not vary significantly between nest and control trees (Table 5).

### City parks versus forest preserves

Seven of our 34 nest trees (20.5 %) were located in city parks, while the other 27 trees were located in forest preserves. There were significant differences in focal tree decay, surrounding tree density, surrounding dead-tree density trees and surrounding mast-tree density in city parks and forest preserve sites (Table 6). Focal tree decay was, on average, one full scale point higher in forest preserves than in city parks, and surrounding density of all trees, dead trees, and mast trees was much higher in forest preserves as well. Nest trees in parks tended to have on average a DBH that was 17.54 cm larger than nest trees in forest preserves, although this was not statistically significant (Table 6). The percentage of canopy cover surrounding nest trees in city parks and forest preserves was very similar even though the density of trees per hectare was more than three times higher in forest preserves than in city parks, and this is likely attributed to the fact that city parks had very low densities of dead trees compared to forest preserves (Table 6). Mast trees in surrounding plots in forest preserves included oaks, beeches,



**Fig. 2** Characteristics of the landscapes, surrounding habitats, and focal trees of RHW0 nest trees (*diamonds*) and randomly selected points and trees (*squares*) in Cook County, IL. Mean±SE is shown. †Total forest area and basal area of mast trees are on secondary y-axes

**Table 3** Ninety percent confidence model set for generalized linear models of combined focal tree and surrounding habitat variables for a binary variable of RHWO nests (success) and random sites (failure); all models include a random term for site to account for the paired design

Model terms	K	$\Delta AIC_c$	$w_i$
Focal tree decay + Canopy cover + Trees with visible fungus	6	0.00	0.27
Focal tree decay + Canopy cover + Trees with visible fungus + Mean surrounding decay	7	0.82	0.18
Focal tree decay + Canopy cover + Trees with visible fungus + Basal area of mast trees	7	1.84	0.11
Focal tree decay + Canopy cover + Mean surrounding decay	6	2.78	0.07
Focal tree decay + Canopy cover	5	2.95	0.06
Focal tree decay + Canopy cover + Trees with visible fungus + Mean surrounding decay + Basal area of mast trees	8	2.98	0.06
Focal tree decay + Trees with visible fungus	5	3.36	0.05
Focal tree decay + Canopy cover + Basal area of mast trees	6	3.95	0.04
Focal tree decay	4	4.01	0.04
Focal tree decay + Canopy cover + Mean surrounding decay + Basal area of mast trees	7	4.40	0.03

hickories, walnuts, and buckeyes. Mast trees in city park sites were rare; there was a maximum 2 per 0.04 ha plot. Instead many of the trees in city parks were maples or ornamental and introduced species that were not found in the forest preserves (e.g., red pine (*Pinus resinosa*), wahoo (*Euonymus atropurpureus*)).

## Discussion

The first goal of our study was to identify the characteristics of RHWO nest selection in an urban environment across three spatial scales in order to determine whether there were differences in characteristics being selected for in urban areas when compared to information from natural areas. As predicted, we found that RHWO tended to avoid urban zones on the landscape, and no nest trees were found in highly residential or business districts. Over smaller spatial extents we found that RHWO in Cook County were selecting nest trees that had i) high decay, and were in habitats with ii) lower canopy cover and iii) where there was higher surrounding fungal growth on trees. These factors may have been favored because they likely provide appropriate substrate in which RHWO can excavate a cavity for nesting and appropriate foraging habitat. Based on the locations of our nest trees, RHWO were capable of

**Table 4** Model-averaged odds ratios and 95 % confidence intervals from the variables included in the 90 % confidence models set combining focal tree and surrounding habitat variables around the binary response variable of RHWO nests (success) and control trees (failure)

Variable	Odds ratio	95 % CI	Variable importance weight
Focal tree decay	3.66	1.39–9.62	1.00
Canopy cover	$8.73 \times 10^{-5}$	$7.88 \times 10^{-3}$ –96.7	0.90
Trees with visible fungus	$1.43 \times 10^2$	$4.20 \times 10^{-1}$ – $4.83 \times 10^6$	0.74
Mean surrounding decay	1.70	0.71–4.03	0.37
Basal area of mast trees	1.00	0.99–1.00	0.26

**Table 5** Means and SE for additional habitat variables, measured in the 0.04 ha plots surrounding RHWO nest trees and control focal trees in Cook County, IL, USA

Variable	Cavity focal tree		Random focal tree		t	p
	$\bar{X}$	SE	$\bar{X}$	SE		
Tree density (ha <sup>-1</sup> )	208.08	21.31	226.41	21.31	0.70	0.487
Basal area(m <sup>2</sup> ha <sup>-1</sup> )	27.01	2.09	26.43	1.63	0.22	0.828
Dead-tree density (ha <sup>-1</sup> ) <sup>a</sup>	57.35	9.99	24.78	4.21	1.95	0.060
Snag density (ha <sup>-1</sup> ) <sup>a</sup>	26.47	5.37	11.76	3.21	1.60	0.119
Mast-tree density (ha <sup>-1</sup> ) <sup>a</sup>	72.79	14.45	93.75	15.30	1.31	0.199
Shrub layer (1–10) <sup>b</sup>	1.64	0.42	1.35	0.35	0.12	0.907

Analysis was conducted on <sup>a</sup> log(+1) transformed or <sup>b</sup> arcsine square root transformed values

residing in both forest preserves and large city parks, provided they had suitable nesting substrate. However, when comparing the landscape around nest sites to the landscape around randomly selected points, we found that there was a negative impact of the levels of urbanization at all four different distinctions (high density, medium density, low density, open space) on whether or not points were selected as RHWO nest sites. As a result of urbanization, physical barriers such as built area, roads, and areas without trees in urban environments may be detrimental to RHWOs' ability to find nesting habitat because urban areas have lower tree densities than natural areas (LaMontagne et al. 2015). In addition, urban areas are also under active management for public safety, which likely does not consider the needs of local wildlife, and therefore results in very few trees having dead branches or being snags (Blewett and Marzluff 2005; Carpaneto et al. 2010). Because decay is important for RHWO nest site selection on multiple spatial scales, the absence of decaying wood material in areas may limit RHWO nesting and contribute to the decline of RHWO in urban areas (Rodewald et al. 2005).

While we expected to find that RHWO were nesting more in forested areas, our analysis demonstrated that the area of surrounding forest in the landscape was not a good predictor of

**Table 6** Measurements of RHWO nest trees in city parks compared to nest trees in Forest Preserves in Cook County, IL, USA

Variable	City parks (n=7)		Forest preserves (n=27)		t	p
	$\bar{X}$	SE	$\bar{X}$	SE		
DBH	71.3	8.73	53.76	4.00	1.94	0.06
Decay class	3.00	0.37	4.05	0.16	2.82	0.008
% Canopy cover <sup>a</sup>	49.10	2.70	45.70	5.00	0.46	0.648
Surrounding tree density (ha <sup>-1</sup> )	71.42	19.90	239.81	21.23	3.89	<0.001
Surrounding Dead-tree Density (ha <sup>-1</sup> )	10.71	7.43	67.59	11.61	2.43	0.02
Surrounding Mast-tree Density (ha <sup>-1</sup> )	10.71	10.71	88.88	16.68	2.33	0.026

<sup>a</sup> Analysis was conducted on arcsine square root transformed values

whether or not a point was a nest site or a random location. This suggests that individual nest tree and the immediate surrounding habitat were more important in RHWO nest site selection than the broader landscape. RHWO historically nested in open oak savannah areas, and they have been found to actually occur less frequently in landscapes with a high percentage of forest cover (Graber et al. 1977; Gentry and Vierling 2008). We did find considerable variation in the forested area within the landscape around nests, and due to fragmentation in the urban environment the range of forest cover at the landscape scale around nests and random points may fall within the range where there was no strong selection. In our case, because of the heterogeneous forest-urban landscape of Cook County, forest patch shapes are long (generally along the Des Plaines River and the Cal-Sag Channel) but most are only approximately 1.5 km from east to west; meaning that in no case did the 1 km radius buffer include complete forest, and instead they included edge habitats and often surrounding housing and commercial areas.

We suggest, however, that the biological importance of forest areas as habitat should not be discounted. This is because most of the nest trees (27 of 34) were located within the forest preserve system of Cook County. At local scales where RHWO occur, we found that there were strong preferences for decayed trees and open canopy, which is consistent with natural areas (King et al. 2007; Waldstein 2012).

RHWO nests were closer to streams than random locations, but this could be an artifact of more natural lands in forest preserves having more stream sources. Streams could be important for RHWO nest selection as some of their insect food sources (e.g. dragonflies or damselflies) require an aquatic environment in which to lay eggs. Insects are the primary summer food source for RHWO (Smith et al. 2000), and bark dwelling insects may be related to decay processes and fungal development which our data suggest are important for RHWO nest site selection (Jackson and Jackson 2004). Additionally, reduced canopy cover may increase the ability of RHWO to catch food on the wing (Smith et al. 2000), thus suggesting the possibility that much of the nest selection process involves the insect food sources available in a given area. Further research should explore the arthropod communities surrounding RHWO nests and clarify the interactions between RHWO, insect food sources, and tree decay.

In addition to insect prey, RHWO also consume hard mast sources, but during the spring and summer nesting seasons when insects are plentiful, the role of hard nut crops may be less important in the selection of cavities for breeding RHWO (Beal 1911; Venables and Collopy 1989). The surrounding basal area of mast trees was not a parameter in any of our highly supported models, likely because much of the forest preserves in this region are comprised of mast trees (Forest Preserve District of Cook County 2001), and so there was little variation between nest sites and control sites in our study area. This may not be true for other areas in the extensive RHWO habitat range. In Ohio, Rodewald et al. (2005) found that RHWO used at least 15 tree species for creating nest cavities, but that 60 % of the nests were in either maples or oaks. In regions dominated by lodgepole pines, other conifers, or maple and ash species, RHWO may actively select for areas with trees that produce hard nut crops which can be cached for the winter (Smith et al. 2000). We looked specifically at cavities that were active during the breeding season, and did not address winter cavity usage. Further work is necessary to determine if the availability of acorns, beech nuts, walnuts etc. impacts the RHWO ability to remain in their cavities throughout the winter, thus removing the need to reclaim or excavate a new cavity in the subsequent spring.

This study demonstrated that RHWO are capable of living in close proximity to human development, as seven of our nest trees were located in city parks within approximately 12 km

of the highly urban center of Chicago, IL. However, there were significant differences in characteristics of RHWO nest trees in city parks versus those in forest preserves. Generally, there was a much higher density of trees in forest preserves than parks, which is likely the cause of higher densities of both mast-producing trees and dead trees. However, the most relevant differences are arguably in the DBH and decay classes of nest trees. While city parks included significantly larger trees, they were not as decayed as those nest trees found in forest preserves. Snags and dead branches are safety hazard, and are often removed from city parks, which are rigorously maintained for human recreation. As a result, habitat quality in city parks may not be ideal for RHWO, and could be a limiting factor to nesting in these spaces. Retaining dead limbs or limb stumps may be a reasonable conservation strategy because most of our observed cavities were on branches rather than trunks (Appendix B), which is consistent with other findings about excavated cavities in urban areas (LaMontagne et al. 2015). When it does not pose a high risk for human users, retaining some dead, decaying, and fungal-inoculated wood in the form of dead limbs or limb stumps extending from the trunk ~30 cm in parks could potentially contribute to encouraging RHWO nesting in urban areas while minimizing human safety risks.

It is important to note that urban areas contain much less potential habitat for RHWO than natural areas because approximately only 17 % of our study area is forest preserve or city park property. Most additional trees within Cook County are located on private property where land management is overseen by homeowners or businesses rather than professionals in the field (Nowak et al. 2010). Furthermore, the loss of habitat in and around cities is ongoing. Human populations are growing and urban areas are expected to increase in size and density (UN DESA 2011), which will by extension reduce the available habitat for wildlife as well as increase the associated urban risks without direct consideration and mitigation (Magle et al. 2010). When tree density is considered, the density of excavated cavities in forested areas is 14 times that in residential and park areas (LaMontagne et al. 2015), supporting our finding that RHWO nested primarily in forest preserves, which are better equipped to meet the needs of cavity excavators.

Understanding RHWO nesting habitat selection across different spatial scales in an urban landscape contributes to a more comprehensive assessment of the nesting needs of RHWO, a near-threatened species, which has thus far only been evaluated in rural and natural areas (e.g., Stauffner and Best 1982; Venables and Collopy 1989; King et al. 2007). While we were limited to evaluating 34 nest trees in our study area, these results are similar to results from studies of RHWO nesting in rural and natural areas (DeGraff et al. 1980; Kahl et al. 1985; Hamel 1992, Jackson and Jackson 2004). Additionally, our sites represent the all of the identifiable RHWO nests reported in Cook County from 2010 to 2013, and low species abundance is an unavoidable reality when working with species of conservation concern, and in an area with fragmented habitat (Blewett and Marzluff 2005).

The difficulty of juxtaposing RHWO needs with the impacts of urban centers is compounded by the fact that Chicago is not the only highly urban area that intersects historic RHWO range. There are ten cities with human population censuses of over one million inhabitants in the United States and Canada that fall within the range of RHWO, and areas of sprawling suburban areas surrounding these metropolises and other smaller cities and towns (Statistics Canada 2011, US Census Bureau 2010). Our study corroborates the importance of dead and decaying wood and open canopy for RHWO nesting in urban areas as compared to natural areas. While these may not be the only factors that are locally important in all cities, our

results combined with the literature from natural areas suggests that promoting the retention of dead wood and open canopy is a viable starting place for habitat conservation in urban centers.

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## Appendix A

**Table 7** Characteristics of individual focal trees that contained RHWO nests ( $n=34$ ) and random controls ( $n=204$ )

Variable	Nest tree ( $n=34$ )		Control tree ( $n=204$ )	
	n	%	n	%
Tree genus				
<i>Tilia</i> (American Basswood)	1	2.94	3	1.47
<i>Prunus</i> (Black Cherry)			6	2.94
<i>Robina</i> (Black Locust)			1	0.49
<i>Acer</i> (Maple ssp)	2	5.88	23	11.27
<i>Quercus</i> (Oak ssp)	14	41.18	105	51.47
<i>Catalpa</i>			3	1.47
<i>Populus</i> (Eastern Cottonwood)	3	8.82	19	9.31
<i>Fraxinus</i> (Ash ssp)	1	2.94	14	6.86
<i>Celtis</i> (Hackberry)			2	0.98
<i>Gleditsia</i> (Honey Locust)	1	2.94	2	0.98
<i>Aesculus</i> (Horse Chestnut)			1	0.49
<i>Carya</i> (Hickory ssp)			5	2.45
<i>Pinus</i> (Red Pine)			1	0.49
<i>Ulmus</i> (Elm ssp)	5	14.71	5	2.45
Unidentifiable	6	17.65	1	0.49
<i>Morus</i> (White Mulberry)			3	1.47
<i>Juglans</i> (Walnut ssp)	1	2.94	8	3.92
<i>Aesculus</i> (Yellow Buckeye)			2	0.98
Decay class				
1 (100 % living)	0	0.00	16	7.84
2 (1–49 % dead)	4	11.76	66	32.35
3 (50–99 % dead)	9	26.47	113	55.39
4 (100 % dead)	10	29.41	8	3.92
5 (snag)	11	32.35	1	0.49

Parenthetical listings are the only species of that genus found in our sites

## Appendix B

**Table 8** Location of RHWO cavity nests on trees ( $n=53$  cavities)

	Location on tree	n	Proportion
Primary branches extend directly from the trunk, and secondary branches extend from primary branches	Trunk	15	0.28
	Primary branch	33	0.62
	Secondary branch	5	0.09

## References

- Beal FEL (1911) Food of the woodpeckers of the United States. U.S. Department of Agriculture Biological Survey Bulletin no. 37
- Blewett CM, Marzluff JM (2005) Effects of urban sprawl on snags and the abundance and productivity of cavity-nesting birds. *Condor* 107:678–693
- Bull EL, Parks CG, Torgersen TR (1997) Trees and logs important to wildlife in the interior Columbia River basin. USDA Forest Service General Technical Report PNW-GTR-391
- Burnham KP, Anderson DR (1998) Model selection and inference: a practical information-theoretic approach. Springer, New York
- Carpaneto GM, Mazziotta A, Coletti G, Luiselli L, Audisio P (2010) Conflict between insect conservation and public safety: the case study of a saproxylic beetle (*Osmoderma eremita*) in urban parks. *J Insect Conserv* 14:555–565
- Cockle KL, Martin K, Wesolowski T (2011) Woodpeckers, decay, and the future of cavity-nesting vertebrate communities worldwide. *Front Ecol Environ* 9:377–382
- Conner RN, Saenz D (1996) Woodpecker excavation and use of cavities in polystyrene snags. *Wilson Bull* 108:449–456
- Conway CJ, Martin TE (1993) Habitat suitability for Williamson's Sapsuckers in mixed-conifer forests. *J Wildl Manag* 57:322–328
- Cooke HA, Hannon SJ (2012) Nest-site selection by old boreal forest cavity excavators as a basis for structural retention guidelines in spatially-aggregated harvests. *For Ecol Manag* 269:37–51
- DeGraff RM, Wentworth JM (1986) Avian guild structure and habitat associations in suburban bird communities. *Urban Ecol* 9:399–412
- DeGraff RM, Whitman GM, Lanier JW, Hill BJ, Keniston JM (1980) Forest habitat for birds of the Northeast. USDA Forest Service, Northeast Forest Experimental Station, Radnor
- Doherty PF Jr, Grubb TC Jr, Bronson CL (1996) Territories and caching-related behavior of Red-headed Woodpeckers wintering in a beech grove. *Wilson Bull* 108:740–747
- Drever MC, Aitken KEH, Norris AR, Martin K (2008) Woodpeckers as reliable indicators of bird richness, forest health and harvest. *Biol Conserv* 141:624–634
- Edworthy AB, Wiebe KL, Martin K (2012) Survival analysis of a critical resource for cavity-nesting communities: patterns of tree cavity longevity. *Ecol Appl* 26:1733–1742
- Forest Preserve District of Cook County, State of the Land Today. December (2001) <http://www.habitatproject.org/webdocs/misc/FPDCCReportStateOfLandToday2001.pdf>
- Frei B, Fyles JW, Nocera JJ (2013) Maladaptive habitat use of a North American woodpecker in population decline. *Ethology* 119:377–388
- Garaffa PI, Filloy J, Bellocq MI (2009) Bird community responses along urban-rural gradients: Does the size of the urbanized area matter? *Landsc Urban Plan* 90:33–91
- Gehrt SD, Anchor C, White LA (2009) Home range and landscape use of coyotes in a metropolitan landscape: conflict or coexistence? *J Mammalogy* 90:1045–1057
- Gentry DJ, Vierling KT (2008) Reuse of woodpecker cavities in the breeding and non-breeding season in old burn habitats in the Black Hills, South Dakota. *Am Midl Nat* 160:413–429
- Germaine SS, Rosenstock SS, Schweinsburg RE, Richardson WS (1998) Relationships among breeding birds, habitat, and residential development in greater Tuscon, Arizona. *Ecol Appl* 8:680–691



- Graber JW, Graber RR, Kirk EL (1977) Illinois birds: Picidae. Illinois Natural History Survey, Biological Notes No. 102, Urbana, USA
- Hamel PB (1992) Land manager's guide to the birds of the South. The Nature Conservancy, Chapel Hill
- Hudson NC, Bollinger EK (2013) Nest success and nest site selection of Red-headed Woodpeckers (*Melanerpes erythrocephalus*) in East-central Illinois. *Am Midl Nat* 170:86–94
- Hurvich CM, Tsai CL (1989) Regression and times series model selection in linear regression. *Biometrika* 76: 297–307
- Illinois Department of Natural Resources (2005) The Illinois comprehensive wildlife conservation plan & strategy. <http://www.dnr.illinois.gov/conservation/IWAP/Documents/WildlifeActionPlanFinal.pdf>
- Illinois Department of Transportation (2012) Illinois Technology Transfer Center. <http://gis.dot.illinois.gov/gist2/>
- Illinois Natural History Survey (2003) Land Cover manual and atlas: Illinois GAP analysis project. Center for Wildlife Ecology, Champaign
- Illinois Natural History Survey (2012) Illinois Gap Analysis Project (IL-GAP). <http://www.inhs.illinois.edu/research/gap/landcover/>
- Ingold DJ (1994) Influences of Nest-Site competition between European starlings and Woodpeckers *Wilson Bull* 106, 227–241
- Jackson JA, Jackson BJS (2004) Ecological relationships between fungi and woodpecker cavity sites. *Condor* 106:37–49
- Johnson DH (1980) The comparison of usage and availability measurements for evaluations of resource preference. *Ecology* 61:65–71
- Kahl RB, Baskett TS, Ellis JA, Burorunghs JN (1985) Characteristics of summer habitats of selected nongame birds in Missouri. University of Missouri Agriculture Experiment Station Research Bulletin 1056. University of Missouri, Columbia, Missouri, USA
- Kilgo JC, Vukovich M (2011) Factors affecting breeding season survival of red-headed woodpeckers in South Carolina. *J Wildl Manag* 76:328–355
- King RS, Brashear KE, Reiman M (2007) Red-headed Woodpecker nest-habitat thresholds in restored savannas. *J Wildl Manag* 71:30–35
- LaMontagne JM, Kilgour RJ, Anderson EC, Magle S (2015) Tree cavity availability across forest, park, and residential habitats in a highly urban area. *Urban Ecosyst* 18:151–167
- Landres PB, Verner J, Thomas JW (1988) Ecological uses of vertebrate indicator species: a critique. *Conserv Biol* 2:316–328
- Loss SR, Ruiz MO, Brawn JD (2009) Relationships between avian diversity, neighborhood age, income, and environmental characteristics of an urban landscape. *Biol Conserv* 142:2578–2585
- Magle SB, Hunt VM, Vernon M, Crooks KR (2010) Urban wildlife research: past, present, and future. *Biol Conserv* 155:23–32
- Martin TE, Paine CR, Conway CJ, Hochachka WM, Allen P, Jenkins W (1997) BBIRD (Breeding Biology Research and Monitoring Database) field protocol. Montana Cooperative
- Marzluff JM, Gehlbach FR, Manuwal DA (1998) Urban environments: influences on avifauna and challenges for the avian conservationist. In: Marzluff JM, Bowman R, Donnelly R (eds) *Avian ecology in an urbanizing world*. Kluwer, Norwell, pp 283–296
- Maser C, Anderson RG, Cromack K, Williams Jr JT, Martin ER (1979) Dead and down wood material. In: Thomas JW (ed) *Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington*. U.S. Department of Agriculture Agricultural Handbook 553. pp. 78–95
- National Audubon Society (2008) The christmas bird count historical results. National Audubon Society, Ivyland
- Norris AR, Martin K (2008) Mountain pine beetle presence affects nest patch choice of Red-breasted Nuthatches. *J Wildl Manag* 72:733–737
- Nowak DJ, Hoehn RE III, Crane DE, Stevens JC, Leblanc Fisher C (2010) Assessing urban forest effects and values, Chicago's urban forest. Resource Bulletin NRS-37. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station, pp 27
- Pulich WM (1988) The birds of north central Texas. Texas A&M Press, College Station
- Rich TD, Beardmore CJ, Berlanga H, Blancher PJ, Bradstreet MSW, Butcher GS, Demarest DW, Dunn EH, Hunter WC, Ingo-Elias EE, Kennedy JA, Martell AM, Panjabi AO, Pashley DN, Rosenberg KV, Rustay CM, Wendt JS, Will TC (2004) Partners in Flight North American Landbird conservation plan. Cornell Lab of Ornithology, Ithaca
- Rodewald PG, Santiago MJ, Rodewald AD (2005) Habitat use of breeding red-headed woodpeckers on golf courses in Ohio. *Wildl Soc Bull* 33:448–453
- Sadoti G (2012) Nesting ecology of common Black-hawks in relation to landscape features. *J Raptor Res* 46: 296–303
- Sauer JR, Hines JE, Fallon J (2008) The North American Breeding Bird Survey, results and analysis 1966–2007. United States Geological Survey

- Smith KG, Scarlett T (1987) Mast production and winter populations of Red-headed Woodpeckers and Blue Jays. *J Wildl Manag* 51:459–467
- Smith KG, Withgott JH, Rodewald PG (2000) Red-headed woodpeckers (*Melanerpes erythrocephalus*). *Birds North Am* 518:1–27
- Statistics Canada (2011) 2011 cumulative profile. CANSIM. Using E-Stat. [http://estat.statcan.ca/cgi-win-CNSMCGLEXE?CANSIMFILE=ESTAT\English\CII\\_1\\_E.htm](http://estat.statcan.ca/cgi-win-CNSMCGLEXE?CANSIMFILE=ESTAT\English\CII_1_E.htm). Accessed 1 May 2014
- Stauffer DF, Best LB (1982) Nest-site selection by cavity-nesting birds of riparian habitats in Iowa. *Wilson Bull* 94:329–337
- Symonds MRE, Moussalli A (2011) A brief guide to model Selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. *Behav Ecol Sociobiol* 65:13–21
- Tews J, Brose U, Grimm V, Tielberger K, Wichmann MC, Schwagger M, Jeltsch F (2004) Animal species diversity driven by habit heterogeneity/diversity: the importance of keystone structures. *J Biogeogr* 32:79–92
- Thomas JW, Miller RJ, Black H, Rodiek JE, Maser CBK (1976) Guidelines for maintaining and enhancing wildlife habitat: forest management in the Blue Mountains of Oregon and Washington. Transactions of the North American wildlife and natural resources conference, No. 41. Wildlife Management Institute, Washington, DC
- Thompson JR, Fleishman E, Mac Nally R, Dobkin DS (2005) Influence of temporal resolution of data on the success of indicator species models of species richness across multiple taxonomic groups. *Biol Cons* 124: 503–518
- Thorne Smith E (1972) Chicagoland birds: where and when to find them. Field Museum of Natural History Press, Chicago, p 33
- Titus R (1983) Management of snags and cavity trees in Missouri—a process. In: Davis JW, Goodwin GA, Ockenfelf RA (eds.) Snag Habitat Management Proceedings of the Symposium, Flagstaff, Arizona. 7–9 June 1983. US Forest Service General Technical Report RM-99. pp 51–59
- Tweit RC, Tweit JC (1986) Urban development effects on the abundance of some common resident birds of the Tucson area of Arizona. *Am Birds* 40:431–436
- U.S. Fish and Wildlife Service (2008) Birds of Conservation Concern 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia. 85 pp. [Online version available at <<http://www.fws.gov/migratorybirds/>>]
- United Nations Department of Economic and Social Affairs (UN DESA) (2011) Population distribution, urbanization, internal migration and development: an international perspective. United Nations, pp.6–31
- United States Census Bureau (2010) Census 2010 Population Profile. <http://www.census.gov/2010census/popmap/>. Accessed 1 May 2014
- Venables A, Collopy MW (1989) Seasonal foraging and habitat requirements of Red-headed Woodpeckers in north-central Florida. Nongame Wildlife Program Final Report Project no. GFC-84-006. Florida Game Fresh Water Fish Commission
- Vierling K, Lentile L (2006) Red-headed Woodpecker nest-site selection and reproduction in a mixed ponderosa pine and aspen woodland following fire. *Condor* 108:957–962
- Waldstein AL (2012) Nest-site selection and nesting ecology of Red-headed Woodpeckers. Master's Thesis
- Zar JH (1999) Biostatistical analysis, 4th edition. Prentice Hall