

Effects of local vegetation and landscape patterns on avian biodiversity in the
threatened oak habitat of the Willamette Valley, Oregon

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Abstract

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Both fine scale patterns of vegetation and coarser scale landscape patterns affect bird community composition and structure. However, the relative importance of the drivers at these two spatial scales continues to be debated. Here, we show how the factors that drive avian diversity and community structure depend on context, including the particular environment studied, the response variables analyzed, and the groups of species examined. We explored the relative roles of landscape pattern and stand structure and composition in defining bird communities in 44 remnant oak stands in the Willamette Valley, Oregon. We focused on two key questions—are bird communities influenced more by landscape patterns (at the matrix and patch levels) or stand composition and structure, and in what contexts are each of these spatial scales more important. We conducted point counts to determine avian abundance, richness, and evenness and categorized birds into functional groups based on diet and foraging tactics. We then used canonical correspondence analysis and generalized linear models to analyze overall community

patterns, functional group diversity, synanthropic and non-synanthropic species diversity, and the abundance of individual species of concern. Both local and landscape factors significantly influenced each group of avian species for every measure of diversity we tested, but their relative importance varied markedly. Local factors explained four times more variance than landscape factors for overall species diversity and double the variance for two functional groups. For the other functional groups, landscape factors were up to ten times more important. We found the same high variability for individual species, depending on the species evaluated. When we evaluated factors more specifically at the landscape level, we found that the surrounding matrix was much more important than patch variables for each group of birds we tested. However, we also found that patch size influenced some groups and individual species much more than others, and some not at all. Understanding the degree to which species respond to local environmental conditions and landscape patterns is an essential part of optimizing scarce conservation resources and our results indicate that such an understanding will need to be put into very specific context.

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Chapter 1 - Effects of local vegetation and landscape patterns on avian biodiversity in the threatened oak habitat of the Willamette Valley, OR

Introduction

Many forest birds throughout the U.S. are in decline (Butcher and Niven 2007, Robbins et al. 1987a). These declines have been attributed, in part to the loss, fragmentation and degradation of habitat (Robinson et al. 1987, Askins and Philbrick 1987). Although many studies have linked birds with specific aspects of vegetation and landscape patterns, we still have a relatively rudimentary understanding of many of the factors that structure avian communities. One critical gap in our understanding is the degree to which the bird community is structured by local patterns of vegetation structure and composition versus landscape scale patterns and how these impacts change across different landscapes or for different communities of birds.

It has long been known that ecological niches of many species can be defined by the structure and composition of vegetation within their territory or home range (Grinnell 1917, Hildén 1965, James and Shugart 1970, James 1971). In 1961, MacArthur and MacArthur began studies of the effects of structural height diversity on avian species and studies since then continue to confirm the importance of vertical complexity on avian species diversity (Roth, 1976, Moss 1978, Hodgkinson et al. 2007, Ranganathan et al. 2008). In oak forests of the Willamette Valley, Oregon, Hagar and Stern (2001) found that shifting vegetation structure from open to closed canopy and from a dominant oak forest to a mixed oak/coniferous forest is influencing the avian species composition.

Compared to studies of local vegetation effects on avian communities, it has only more recently been established that birds respond to landscape patterns (e.g., Freemark et al. 1995, Hawrot and Nieme 1996). Initially those studies predominantly focused on how patch size, shape and

isolation (or connectivity) influence species, populations, and communities. In 2008, however, Prugh et al., using a meta-analysis to look at which landscape patterns affect wildlife communities, found that area and isolation by themselves were often poor predictors of occupancy, although avian species were most affected by patch size (on average, 24% of explained deviation). They showed that for all species examined, the surrounding matrix most often helped explain the remaining variation.

Although it is now known that birds respond to both local vegetation and landscape patterns, it is not yet clear which of these factors is more important for explaining avian biodiversity or in structuring communities. For example, some previous analyses found local environmental factors to be more influential in structuring avian communities (Fletcher and Hutto 2008 – in riparian habitat, Roberts 2001 – in mixed forests of Wisconsin) whereas others have found that landscape factors dominate (Smith and Wachob 2006 – in riparian habitat). Still others found that both local and landscape factors strongly influence the avian communities (Hodgkinson et al. 2007 – in habitat refuges like golf courses, Mahon et al. 2008 – in coniferous or mixed forests of British Columbia, Canada).

To date, only one meta-analysis has evaluated whether landscape or local variables affected species diversity and occupancy (Mazerolle and Villard 1999). However, Mazerolle and Villard (1999) were unable to compare the magnitude of the effects and simply examined whether each level had any effect at all for each study. They found local patch variables were predictors in almost all studies (93.4%) and landscape variables in 79.5% of the studies on vertebrate species (59% for all species) but could not compare which level was more significant in each study (nor

a quantified significance for all studies).

Here, we investigate the degree to which local and landscape factors affect avian communities in the threatened oak habitats of the Willamette Valley. These oak woodlands, dominated by Oregon white oak (*Quercus garryana*), once covered much of the Willamette Valley and extended up into the Puget Trough in Washington. Presently, these oak habitats suffer from conifer encroachment due to fire suppression as well as conversion to agriculture and urban areas. In the absence of regular burning, many oak habitats have been invaded by conifers and other hardwoods, particularly in the foothills of the Coast Range and Cascades. Today, less than one percent of historical Oregon white oak savannah and forest in the Willamette Valley remains (Oregon Department of Fish and Wildlife 2006, Ingersoll and Wilson 1999, Noss et al. 1995). The remaining savannah and woodlands of the Willamette Valley provide habitat for several threatened and endangered species including the Fender's blue butterfly (*Icaricia icarioides fenderi*), Kincaid's lupine (*Lupinus sulphureus ssp. kincaidii*), golden paintbrush (*Castilleja levisecta*), Nelson's checker-mallow (*Sidalcea nelsoniana*), Willamette daisy (*Erigeron decumbens var. decumbens*), and Bradshaw's desert parsley (*Lomatium bradshawii*). They also provide a unique set of habitat characteristics for several at risk bird species and a diverse avian community (Hagar and Stern 2001).

We explore the extent to which vegetation and landscape patterns affect avian community composition and diversity in Willamette Valley oak stands at three spatial scales for four groups of birds using multiple response variables. We assess the relative influence of local, within patch variables (such as number of tree stems and foliage height diversity), landscape patch variables

(such as area and perimeter) and landscape matrix variables (such as percentage of surrounding area that is agricultural or developed land). We focus on avian diversity and composition for the entire bird community, for synanthropic and non-synanthropic species, for functional groups and for several avian species of concern. We examine both community composition and three diversity measures – richness, abundance and evenness.

Methods

Study area and site selection

Our study area, the Willamette Valley in Oregon, USA, is a 120-mile long watershed up to 40 miles wide draining into the Columbia River on its northern border (Fig. 1). It covers approximately 12,000 square miles (over 31,000 km²) and is bounded by the Columbia River in the north, the Calapooya Mountains in the south, and the crests of the Oregon Coast Range and Cascade Range in the east and west, respectively.

Our study focused on oak savannah and woodlands within the Willamette Valley, which occur mostly on privately owned lands. Because access issues (especially on private lands) and lack of suitable oak habitat maps eliminated the possibility of stratifying our sites randomly by explanatory variables, we chose sites opportunistically. We contacted approximately 25 researchers and known landowners with oak patches on their properties. We identified 103 survey points in 75 sites, all strategically located within a two hour drive of each other (centered around Eugene and Corvallis, OR) to maximize the number of sites visited per day and within the short breeding bird season in the Willamette Valley (Fig. 1). Sites ranged in size from roughly 596 m² to 401,729 m² (Appendix, Supplementary Table 1). Thirty-three sites (44%)

were located on private lands and 42 sites (56%) on public lands.

We define a site or oak “patch” as a distinct cluster of oak savannah (between 10 and 50% tree cover on the landscape) or woodland (greater than 50% tree cover) containing at least 50% *Quercus garryana* (Garry oak) and/or *Quercus kelloggii* (California black oak) trees. All of our sites were dominated by these two oak species (>50% oak) and were located in non-riparian areas.

Avian surveys

We conducted over 400, 50-meter fixed-radius point count surveys at 103 sample points (points) in 75 oak patches (sites), based on the methods described in Bibby et al. (2000) and Huff et al. (2000). The patchy nature of our habitat precluded using variable distance estimators and calculating detectability. Locations were visited a minimum of two times per year during the breeding season of May 15 to July 8, 2010 and 2011 (ten sites were visited six to nine times for sampling intensity analyses). To minimize error between observers, we used a single observer for all sites in both years. All point counts were conducted between 0.5 hours prior to and 4.25 hours after sunrise. For each point, we recorded all birds identified by sight or sound during a ten-minute period. Nocturnal species, raptors and birds that were flying over or through a patch were noted but not further analyzed, but birds circling above the canopy and using the site were included in our analyses (e.g., swallows foraging above the canopy). Counts were not done in heavy rain or strong wind. We recorded temperature, cloud cover (total, partial, none) and the location (measured with a GPS) of each point.

For each site, one to four point counts were conducted per visit. Where breadth of a site exceeded 100 m in at least one dimension, multiple counts were done, spaced at least 50 m apart, maximizing total possible points within each site while minimizing double-counting of birds across points. When we estimated site size to be less than 10,000 m² (or less than 100 m in any direction), a single point count was conducted at what was approximated as the middle of the site. Sites served as our experimental units for all subsequent analyses, while multiple survey points per site strengthened our individual site accuracy.

Vegetation surveys – Local habitat characteristics

We selected local patch variables and applicable plot sizes based on a literature search of variables important to avian diversity (James and Shughart 1970, Smith and Wachob 2006, Hagar and Stern 2001, Fletcher and Hutto 2008, James 1980, MacArthur and MacArthur 1961, MacArthur 1962, MacArthur et al. 1966, Moss 1978, Hodgkinson et al. 2007, Mahon et al. 2008, Donnelly and Marzluff 2006, Robbins et al. 1989b). We determined canopy cover by averaging four densitometer readings at 0, 90, 180 and 270° one meter from the estimated centermost tree (equal to the GPS coordinate). We estimated average canopy height in the patch using a laser range finder. We counted the number of snags (standing dead trees) and fallen logs within a circle of 0.04 ha (0.1 acre) radius from the center of the point. We counted the number of trees of each species within the same 0.04 ha plot and placed them into one of seven size classes based on their diameter at breast height (dbh); <2.5 cm, 2.5-8 cm, 8-15cm, 15-23 cm, 23-38 cm, 38-60 cm and >60 cm (James and Shughart 1970). We calculated the total number of seedling (dbh <2.5 cm), sapling (2.5 < dbh <8 cm), and large (dbh >8 cm) oak, non-oak deciduous, coniferous and all tree species. We estimated the percentage of ground cover that was covered by grasses or

forbes, bare ground, impervious surface and water within a circle of 0.01 ha (0.025 acre) radius from the center point. Within the same area circle, we estimated the percentage of the understory covered by tree saplings and what percentage was *Rhus diversiloba* (poison oak) and *Rubus discolor* (Himalayan blackberry), identified in the first field season as the main invasive understory species in our sites. For each point, we counted the number of nest boxes, noted the presence of recent tree harvest, cow and/or sheep grazing, and estimated the percentage of impervious area and water within 50 m of the point (Appendix, Supplementary Table 1).

Height diversity was measured based on the methods in Moss (1978). Using a ruler and a laser rangefinder, for each vegetation layer, we measured the height of the lowest, the highest and the most widespread vegetation points as well as the percentage of the vegetation that the most widespread point covered at the center of the point and at four random points within 50 m of the center point. These layers included one or more ground cover, understory (shrub) and canopy (tree) layers. Later, we sketched a profile of each layer using these data.

Site and matrix mapping – Landscape characteristics

For each patch we used a 1 Trimble Juno (GPS + Handheld Computer) and 1 TruPulse 360B Rangefinder installed with ArcPad 7.1.1 to mark the location of the outermost oak trees within the patch, creating the patch perimeter. We used two criteria for determining the edge of the patch. A tree was outside the patch if 1) it was farther than 20 m from the nearest oak tree or farther than the average distance between trees within the patch, whichever was greater and 2) density more than doubled or decreased by more than half the average of the rest of the patch. Using these criteria, we created ArcGIS shapefiles for 75 oak sites from the 103 survey points.

Data analyses

Our experimental unit is the oak patch, and we computed three measures of avian diversity – abundance, richness and evenness – for each patch. Mean relative abundance, calculated as the mean number of individual birds detected per site, per survey, has been shown to be preferable to other metrics of abundance (Hepinstall et al. 2008). We calculated mean richness as the mean number of avian species for each point per survey, averaged for the site. For example, if a site had three points averaging three, five and eight species over four visits (two per year), the richness for that site would be 5.3. We calculated evenness using the Shannon Index for diversity divided by the natural logarithm of total species (S):

$$\text{Evenness} = -\sum p_i \ln(p_i) / \ln(S)$$

where p_i is the fraction of species i within S , the total number of species at that site.

We grouped bird species into functional groups based on each species' foraging habitat, behavior and food preferences (Ehrlich et al. 1988, Poole 2005) (Appendix, Supplementary Table 4).

Using the Cluster Package, Agnes method in R Project for Statistical Computing, v.2.14.1 (R) (R Development Core Team 2010, Oksanen 2010), we grouped species based on a hierarchical cluster analysis using Euclidean distance and the unweighted pair-group method using arithmetic averages (UPGMA) with standardized variables having a zero mean and unit variance (as done in other avian studies, e.g. Flynn et al. 2009, Petchey and Gaston 2002, Jaksic and Medel 1990).

This process resulted in a dendrogram depicting potential cluster groups (Appendix, Supplementary Fig. 1). Twenty functional groups were separated and used in subsequent analyses (Appendix, Supplementary Table 4). One additional group consisted entirely of raptors and nocturnal species and was removed from any subsequent analyses.

We calculated height diversity of the vegetation layers using the Shannon Index for diversity:

$$\text{Height diversity} = -\sum p_i \ln(p_i)$$

where p_i is the percentage coverage of each layer (Moss 1978). Areas, perimeters, core areas and the ratios of area to perimeter were calculated for each patch shapefile using Hawth Tools (Beyer 2006) in ArcGIS, v.9.3.1 (ESRI 2009).

To assess the composition of the surrounding matrix, we used digital sample plots of 570,000 m² (425 m radius, medium buffer) and 1,542,500 m² (701 m radius, large buffer), based on biologically relevant known territory sizes for bird species found in our sites (Poole 2005). These correspond to the median and 75th percentile of home-range scores (the 25th percentile equaling 70,000 m² was smaller than many of our sites and so we did not use it). Within each buffer, we calculated the percentage of the area covered by oak forests, other forest types (including coniferous, other deciduous and mixed forests), development (including urban, suburban, residential, commercial and rural), agriculture (crops, seeds, grains, nurseries, berries, vineyards, hops, mint, grass fields, hayfields, pastures, orchards and tree lots) and everything else (roads, water, bare ground, etc.) from the vegetation layer. The vegetation layer we used (NatureServe 2005) had an 81% overall fuzzy accuracy and a 59% deterministic accuracy calculated using the error analysis described in Jensen (2004).

We narrowed the original set of 75 patches to 44 patches because the proximity of some of the patches caused some of the buffers to overlap. We limited buffer overlap to a maximum of 25% for medium buffers (or 30% for larger buffers). This resulted in a median overlap of 0% for both medium and large buffers, and a mean of 3% and 6% for medium and large buffers, respectively.

Of the remaining 44 sites, 50% were on public and 50% on private lands.

Canonical correspondence analysis (CCA)

We examined the effects of the measured local, patch, and matrix variables on overall avian community structure using CCA in the Vegan Package in R (Oksanen et al. 2011). CCA is a direct ordination technique that arranges sites and species along environmental gradients. We chose this approach because it can be used with large, complex data sets without preprocessing, it does not produce the arch effect found in other ordination techniques, it can handle rare species and it produces quantified effects of environmental variables on sites and species (Palmer 1993, Ter Braak 1986).

We reduced our list of candidate explanatory variables to six local and six landscape variables by excluding obviously correlated variables (e.g., area and core area) and variables with relatively uniform distributions across sites (e.g., few sites contained any nest boxes or were recently cut) (Table 1). We used a combined forward and backward stepwise model building approach in CCA in conjunction with Monte Carlo permutation tests (1000 random permutations) to determine which of these environmental factors explained a significant amount of variation in the species communities across sites and which spatial scales (local, patch or matrix) were most significant.

We performed CCA and partial CCA on the overall bird community, on synanthropic and non-synanthropic groups of species separately and on species split into their functional groups.

Partially constrained CCA allowed us to separate out the effect of one set of variables (e.g., local

effects) after removing the effects of another set (e.g., landscape effects). Hence, we determined local, patch, matrix and shared effects (e.g., matrix and patch) for all of our sets of avian species.

The results of the canonical correspondence analyses are illustrated in triplots, depicting species, sites and environmental variables on one plot (we sometimes use biplots for simplicity, showing only species or sites but not both). Vectors represent environmental variables whereas site codes and species codes represent the centroids of the weighted averages of each relative to the CCA axes (Ter Braak 1986, Palmer 1993). Longer vectors indicate stronger relationships whereas the position of a vector relative to another vector indicates the amount of correlation among environmental variables. The position of a species (or site) relative to a vector indicates how strongly it is positively or negatively associated with that factor.

Generalized linear models (GLMs)

We built GLMs to analyze the effects that local, patch and matrix variables have on the richness and abundance of all identified species, the richness and abundance of synanthropic and non-synanthropic species, the richness and evenness of our 20 functional groups, the abundance of each functional group and the abundance of four key species of concern. Three additional species of concern that we identified were found in fewer than 10% of our sites, precluding the use of GLMs for these species. We used GLMs because our preliminary data analyses showed no complex relationships, all of our variables were approximated by or could be transformed to have normal distributions and these models could determine which variables or sets of variables had the largest influence on our three diversity measures.

For the GLMs, we reduced our set of explanatory variables from the original list by excluding one of any two explanatory variables exceeding a pairwise Spearman correlation of $|0.8|$ to limit multicollinearity (Ritters et al. 1995, Bollamnet al. 2005). We arcsine-transformed all proportion data (canopy cover and all surrounding matrix percentages including oak forests, other forests, development and agricultural lands) and used the square root transformation with variance stabilizing properties ($x=\sqrt{x} + \sqrt{x+3/8}$) for all Poisson distributed data (area, canopy height and total tree stems) (Zar 1999). Total large tree stems, canopy height and height diversity were all normally distributed and did not need transformation. All GLM models were constructed in R.

To identify the most biologically relevant models, we used the small sample size Akaike's Information Criterion (AICc) to rank all candidate models (Akaike 1973, Burnham and Anderson 2002). This criterion is recommended when the ratio of sample size to explanatory variables is less than 40:1 (Burnham and Anderson 2002). We identified the lowest AICc ($AICc_{min}$) as the best model and any models having an AICc of $AICc_{min} - 2$ as viable alternatives (Burnham and Anderson 2002). We also used GLMs to partition the variation explained by local, landscape and shared local and landscape factors on the richness, evenness and abundance of birds for the groups described above. For analyses in which the null model was a viable model using the AICc criteria described above, we did not calculate the variation in avian diversity explained by local, landscape and shared local and landscape factors.

Results

We identified 5840 birds of 74 species in the 75 sites in the Willamette Valley. Of the 74 avian species identified, we classified 45 as synanthropic species, and 29 as non-synanthropic, based on established lists of synanthropic species in the literature (Johnston, 2001, Donnelly and Marzluff, 2006, Appendix, Supplementary Table 5). We identified seven sensitive and/or oak-associated bird species from the literature to be further analyzed – Acorn Woodpeckers, Anna's Hummingbirds, Chipping Sparrows, Western Bluebirds, Western Meadowlarks, Western Scrub Jays and White-breasted Nuthatches (Altman 2011, Huff et al. 2005). Hagar and Stern (2001) suggest the White-breasted Nuthatch may be the most threatened species in this habitat whereas Huff et al. (2005) note that the Acorn Woodpecker, the Western Scrub Jay and the White-breasted Nuthatches are the species most affected by decline in oak habitats due to fire suppression. Species and their codes are listed in Appendix, Supplementary Table 2. After removing all raptors (Red-tailed Hawks and American Kestrels), nocturnal species (Great Horned Owls) and any species flying over or through but not using the habitat and reducing the number of analyzed sites due to buffer overlaps, 4990 birds of 68 species in the 44 sites remained in our study. Overall, in four surveys we captured 65% of the species encountered in ten visits (Appendix, Supplementary Table 6). An analysis of annual variation established that our results were not affected by yearly variation; hence we grouped all species data by sites for both years (Appendix, Supplementary Fig. 2). An analysis of medium versus large buffers showed no difference in results; hence we show all results for medium buffers only. Mantel tests showed no spatial autocorrelation for overall bird richness, abundance or evenness using a p value of 0.05.

We found that both local and landscape factors significantly influenced each group of avian

species for every measure of diversity we tested, but their relative importance varied considerably. The variation explained by landscape factors differed from being $\frac{1}{4}$ as important as local factors to being ten times as important as local factors. For each response variable and each bird group we analyzed, the composition of the surrounding matrix explained more variance than patch variables. For overall bird diversity, patch variables were not significant. However, some groups and individual species were influenced by the size and shape of the patch and those influences differ among response variables as well.

Overall bird community and diversity

The results of the CCA performed on the total bird community showed that the composition of the local vegetation structure (local factors) was approximately equally as important as patch size, shape and surrounding matrix (landscape factors) in defining overall community structure (Fig. 2). At the landscape level, however, the surrounding matrix, accounting for approximately 12% of the explained variation, was much more important than patch size (area) or shape (perimeter), together accounting for just 3.5% of the variation (Figs. 2 and 3). The long arrows in Fig. 3 representing local and surrounding matrix variables show these factors influenced the overall avian community structure more than the patch variables – area and perimeter – which were also highly correlated (shorter and overlapping arrows, Fig. 3). Together, all environmental factors explained 35.4% of the variation in community structure (Fig. 2).

Our step-wise model building CCA for the whole bird community corroborates the results of the overall CCA (Table 2). The amount of surrounding development and other forests, as well as three local variables, contributed to the overall avian community structure. Monte Carlo

permutation tests (1000 random tests) found these five variables to be significant ($P < 0.1$). Patch variables of area and perimeter were not significant for organizing overall bird community structure (P values of 0.93 and 0.24, respectively).

Our GLMs indicated similar impacts of local and landscape factors on overall avian diversity (richness and abundance) as our CCA found for overall community structure (Tables 3 and 4). Local and matrix variables each influenced both richness and abundance of the overall bird community in our oak patches. Six of the ten factors affected total species richness, most of them (five of six variables) local vegetation structure: height diversity; total number of stems; canopy cover; canopy height; amount of surrounding development; and total number of large stems. Five factors helped to predict total species abundance, comprising both local and matrix variables: amount of surrounding agriculture; amount of surrounding oak; canopy height, total number of large stems; and canopy cover. Although both local and landscape factors influenced richness and abundance, local factors were more of a driver for richness (local explained 20% of variance versus just 5% explained by landscape) than abundance (local and landscape equally important) (Table 4). In addition, area was not significant for either total species richness or abundance (perimeter was not analyzed through GLMs due to its strong correlation to area as described above in Methods).

Synanthropy

Landscape factors, especially the surrounding matrix, were at least equally if not more important in structuring the community of synanthropic birds as they were for the entire bird community (Appendix, Supplementary Fig. 3 and 4). For synanthropic birds, landscape factors explained

approximately 18% of the variation defining community structure and local factors about 15%, compared to 15% (landscape factors) and 16% (local factors) for the overall bird community. Patch area and perimeter still explained only about 4% of the variation of the synanthropic bird community composition and were not found to be significant through Monte Carlo simulations (1000 permutations, Appendix, Supplementary Table 7).

As expected, GLMs showed that surrounding development and agriculture positively affected synanthropic birds, whereas the area of surrounding oak forest in the matrix was negatively correlated with synanthropic bird richness and abundance (Table 3). Contrary to the effects on overall bird diversity or synanthropic community structure, area had a positive effect on synanthropic bird abundance (Table 3) and landscape factors (11% of the explained variance) were more important than local factors (7%) (Table 4).

Landscape factors were much less important for non-synanthropic birds (Appendix, Supplementary Fig. 5); 20% of the variation explaining non-synanthropic avian community composition was attributed solely to local variables, compared to 11% from landscape variables alone (Appendix, Supplementary Fig. 6). Only 2.5% of the variation was attributed to patch size and shape. Monte Carlo permutation tests in CCA revealed no significant landscape variables (Appendix, Supplementary Table 8). Because the null model was considered a viable model, we did not further evaluate GLMs for non-synanthropic species richness or abundance (Tables 3 and 4).

Functional Group Diversity

We examined functional diversity to assess the extent to which each environmental factor impacted the diversity of functional groups and the possible ecosystem functions provided by the avian species. Using CCA and treating each functional group as an individual (equal to a species in our above overall analyses), we found that local and landscape factors were approximately equally important in defining functional community composition (Appendix, Supplementary Figs. 7 and 8). These results mimic the environmental effects on the overall bird community, described above. Likewise, patch size and shape contributed little to the community composition of functional groups, as they did for individual species.

Although patch area had little effect on overall bird diversity, it had a greater impact on the functional groups of birds. Area was a significant determinant of the evenness of the twenty functional groups, appearing in the second best model (Table 3). Area was also an important determinant of the abundance of several functional groups. Of the five functional groups containing more than a single species and having only viable models that did not include the null model, three groups were influenced by area along with local vegetation and surrounding matrix variables (Table 3). The first contained over 60% of the seed eaters, one third of the frugivores, and half of the ground foragers, as well as all of the wren species (Appendix, Supplementary Table 4). The second was two-thirds of identified bark foragers, including all identified nuthatches, chickadees and woodpeckers except the Acorn Woodpecker and RBSA. The third contained all identified warblers except one (OCWA) and all species that forage both in the air and at foliage using multiple foraging methods (gleaning, hawking and hovering and gleaning). Of the two groups that did not include area as a viable model predictor, the first group included

only highly adaptable foragers, omnivore gleaners that forage on a variety of substrates. This group was all *corvidae*, large generalist species having large territory sizes. The second group unaffected by the size of the patch was comprised of all flycatchers, insectivores foraging in the air by hawking and hovering. These species are also large birds with large territory sizes.

Using GLMs to partition the magnitude of the effects that local, landscape and shared local and landscape factors had on richness, evenness and abundance, we found striking differences in the factors that influenced different functional groups. Landscape factors were five to ten times more important for the *corvidae* omnivores (five times) and the flycatchers (ten times), whereas local factors were twice as important for the group of seed eaters, frugivores and ground foragers and the group of bark foragers (Table 4). We also note that the groups influenced by area were also the groups more affected by local factors than landscape factors (and vice versa) (Tables 3 and 4).

Species of Concern

Two local factors and all matrix variables had the most influence on the community composition of the species of concern that we analyzed – Acorn Woodpeckers, Anna’s Hummingbird, Chipping Sparrows, Western Scrub Jays, White-breasted Nuthatches, Western Bluebirds and Western Meadowlarks (Appendix, Supplementary Fig. 9, a replicate of Fig. 3 with species of concern highlighted). Long arrows near the positions of most of the species of concern on the CCA biplot show that average canopy height, canopy cover and the amount of surrounding development, agriculture, oak and other forests impacted those species most.

We found differences in the effects that local vegetation, patch shape and size and the surrounding matrix had on the abundances of the individual species of concern that we analyzed. Although local vegetation characteristics and surrounding matrix most influenced community structure for the seven species of concern (Appendix, Supplementary Fig. 9), area did have an affect on the abundance of one species, the Chipping Sparrow (Table 3). We constructed GLMs for the abundance of four species of concern –Acorn Woodpeckers, Chipping Sparrows, Western Scrub Jays and White-breasted Nuthatches. As mentioned above, three species of concern – Anna’s Hummingbirds, Western Bluebirds and Western Meadowlarks – had detections at only two to four of the 44 sites and were not analyzed with GLMs. Chipping Sparrows were influenced by lack of surrounding development, taller average canopy height, fewer total stems and a larger patch size. Like Western Scrub Jays, Chipping Sparrows were also more influenced by landscape variables than by local variables, although Western Scrub Jays were only affected by the matrix surrounding the patch, not the size of the patch itself (Tables 3 and 4). As expected, the Acorn Woodpecker, an oak dependent species, was more than twice as dependent on local environmental factors than the composition of the matrix surrounding the patch and was unaffected by the size of the patch. The White-breasted Nuthatch was approximately equally affected by local and landscape variables, but not influenced by patch size.

Discussion

To best inform wildlife-conservation strategies, it is crucial that we understand the effects that environmental conditions have on the community composition and the diversity of species. We found that when the context changes from a particular at risk avian species to a foraging guild or the entire avian community, the relative effects of local environmental variables and habitat

fragmentation and loss at the landscape level are markedly different. While this means there is no catch-all conservation strategy for wildlife conservation, our analysis also shows that we can more successfully manage conservation efforts given a properly designed study. Targeting a specific species of concern, a functional group or the proper response variable will lead to greater gains in comparable conservation efforts.

In 2000, Partners in Flight identified oak woodlands as high priority habitats for monitoring and managing avian species of concern. Still, twelve years later, few studies have been published on avian diversity in oak habitats in the Willamette Valley. Those studies that do exist focus either on a single bird species (Viste-Sparkman 2005), local habitat factors only (Hagar and Stern 2001, Gumtow-Farrior 1991) or seasonal variations in avian diversity (Anderson 1970). No previous work has simultaneously evaluated both local and landscape metrics in these woodlands, nor has any compared the effects at different landscape extents (Altman 2010). Given the range of the effects that local and landscape variables have in different habitats, it is necessary to explore the spatial scales at which avian species respond specifically in oak woodland and savannah of the Willamette Valley as was done in this study.

As predicted, the effects that local vegetation and landscape patterns have on bird community structure and diversity in the Willamette Valley greatly depends on the birds or groups of birds examined and the response variables evaluated. We found that local and landscape factors significantly influenced each group of avian species we tested, but their relative importance greatly varied depending on the measure of diversity examined and the group of birds evaluated. Whereas local and landscape factors were approximately equally important in defining overall

community structure and driving abundance (Fig. 2, Table 4), local factors were four times more important in predicting overall species richness (Table 4). Landscape factors were five to ten times more important in explaining the abundance of *corvidae* omnivores (five times), flycatchers (ten times), Western Scrub Jays (six times) and Chipping Sparrows (6.5 times), whereas local factors were approximately twice as important to the abundance of seed eaters, frugivores and ground foragers, bark foragers, and Acorn Woodpeckers (Table 4).

In terms of the effects of landscape level drivers, Prugh et al. (2008) were able to show in their meta-analysis on 1015 populations of bird, mammal, reptile, amphibian and invertebrate populations, that the surrounding matrix explained much of the otherwise unexplained variation from patch effects alone. However, they were unable to quantify the effects of these different landscape level drivers and they did not compare the effects for different species, guilds or communities in finer contexts than the five broad populations mentioned above. They also only evaluated occupancy and did not compare effects across a number of response variables.

Our results generally agreed with the broad study performed by Prugh et al. (2008); patch area alone was not a good predictor of avian diversity. Our results show that patch area was not at all associated with overall avian diversity and community structure and that the surrounding matrix was always much more significant than patch size or shape for all avian communities, guilds and individual species and all response variables we analyzed. However, although the nature of the surrounding matrix was still more important, patch area *did* influence every bird group *except* the entire bird community. The abundance of synanthropic species, three functional groups, and Chipping Sparrows, as well as the evenness of functional groups were all affected by patch size

to varying degrees.

The difference we observe in factors affecting overall species richness and abundance is likely attributed to the types of species found in each patch and the way they use their environment. Surrounding agriculture and development bring more common species (American Crows, European Starlings) found in larger groups (e.g. European Starlings, Red-winged Blackbirds, and Band-tailed Pigeons) but potentially fewer rare species or species found in smaller numbers (e.g. many warblers, vireos and woodpeckers). Thus, the human-dominated landscapes surrounding some of our sites increase the total abundance of avian species within the encircled oak patches but not the total richness in those patches, as other researches have found (Andr n 1994). Local factors, conversely, contribute to a more diverse community within the patch, increasing available habitat (e.g., through increased height diversity) for a number of less common species, increasing richness but not necessarily the total abundance of birds. Our data support these claims. For example, the most birds detected at any site used in our analyses were European Starlings, a synanthropic and invasive species clearly associated with the amount of surrounding development (Fig. 3). Other sites (from our original 75 sites) surrounded by a majority of agricultural land had relatively large numbers of Band-tailed Pigeons and Red-winged Blackbirds (sometimes 20 or more).

Our ordination results support previously known associations for many species. For example, the distributions of several synanthropic species (e.g., European Starlings, American Crows) are strongly associated with the nature of the surrounding matrix, positively influenced by the percentage of development near the patches. Red-winged Blackbirds, Western Meadowlarks and

Bullock's Orioles are highly positively influenced by the area of surrounding agriculture.

The stronger impact of matrix variables relative to local variables, as well as the lack of influence of patch size on some functional groups and individual birds, highly depends on species' adaptability in habitat use and food consumption. Our results agree with the meta-analyses of Prugh et al. (2008) and Bender et al. (1998) who found that generalists and omnivores are less likely to be influenced by the size of the patch. The Western Scrub Jay and every species in the *corvidae* omnivore group are all generalists and omnivores (Ehrlich et al. 1988, Poole 2005) and, as expected, unaffected by the size of the patch (Andrén 1994) but highly influenced by the composition of the surrounding matrix (Tables 3 and 4). These species are likely unaffected by the size of the oak patches because they forage, nest and live not only in oak forests but can also use resources in other forests, agricultural and urban areas (Andrés 1994). The more diverse the surrounding landscape for them, the more abundant they are within the oak sites. The flycatchers were also unaffected by patch area and mainly dependent on the surrounding matrix (Tables 3 and 4). These birds depend on open areas for foraging (Fitzpatrick 1981, Poole 2005), and the positive relationship with agriculture in the matrix that we identified reflects this (Table 3). In addition, all of the birds in each of these two functional groups as well as the Western Scrub Jay are larger birds with larger territory sizes (Ehrlich et al. 1988, Poole 2005) that likely extend beyond the size of many of our patches. These birds likely perceive each patch as only a fraction of their oak habitat, because their large territory size includes other patches as well (Wiens 2008). Other researchers support this idea, finding that the home ranges of larger species are more affected by fragmentation than those of smaller species (Haskel et al. 2002).

In contrast to the larger generalists and omnivores, the group of seed eaters, frugivores and ground foragers and the group of bark foragers, as well as the Acorn Woodpecker and the White-breasted Nuthatch are all influenced more by local variables than landscape variables (Table 4). These birds are all specialists – eating fruits, seeds or acorns or gleaning insects from the tree bark (Ehrlich et al. 1998, Pool 2005). They rely more on local habitat characteristics to provide the specialized food they require (Table 4). Species in the specialist guilds are also more restricted to the oak patches they inhabit (Andrén 1994) and are, therefore, more affected by the size of the patch. Other researchers have also found patch size and local habitat variables are the most important predictors of the richness of avian forest specialists (Fernández-Juricic 2004).

If development in the Willamette Valley continues, it is likely that the remaining oak patches will continue to shrink and the surrounding matrix will become more uniform. As this study shows, these changes may lead to the loss of some species of concern like the Chipping Sparrow, some functional groups like the seed and fruit dispersers and the bark foragers and perhaps even some ecosystem functionality as a result (Sekercioglu 2006). Retaining avian diversity by expansion of current oak forest reserves as well as land-use planning or conservation easements on adjacent lands may be important for a fully functioning, healthy ecosystem with a diversity of avian species (Sekercioglu 2006). If unplanned, development may cause some species of concern and functional groups to diminish and generalists and omnivores to increase, causing a loss in ecosystem functionality with effects yet to be fully realized (Sekercioglu 2006).

Although this study focused on oak woodlands and savannahs of the Willamette Valley in Oregon, results from this research can be applied to other landscapes. As shown above, many

factors affect the community of avian species found in habitats with differing local vegetation, patch size and shape and surrounding matrices, but specific factors and spatial scales affect certain species, synanthropic species and foraging guilds more than others. Directing studies to focus on these types of explicit guilds, species or response variables depending on the specific conservation needs will help improve the efficiency of wildlife conservation efforts in most ecosystems.

Figures

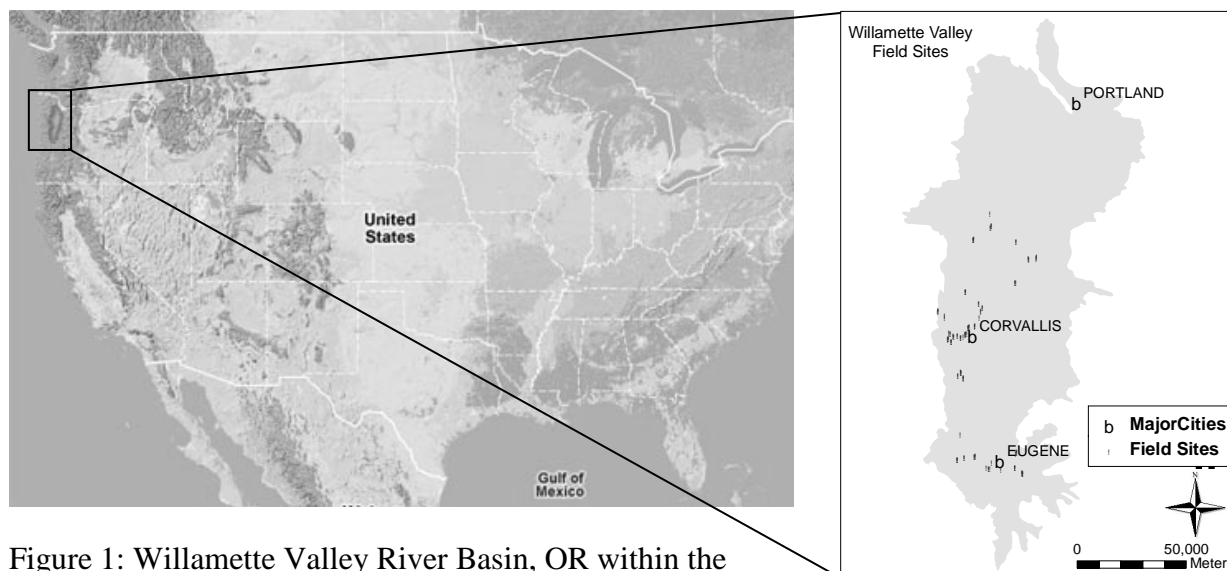


Figure 1: Willamette Valley River Basin, OR within the United States of America (left) and inset of our field sites in the Willamette Valley (right).

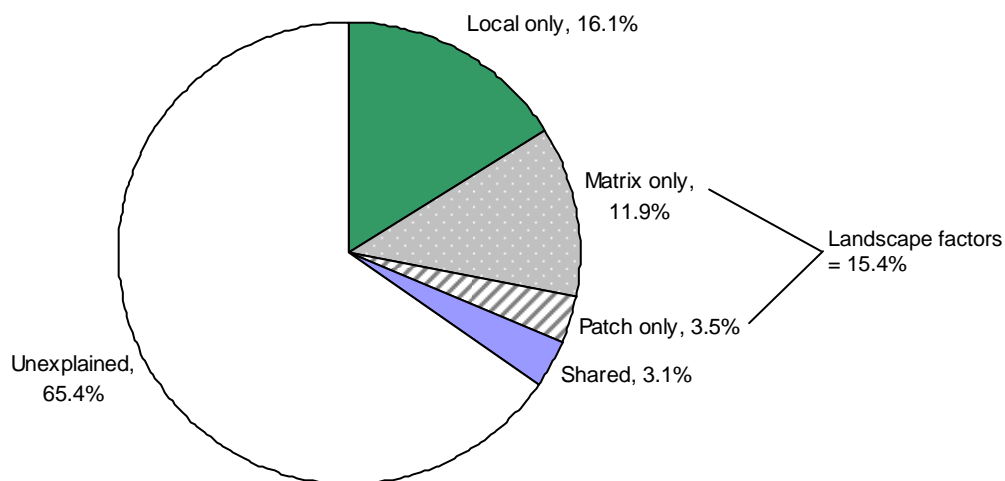


Figure 2. Variation explained by local (solid green), landscape (grey patterns) and shared local and landscape (solid blue) factors for overall bird community structure. Landscape factors include both patch (striped grey) and matrix (dotted grey) variables.

Tables

Table 1: Candidate explanatory variables for canonical correspondence analysis (CCA) and generalized linear models (GLM)

		<i>Included in CCA</i>	<i>Included in GLM</i>	<i>Code</i>
<i>Patch variables</i>				
Area	m ²	yes	yes	Area
Core area (amount of area 50 m from any edge)	m ²	no [†]	no [†]	
Perimeter	M	yes	yes*	Perim
Area:perimeter	M	no [†]	no [†]	
<i>Matrix variables</i>				
Amount of surrounding oak forests	%	yes	yes	Oak
Amount of surrounding other forests	%	yes	yes	Forest
Amount of surrounding development	%	yes	yes	Develop
Amount of surrounding agriculture	%	yes	yes	Ag
Amount of surrounding “other” (everything not included in other four matrix variables)	%	no [†]	no [†]	
Distance to nearest oak	m	no [†]	no [†]	
<i>Local variables</i>				
Average canopy height	m	yes	yes	CanopyHeight
Average canopy cover	%	yes	yes	CanopyCover
Height diversity	#	yes	yes	HD
Number of snags and logs	#	yes	no*	SnagsAndLogs
Number of large stems (total)	#	yes	yes	TotalStems
Number of large tree stems (total)	#	yes	yes	Total Large Stems
Number of seedling tree stems	#	no [†]	no [†]	
Number of sapling tree stems	#	no [†]	no [†]	
Basal area	#	no [†]	no [†]	
Tree species diversity	#	no [†]	no [†]	
Presence of cuts	y/n	no [‡]	no [‡]	
Presence of grazing	y/n	no [‡]	no [‡]	
Understory vegetation (<i>Rhus diversiloba</i> , <i>Rubus discolor</i> , tree saplings, other)	%	no [†]	no [†]	
Ground cover (grasses/forbes, bare ground, impervious surface, water)	%	no [†]	no [†]	
Number of next boxes	#	no [‡]	no [‡]	
Impervious area	%	no [†]	no [†]	
Water	%	no [†]	no [†]	

[†] removed based on inclusion in other variables

[‡] removed based on distribution and simple regressions

*removed based on multicollinearity

Table 2. Summary Statistics for the overall species canonical correspondence analysis (CCA) obtained from Monte Carlo significance tests and a step-wise CCA approach. CCA explained 35.4% of the total variation in 68 bird species.

<i>Variable Code</i>	<i>F</i>	<i>P</i>	<i>Eigenvalue</i>	<i>Explained Variance</i>
<i>Developed (%)</i>	3.053929	0.01	0.186193018	7%
<i>CanopyHeight (m)</i>	1.673039	0.08	0.102002425	4%
<i>TotalStems (#)</i>	1.592758	0.09	0.097107852	4%
<i>Forest (%)</i>	1.423526	0.09	0.086790008	3%
<i>Total Large Stems (#)</i>	1.404972	0.1	0.08565881	3%
<i>SnagsAndLogs (#)</i>	1.318787	0.14	0.080404276	3%
<i>Oak (%)</i>	1.197904	0.3	0.073034229	3%
<i>Perim (m)</i>	1.197283	0.24	0.072996393	3%
<i>CanopyCover (%)</i>	1.109018	0.34	0.067615018	2%
<i>HD (#)</i>	0.936969	0.71	0.057125428	2%
<i>Ag (%)</i>	0.813851	0.68	0.049619164	2%
<i>Area (ha)</i>	0.679916	0.93	0.041453379	2%
<i>Total</i>				35.4%

Table 3. Generalized linear model results for diversity of all identified species (richness, abundance), for synanthropic species (richness, abundance), for non-synanthropic species (richness, abundance), for functional groups (richness, evenness and abundance) and for individual species of concern (abundance). Functional group abundances are listed by the description of the functional group and are given only for groups with more than one species. A more detailed account every species in each functional group is listed in Appendix Supplementary Table 4. When the null model is one of the viable models ($AIC_c = AIC_{cmin} \pm 2$), only the null is reported. Codes: HD=height diversity; Develop, Ag, Oak, Forest = % of development, agriculture, oak or other forest in the surrounding matrix, respectively.

<i>Scope</i>	<i>Diversity Indicator</i>	<i>Model Predictors ($\Delta AIC_c \pm 2$)</i>	<i>Best Model</i>
Overall	Richness	HD (+) Total Stems (-) Canopy Cover (+) Canopy Height (+) Develop (-) Total Large Stems (+)	HD(+)
	Abundance	Ag (+) Canopy Height (+) Total Large Stems (+) Oak (-) Canopy Cover (+)	Ag (+) CanopyHeight (+) Total Large Stems (+)
Non-synanthropic	Richness	Null	HD (+)
	Abundance	Null	Null
Synanthropic	Richness	Null	Canopy Height (+)
	Abundance	Oak (-) Canopy Height (+) Area (+) Ag (+)	Oak (-)
Functional Diversity (where only functional group is listed, the abundance of that group was evaluated)	Richness	Null	Null
	<i>Corvidae</i> omnivores	Oak (-) Forest (-) Develop (-) Ag (-) HD (+) Total Stems (-) Canopy Height (-) Total Large Stems (+) Canopy Cover (+)	Oak (-) Forest (-) Develop (-) Ag (-) HD (+) Total Stems (-) Canopy Height (+) Total Large Stems (+)
	Seed eaters, frugivores, ground foragers	Canopy Height (+) Total Large Stems (+) Total Stems (+) Area (+) Ag (+)	Canopy Height (+) Total Large Stems (+)
	Bark foragers	Canopy Cover (+) Area (-) Oak (-)	Canopy Cover (+)
	Flycatchers	Ag (+) Develop (-) CanopyHeight (+) Forest (+)	Ag (+)
	Foliage gleaners	Area (+) Forest (+) Develop (-) Total Large Stems (-) Total Stems (+) Canopy Cover (+) HD (-) Ag (+)	Area (+) Forest (-) Develop (-) Total Large Stems (-)
	Vireos, Sparrows, Warblers	Null	HD (+) Total Stems (-)
	Hummingbirds	Null	Develop (+)
	Swallows	Null	HD (-)
	Evenness	Ag (-) Total Large Stems (-) Area (+) Total Stems (-) Forest (-) Develop (-) Oak (-)	Ag (+) Total Large Stems (-)
Acorn Woodpecker	Abundance	Canopy Height (+) HD (-) Total Large Stems (+) Canopy Cover (+) Oak (-)	Canopy Height (+) HD (-)
Chipping Sparrow	Abundance	Develop (-) Total Stems (-) Area (+) Canopy Height (+)	Develop (-)
Western Scrub Jay	Abundance	Develop (+) Forest (-) Canopy Height (-)	Develop (+)
White-breasted Nuthatch	Abundance	Ag (+) HD (+) Total Stems (-) Total Large Stems (-) Forest (+)	Ag (+) HD (+) Total Stems (-)

Table 4. Variation explained by local, landscape and shared local and landscape variables determined through generalized linear models for all bird groups analyzed. The level (local or landscape) that affects diversity more is highlighted in bold print. Variation is not provided where the null model is a viable model ($AIC_c = AIC_{cmin} \pm 2$) (see Table 3).

<i>Scope</i>	<i>Diversity Indicator</i>	<i>Local Only (%)</i>	<i>Landscape Only (%)</i>	<i>Shared (%)</i>
Overall	Richness	20%	5%	1%
	Abundance	16%	16%	4%
Non-synanthropic	Richness	-	-	-
	Abundance	-	-	-
Synanthropic	Richness	-	-	-
	Abundance	7%	11%	3%
Functional Diversity (where only functional group is listed, the abundance of that group was evaluated)	Richness	-	-	-
	<i>Corvidae</i> omnivores	8%	38%	0%
	Seed eaters, frugivores, ground foragers	16%	8%	2%
	Bark foragers	12%	6%	0%
	Flycatchers	3%	28%	0%
	Foliage gleaners	19%	14%	0%
	Vireos, Sparrows, Warblers	-	-	-
	Hummingbirds	-	-	-
	Swallows	-	-	-
	Evenness	17%	11%	0%
Acorn Woodpecker	Abundance	18%	8%	5%
Chipping Sparrow	Abundance	2%	13%	0%
Western Scrub Jay	Abundance	3%	19%	0%
White-breasted Nuthatch	Abundance	18%	14%	6%

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Appendix

Supplementary Table 1. Raw data: local, patch and matrix environmental variables for each site.

FID	Site	Points #	Nest		Water (%)	Impervious (%)	Grazing 0=no1=cow 2=sheep	Cuts (0=no 1=yes)
			boxes #					
0	CA1-1	3	0	0	0	0	0	0
1	CA1-2	2	0	3	0	0	0	0.5
2	CA1-3	1	0	0	0	0	0	1
3	CA1-4	3	0	3	0	0	0	0.5
4	CB1-1	1	0	0	0	0	0	1
5	CB1-2	2	0	0	0	0	0	1
6	CB1-3	1	0	0	0	0	0	0
7	CB2	4	0	0	0	0	0	0
8	CB3	1	0	0	0	0	0	0
9	CC1	1	0	0	0	4	0	0
10	CC2-1	1	5	0	0	5	0	0
11	CC2-2	1	1	0	0	0	0	1
12	CC2-3	1	0	0	0	0	0	1
13	CC2-4	1	0	0	0	0	0	1
14	CC2-5	1	1	0	0	0	0	1
15	CC2-6	1	1	0	0	0	0	1
16	CC2-7	1	3	0	0	0	0	1
17	CC2-8	1	1	0	0	0	0	1
18	CC2-9	1	0	0	0	0	0	1
19	CD2	2	0	0	0	0	0	0
20	CD3	1	0	0	0	10	0	0
21	CD4	3	0	0	0	0	0	0
22	CE1-1	1	0	0	0	0	0	1
23	CE1-2	1	0	0	0	0	0	0
24	CE1-3	1	0	0	0	0	0	1
25	CE2-1	1	0	0	0	0	0	1
26	CE2-2	1	0	5	0	0	0	0
27	CE3-1	1	0	0	0	5	0	1
28	CE3-2	1	0	0	0	0	0	1
29	CE3-3	1	0	0	0	0	0	1
30	CF1-1	2	0	0	0	0	0	1
31	CF1-2	1	0	0	0	0	0	1
32	CF2-1	2	0	3	0	0	1	0.5
33	CF2-2	2	0	0	0	0	1	0.5
34	CG1	1	0	0	0	10	0	0
35	CG2-1	1	0	0	0	0	0	0
36	CG2-2	3	0	0	0	0	0	0
37	CG3-1	1	0	0	0	0	0	1
38	CG3-2	1	0	0	0	0	0	0
39	CG3-3	1	1	3	0	0	0	1
40	CG4-1	1	0	0	0	0	0	1

FID	Site	Points #	Nest		Water (%)	Impervious (%)	Grazing 0=no1=cow 2=sheep)	Cuts (0=no 1=yes)
			boxes #					
41	CG4-2	1	0	1	0	0	1	
42	CH1	3	0	0	0	1	0	
43	CH2	2	0	0	5	0	0	
44	CH3-1	1	0	0	0	0	0	
45	CH3-2	1	0	0	0	0	0	
46	CI1-1	1	0	0	0	0	0	
47	CI1-2	1	0	1	0	0	0	
48	CI2	1	0	0	0	0	0	
49	CI3-1	2	1	0	0	0	0	
50	CI3-2	1	0	0	0	0	0	
51	CI4-1	1	0	0	0	0	0	
52	CI4-2	2	1	0	0	0	0.5	
53	EA1	1	2	0	0	2	0	
54	EA2	3	0	4	0	0	0	
55	EA3-1	1	0	0	0	0	0	
56	EA3-2	1	0	0	0	0	0	
57	EB1	1	0	0	0	0	0	
58	EB3-1	1	0	5	0	0	0	
59	EB3-2	2	0	0	0	0	0	
60	EB3-3	1	0	0	0	0	0	
61	EC1-1	1	0	1	0	0	0	
62	EC1-2	1	0	0	0	0	0	
63	EC1-3	1	0	0	0	0	0	
64	EC1-4	1	0	0	0	0	0	
65	EC1-5	1	0	2	0	0	0	
66	EC2-1	2	0	0	0	0	0	
67	EC2-2	1	0	0	5	0	0	
68	ED1	1	0	0	0	0	0	
69	ED2	1	0	1	0	0	0	
70	ED3	1	1	0	0	0	0	
71	ED4	1	0	0	2	0	1	
72	ED5	1	0	0	0	0	0	
73	ED6-1	1	0	0	0	0	0	
74	ED6-2	3	0	0	0	0	0	

FID	Site	Canopy cover (%)	Snags & Logs (#)	Average Canopy Height (m)	Poison oak (%)	Black-berries (%)	Tree saplings (%)	Other Understory (%)
0	CA1-1	93	11	21	2	20	0	4
1	CA1-2	88	10	21	7	2	0	17
2	CA1-3	67	43	27	1	0	0	90
3	CA1-4	88	10	21	7	2	0	17
4	CB1-1	75	17	14	0	0	0	0
5	CB1-2	92	16	12	13	0	3	8
6	CB1-3	75	3	7	0	0	2	20
7	CB2	83	12	17	3	0	2	4
8	CB3	69	10	20	1	2	0	0
9	CC1	88	1	27	0	0	0	0
10	CC2-1	92	4	20	0	3	0	0
11	CC2-2	83	12	23	0	0	0	10
12	CC2-3	91	8	20	0	0	5	33
13	CC2-4	93	8	18	0	0	0	96
14	CC2-5	61	3	15	2	3	0	15
15	CC2-6	68	1	18	0	0	0	13
16	CC2-7	64	1	12	0	1	2	30
17	CC2-8	92	6	14	1	0	0	0
18	CC2-9	77	0	7	5	0	0	10
19	CD2	92	6	14	7	2	1	6
20	CD3	95	0	26	0	0	0	0
21	CD4	92	11	16	6	0	5	5
22	CE1-1	89	4	15	1	0	0	5
23	CE1-2	91	0	13	0	3	0	10
24	CE1-3	56	3	18	0	0	5	2
25	CE2-1	94	12	26	0	0	3	10
26	CE2-2	98	6	17	4	0	3	10
27	CE3-1	82	19	19	2	0	0	35
28	CE3-2	63	2	12	1	0	0	0
29	CE3-3	5	0	12	0	0	0	0
30	CF1-1	81	25	19	22	0	0	7
31	CF1-2	78	42	17	10	0	0	0
32	CF2-1	86	10	17	1	9	0	4
33	CF2-2	76	2	10	2	3	1	7
34	CG1	91	0	21	0	0	0	0
35	CG2-1	96	1	13	0	65	5	0
36	CG2-2	94	14	19	2	1	2	28
37	CG3-1	94	5	10	0	0	2	2
38	CG3-2	47	0	15	0	0	0	0
39	CG3-3	87	1	12	3	0	0	8
40	CG4-1	69	7	18	1	0	0	0
41	CG4-2	85	14	20	2	1	0	0
42	CH1	95	20	17	1	0	1	42
43	CH2	95	18	23	1	32	10	14
44	CH3-1	92	1	11	1	0	0	0

FID	Site	Canopy cover (%)	Snags & Logs (#)	Average Canopy Height (m)	Poison oak (%)	Black-berries (%)	Tree saplings (%)	Other Understory (%)
45	CH3-2	96	11	13	18	0	2	3
46	CI1-1	99	14	19	0	1	4	25
47	CI1-2	93	1	24	0	0	0	3
48	CI2	96	17	18	1	0	0	20
49	CI3-1	79	1	21	5	8	2	25
50	CI3-2	98	6	22	2	0	2	20
51	CI4-1	84	0	5	18	0	0	1
52	CI4-2	96	14	19	10	0	0	3
53	EA1	91	0	21	1	2	25	0
54	EA2	95	8	25	0	0	3	11
55	EA3-1	91	0	11	0	6	0	0
56	EA3-2	96	11	24	0	5	3	7
57	EB1	93	17	17	10	0	0	0
58	EB3-1	85	15	18	1	0	0	5
59	EB3-2	91	10	20	2	5	0	0
60	EB3-3	89	16	17	3	15	0	0
61	EC1-1	94	14	14	3	0	0	0
62	EC1-2	92	10	17	0	2	0	0
63	EC1-3	92	10	20	2	1	0	0
64	EC1-4	65	0	11	2	0	0	0
65	EC1-5	57	7	10	12	0	3	2
66	EC2-1	97	10	20	0	0	3	1
67	EC2-2	92	5	18	0	0	0	0
68	ED1	69	8	25	0	6	0	0
69	ED2	91	9	17	1	0	0	0
70	ED3	84	4	24	0	0	0	0
71	ED4	96	15	18	2	10	3	2
72	ED5	99	20	19	0	0	0	10
73	ED6-1	64	4	18	2	15	1	0
74	ED6-2	73	6	18	6	5	2	8

FID Site		Bare	Other	Height	Total # Tree Stems				Large	
		Grasses	ground	Ground	Diversity	Other	Deciduous	Conifer	QUGA	QUKE
		(%)	(%)	(%)						Stems
										Total
0	CA1-1	70	10	20	0.343809	4	0	7	0	8
1	CA1-2	32	44	25	0.33004	6	0	11	0	11
2	CA1-3	7	10	83	0.445873	3	7	12	0	19
3	CA1-4	32	44	25	0.455791	52	0	3	0	3
4	CB1-1	95	1	4	0.286184	0	0	9	0	9
5	CB1-2	60	23	18	0.443561	2	0	27	0	25
6	CB1-3	70	15	15	0.40774	1	0	147	0	29
7	CB2	73	16	12	0.480784	172	0	21	0	16
8	CB3	77	20	3	0.42302	3	0	4	0	7
9	CC1	82	10	8	0.305496	0	0	3	0	3
10	CC2-1	95	2	3	0.299753	0	0	5	0	5
11	CC2-2	75	15	10	0.30103	0	0	7	0	7
12	CC2-3	35	28	37	0.539726	128	0	6	0	14
13	CC2-4	7	12	81	0.448801	30	0	9	0	9
14	CC2-5	45	35	20	0.313137	0	0	3	0	3
15	CC2-6	80	7	13	0.440325	27	0	7	0	7
16	CC2-7	38	35	27	0.408599	28	0	3	0	4
17	CC2-8	97	2	1	0.383422	0	0	15	0	15
18	CC2-9	78	7	15	0.43379	0	0	7	0	7
19	CD2	40	44	17	0.410542	5	4	16	0	13
20	CD3	85	15	0	0.299924	0	0	8	0	8
21	CD4	26	55	20	0.487086	119	1	17	0	11
22	CE1-1	55	32	13	0.428029	0	0	41	0	27
23	CE1-2	51	34	15	0.421174	38	0	16	0	10
24	CE1-3	52	31	17	0.539782	164	0	9	0	1
25	CE2-1	48	33	19	0.596946	99	0	4	0	4
26	CE2-2	36	47	17	0.419743	52	0	32	0	16
27	CE3-1	65	5	30	0.429786	2	5	16	0	19
28	CE3-2	63	37	0	0.377167	4	0	3	0	3
29	CE3-3	80	20	0	0.241818	2	0	6	0	6
30	CF1-1	13	49	39	0.412173	5	0	23	0	23
31	CF1-2	38	40	22	0.421249	7	0	16	0	16
32	CF2-1	45	41	15	0.385426	5	1	14	0	13
33	CF2-2	73	24	4	0.391467	8	1	29	0	21
34	CG1	100	0	0	0.21057	0	0	1	0	1
35	CG2-1	25	35	40	0.379062	14	1	36	0	31
36	CG2-2	52	23	25	0.433726	23	0	25	0	19
37	CG3-1	59	37	4	0.420944	17	5	21	0	23
38	CG3-2	30	70	0	0.333991	31	0	7	0	9
39	CG3-3	65	30	5	0.385015	0	0	9	0	8
40	CG4-1	55	40	5	0.430256	0	0	4	0	4

FID Site	Grasses (%)	Bare ground (%)	Other Ground (%)	Height Diversity	Total # Tree Stems				Large Tree Stems Total
					Other	Deciduous	Conifer	QUGA QUKE	
41 CG4-2	95	0	5	0.388046	0	0	14	0	14
42 CH1	39	16	45	0.393826	57	0	26	0	29
43 CH2	1	44	56	0.427492	49	0	2	0	5
44 CH3-1	65	30	5	0.294657	0	0	16	0	14
45 CH3-2	45	30	25	0.446767	22	0	28	0	20
46 CI1-1	3	58	39	0.502589	154	1	9	0	19
47 CI1-2	85	12	3	0.307892	0	0	7	0	7
48 CI2	25	50	25	0.381909	0	0	30	0	30
49 CI3-1	54	6	40	0.262046	22	0	2	0	2
50 CI3-2	0	26	74	0.46755	227	0	2	0	31
51 CI4-1	59	22	19	0.426848	12	0	8	0	7
52 CI4-2	37	44	20	0.434075	1	6	12	0	14
53 EA1	60	10	30	0.400328	20	0	6	0	12
54 EA2	10	65	25	0.544484	169	1	8	0	12
55 EA3-1	65	26	9	0.438321	4	1	0	11	12
56 EA3-2	1	76	23	0.457916	121	3	1	15	23
57 EB1	15	34	51	0.402462	32	0	17	0	17
58 EB3-1	80	5	15	0.377434	0	0	13	14	24
59 EB3-2	88	6	7	0.383729	3	0	9	8	16
60 EB3-3	43	50	7	0.387081	0	0	6	0	6
61 EC1-1	71	21	8	0.416199	8	0	31	0	28
62 EC1-2	60	28	12	0.470501	0	0	16	0	16
63 EC1-3	69	26	5	0.420689	7	0	17	0	17
64 EC1-4	49	49	2	0.401122	0	0	57	0	5
65 EC1-5	37	41	22	0.371991	0	0	21	0	20
66 EC2-1	58	38	5	0.514457	199	0	10	0	22
67 EC2-2	33	57	10	0.294294	45	0	8	0	13
68 ED1	65	9	26	0.364399	0	0	0	3	2
69 ED2	66	29	5	0.396154	1	0	28	2	31
70 ED3	85	15	0	0.465653	14	5	6	4	12
71 ED4	1	75	24	0.403721	23	0	14	2	19
72 ED5	28	52	20	0.440515	10	1	15	4	20
73 ED6-1	59	20	21	0.437973	108	0	1	28	3
74 ED6-2	34	42	23	0.442814	67	0	12	5	12

FID	Site	Area (m ²)	Perimeter (m)	Surrounding Matrix (% within median buffer=570000m ²)				
				Oaks	Other Forest	Developed	Ag	Other
0	CA1-1	61,836	2,167	36%	1%	2%	61%	0%
1	CA1-2	38,186	1,226	37%	32%	6%	24%	1%
2	CA1-3	6,624	660	29%	19%	12%	40%	0%
3	CA1-4	135,317	3,917	32%	9%	3%	56%	0%
4	CB1-1	2,007	239	61%	39%	0%	0%	0%
5	CB1-2	192,906	2,891	38%	10%	5%	47%	0%
6	CB1-3	3,080	468	46%	54%	0%	0%	0%
7	CB2	284,017	5,143	42%	4%	0%	53%	0%
8	CB3	2,810	376	24%	11%	9%	56%	0%
9	CC1	28,708	893	0%	0%	100%	0%	0%
10	CC2-1	2,776	209	2%	1%	12%	74%	11%
11	CC2-2	6,360	364	1%	0%	9%	90%	0%
12	CC2-3	22,520	1,218	9%	4%	7%	71%	9%
13	CC2-4	6,110	736	4%	0%	2%	94%	0%
14	CC2-5	109,819	3,667	31%	6%	0%	56%	7%
15	CC2-6	15,745	733	5%	0%	1%	94%	0%
16	CC2-7	14,688	682	5%	0%	3%	92%	0%
17	CC2-8	10,570	609	52%	23%	0%	24%	2%
18	CC2-9	41,753	1,854	18%	3%	0%	77%	2%
19	CD2	42,584	1,514	35%	5%	0%	54%	6%
20	CD3	12,327	607	5%	0%	40%	55%	0%
21	CD4	401,729	4,831	78%	2%	0%	19%	0%
22	CE1-1	962	202	36%	39%	12%	13%	0%
23	CE1-2	4,323	349	19%	17%	14%	48%	3%
24	CE1-3	6,181	803	36%	27%	15%	20%	2%
25	CE2-1	26,047	981	14%	71%	11%	2%	2%
26	CE2-2	4,552	367	27%	49%	11%	11%	2%
27	CE3-1	16,664	894	41%	23%	3%	24%	9%
28	CE3-2	2,542	263	41%	15%	4%	30%	9%
29	CE3-3	2,905	524	50%	33%	2%	11%	5%
30	CF1-1	136,917	3,277	61%	1%	7%	28%	3%
31	CF1-2	4,539	344	55%	0%	6%	37%	2%
32	CF2-1	67,608	3,627	12%	0%	3%	86%	0%
33	CF2-2	25,256	1,346	34%	3%	10%	49%	4%
34	CG1	3,084	225	17%	0%	83%	0%	0%
35	CG2-1	13,227	964	71%	7%	17%	4%	0%
36	CG2-2	167,367	3,257	50%	7%	17%	21%	5%
37	CG3-1	1,996	278	79%	2%	0%	6%	13%
38	CG3-2	4,670	470	78%	0%	0%	10%	12%
39	CG3-3	2,612	323	74%	1%	0%	13%	12%
40	CG4-1	12,401	893	36%	16%	27%	21%	0%
41	CG4-2	12,099	1,330	41%	24%	25%	9%	0%

FID	Site	Area (m ²)	Perimeter (m)	Surrounding Matrix (% within median buffer=570000m ²)				
				Oaks	Other Forest	Developed	Ag Other	
42	CH1	269,145	3,294	44%	0%	7%	49%	0%
43	CH2	34,864	797	28%	0%	45%	13%	14%
44	CH3-1	2,295	590	20%	30%	18%	32%	0%
45	CH3-2	4,048	323	22%	18%	23%	33%	5%
46	CI1-1	30,796	1,082	2%	6%	72%	19%	0%
47	CI1-2	8,428	402	2%	1%	80%	17%	0%
48	CI2	120,186	2,367	26%	5%	3%	65%	0%
49	CI3-1	23,848	992	32%	6%	12%	50%	0%
50	CI3-2	142,200	2,708	39%	3%	0%	58%	0%
51	CI4-1	2,608	302	28%	18%	21%	30%	4%
52	CI4-2	14,405	1,254	27%	43%	10%	17%	3%
53	EA1	1,655	181	23%	50%	14%	12%	1%
54	EA2	29,739	1,746	14%	63%	0%	0%	24%
55	EA3-1	5,004	363	33%	11%	7%	0%	50%
56	EA3-2	18,052	763	40%	16%	7%	0%	37%
57	EB1	42,087	1,220	10%	11%	79%	0%	0%
58	EB3-1	48,588	1,951	55%	29%	0%	10%	6%
59	EB3-2	94,351	4,663	37%	34%	1%	22%	6%
60	EB3-3	12,318	767	13%	33%	6%	40%	9%
61	EC1-1	30,274	1,492	37%	23%	1%	0%	39%
62	EC1-2	6,585	597	36%	13%	0%	2%	49%
63	EC1-3	19,443	885	39%	10%	8%	2%	41%
64	EC1-4	5,226	445	40%	18%	2%	0%	41%
65	EC1-5	1,868	210	48%	21%	2%	1%	28%
66	EC2-1	17,564	772	47%	18%	14%	0%	21%
67	EC2-2	4,764	313	48%	10%	19%	0%	22%
68	ED1	586	97	7%	0%	71%	22%	0%
69	ED2	10,297	590	26%	25%	9%	38%	2%
70	ED3	17,697	694	7%	15%	19%	48%	11%
71	ED4	6,051	349	9%	17%	25%	36%	12%
72	ED5	49,246	1,537	11%	14%	15%	40%	20%
73	ED6-1	26,531	828	31%	0%	0%	10%	58%
74	ED6-2	240,060	4,191	57%	6%	1%	2%	35%

Supplementary Table 2. Avian species detected and their four-letter codes.

<i>Species</i>	<i>Code</i>	<i>Species</i>	<i>Code</i>
Acorn Woodpecker	ACWO	Lesser Goldfinch	LEGO
American Crow	AMCR	MacGillivray's Warbler	MGWA
American Goldfinch	AMGO	Mourning Dove	MODO
American Kestrel	AMKE	Nashville Warbler	NAWA
American Robin	AMRO	Northern Flicker	NOFL
Anna's Hummingbird	ANHU	Orange-crowned Warbler	OCWA
Ash-throated Flycatcher	ATFL	Pine Grosbeak	PIGR
Barn Swallow	BASW	Pileated Woodpecker	PIWO
Black-capped Chickadee	BCCH	Pacific Slope Flycatcher	PSFL
Bewick's Wren	BEWR	Purple Finch	PUFI
Brown-headed Cowbird	BHCO	Red-breasted Nuthatch	RBNU
Black-headed Grosbeak	BHGR	Red-breasted Sapsucker	RBSA
Black Phoebe	BLPH	Red-tailed Hawk	RTHA
Brown Creeper	BRCR	Rufous Hummingbird	RUHU
Black-throated Gray Warbler	BTGW	Red-winged Blackbird	RWBL
Band-tailed Pigeon	BTPI	Western Scrub Jay	SCJA
Bullock's Oriole	BUOR	Sooty Grouse	SOGR
Bushtit	BUSH	Song Sparrow	SOSP
California Quail	CAQU	Spotted Towhee	SPTO
Cassin's Vireo	CAVI	Steller's Jay	STJA
Chestnut-backed Chickadee	CBCH	Swainson's Thrush	SWTH
Cedar Waxwing	CEWA	Townsend's Warbler	TOWA
Chipping Sparrow	CHSP	Violet-green Swallow	VGSW
Common Raven	CORA	Warbling Vireo	WAVI
Common Yellowthroat	COYE	White-breasted Nuthatch	WBNU
Dark-eyed Junco	DEJU	White-crowned Sparrow	WCSP
Downy Woodpecker	DOWO	Western Blue Jay	WEBL
European Starling	EUST	Western Tanager	WETA
Evening Grosbeak	EVGR	Wild Turkey	WITU
Great-horned Owl	GHOW	Wilson's Warbler	WIWA
Gray Jay	GRJA	Winter Wren	WIWR
Harry Woodpecker	HAWO	Western Meadowlark	WMLA
Hermit Warbler	HEWA	Wrentit	WREN
House Finch	HOFI	Western Wood-Pee-wee	WWPE
House Wren	HOWR	Yellow-breasted Chat	YBCH
Hutton's Vireo	HUVI	Yellow Warbler	YEWA
Lazuli Bunting	LABU	Yellow-rumped Warbler	YRWA

Species	Food Group													
	omni-vore	small verti-brates	small mam-mals	birds	insects	fruit	sap	fol-iage	buds	ber-ries	seeds	nectar	nuts	grains
PUFI					x	x					x			
RBNU					x									
RBSA					x	x	x							
RTHA*		x	x	x	x									
RUHU					x							x		
RWBL					x						x			
SCJA	x													
SOGR					x			x		x	x			
SOSP					x						x			
SPTO					x	x					x			
STJA	x													
SWTH					x	x								
TOWA					x									
TUVU		x	x	x										
VGSW					x									
WAVI					x					x				
WBNU					x									
WCSP					x					x	x			
WEBL					x	x								
WETA					x	x								
WITU	x													
WIWA					x									
WIWR					x									
WMLA					x						x			
WWPE					x									
YBCH					x					x				
YEWA					x									
YRWA					x					x				
Sum	7	4	4	3	63	18	3	2	2	8	23	5	3	2
% of species	9%	5%	5%	4%	83%	24%	4%	3%	3%	11%	30%	7%	4%	3%
Species	Forage Substrate				Forage Type									
	air	foliage	bark/trunk	ground	Glean	Hawks	Hover & Glean	Swoops	High Patrol	Drill	Hover & Pounce	Aerial Foraging		
ACWO	1		1		1	1				1				
AMCR				x	x									
AMGO				x	x									
AMKE*	x					x		x			x			
AMRO		x		x	x									
ANHU	x					x	x							
ATFL	x			x	x	x	x							
BASW	x													x
BCCH			x		x									
BEWR		x		x	x									
BHCO				x	x									
BHGR		x			x									
BLPH	x					x	x							
BRCR			x		x	x								
BTGW	x	x			x	x	x							

Species	Forage Substrate				Forage Type							
	air	foliage	bark/ trunk	ground	Glean	Hawks	Hover & Glean	Swoops	High Patrol	Drill	Hover & Pounce	Aerial Foraging
BTPI		x		x	x							
BUOR	x	x			x	x						
BUSH		x	x		x							
CAQU				x	x							
CAVI		x			x							
CBCH		x	x		x							
CEWA	x	x			x	x						
CHSP	x	x		x	x	x						
CORA				x	x							
COYE	x	x	x		x	x	x					
DEJU	x			x	x	x						
DOWO			x		x							
EUST		x		x	x							
EVGR		x		x	x							
GHOW*	x							x				
GRJA		x		x	x							
HAWO			x		x							
HEWA	x	x			x	x	x					
HOFI		x		x	x							
HOWR		x		x	x							
HUVI		x			x							
LABU		x		x	x							
LEGO		x			x							
MGWA		x	x	x	x							
MODO		x		x	x							
NAWA	x	x		x	x				x			
NOFL	x		x	x	x	x						
OCWA		x			x							
OSFL	x									x		
PIGR		x		x	x							
PIWO			x		x							
PSFL	x	x							x	x		
PUFI		x		x	x							
RBNU	x		x		x	x						
RBSA	x		x		x	x						
RTHA*	x								x	x		
RUHU	x	x								x	x	
RWBL		x		x	x	x						
SCJA				x	x							
SOGR		x		x	x							
SOSP		x		x	x							
SPTO		x		x	x							
STJA		x		x	x							
SWTH	x	x			x	x				x		
TOWA	x	x			x	x						
TUVU	x									x		
VGSW	x											x
WAVI	x	x			x							
WBNU			x		x							
WCSP	x	x		x	x	x						

<i>Species</i>	<i>Forage Substrate</i>				<i>Forage Type</i>							
	<i>air</i>	<i>foliage</i>	<i>bark/ trunk</i>	<i>ground</i>	<i>Glean</i>	<i>Hawks</i>	<i>Hover & Glean</i>	<i>Swoops</i>	<i>High Patrol</i>	<i>Drill</i>	<i>Hover & Pounce</i>	<i>Aerial Foraging</i>
WEBL	x	x			x	x						
WETA	x	x			x	x						
WITU				x	x							
WIWA	x	x	x		x	x	x					
WIWR		x		x	x							
WMLA				x	x							
WWPE	x					x	x					
YBCH		x			x							
YEWA	x	x	x		x	x	x					
YRWA	x	x			x	x	x					
Sum	34	45	16	33	63	29	15	3	2	1	1	2
% of species	45%	59%	21%	43%	83%	38%	20%	4%	3%	1%	1%	3%

* Species removed in subsequent analyses (see main text)

Supplementary Table 4. List of functional groups resulting from Cluster Analysis (see text for description of analysis). Species codes given in Appendix, Supplementary Table 2.

<i>Group</i>	<i>Species Included</i>	<i>Group</i>	<i>Species Included</i>
1 Acorn Woodpeckers	ACWO	11 Brown Creepers	BRCR
2 <i>Corvidae</i> omnivores	AMCR, CORA, SCJA, WITU, GRJA, STJA	12 Orange-crowned Warblers	OCWA
3 Seed eaters, frugivores, ground foragers	AMRO, BHGR, EUST, EVGR, PUFI, SPTO, BEWR, HOWR, WIWR, WREN, CAVI, BHCO, WMLA, LABU, SOSP, LEGO, CHSP, RWBL, DEJU	13 Red-breasted Sapsuckers	RBSA
4 Bark foragers	BCCH, BUSH, CBCH, DOWO, HAWO, PIWO, WBNU, MGWA, NOFL, RBNU	14 Swallows	BASW VGSW
5 Flycatchers	BLPH, WWPE, PSFL, OSFL	15 House Finches	HOFI
6 Foliage gleaners	BTGW, HEWA, SWTH, NAWA, COYE, WIWA, YEWA, CEWA, WEBL, WETA, TOWA	16 Pine Grossbeaks	PIGR
7 Vireos, Sparrows, Warblers	ATFL, WAVI, YRWA, HUVI, YBCH, WCSP	17 California Quails	CAQU
8 American Goldfinches	AMGO	18 Sooty Grouses	SOGR
9 Bullock's Oriole	BUOR	19 Band-tailed Pigeons	BTPI
10 Hummingbirds	ANHU, RUHU	20 Morning Doves	MODO

Supplementary Table 5. Synanthropy of individual species (Johnston, 2001; Donnelly and Marzluff, 2006). N=non-synanthropic, S=synanthropic. Species codes given in Appendix, Supplementary Table 2.

<i>Species</i>	<i>Synanthropy</i>	<i>Species</i>	<i>Synanthropy</i>	<i>Species</i>	<i>Synanthropy</i>	<i>Species</i>	<i>Synanthropy</i>
ACWO	N	CAQU	S	LEGO	S	SPTO	N
AMCR	S	CAVI	S	MGWA	S	STJA	N
AMGO	S	CBCH	N	MODO	S	SWTH	N
AMKE	S	CEWA	S	NAWA	N	TOWA	N
AMRO	N	CHSP	S	NOFL	S	TUVU	S
ANHU	S	CORA	S	OCWA	S	VGSW	S
ATFL	N	COYE	S	OSFL	S	WAVI	S
BASW	S	DEJU	N	PIGR	S	WBNU	S
BCCH	S	DOWO	N	PIWO	N	WCSP	S
BEWR	S	EUST	S	PSFL	N	WEBL	N
BHCO	S	EVGR	S	PUFI	S	WETA	N
BHGR	S	GHOW	S	RBNU	N	WITU	N
BLPH	S	GRJA	S	RBSA	N	WIWA	N
BRCR	N	HAWO	N	RTHA	S	WIWR	N
BTGW	N	HEWA	N	RUHU	S	WMLA	N
BTPI	S	HOFI	S	RWBL	S	WWPE	S
BUOR	S	HOWR	S	SCJA	S	YBCH	N
BUSH	S	HUVI	N	SOGR	N	YEWA	S
CAGO	S	LABU	S	SOSP	S	YRWA	S

Supplementary Table 6. Sampling intensity of individual bird species. Species codes are given in Appendix, Supplementary Table 2.

<i>Species Code</i>	<i>Sampling Intensity</i>	<i>Species Code</i>	<i>Sampling Intensity</i>	<i>Species Code</i>	<i>Sampling Intensity</i>	<i>Species Code</i>	<i>Sampling Intensity</i>
ACWO	72%	CAVI	79%	MGWA	44%	SPTO	68%
AMCR	58%	CEWA	62%	MODO	44%	STJA	81%
AMGO	72%	CHSP	76%	NOFL	64%	TOWA	44%
AMRO	74%	COYE	89%	OCWA	56%	VGSW	71%
ANHU	62%	DEJU	82%	PIGR	44%	WBNU	70%
BASW	44%	DOWO	47%	PIWO	44%	WCSP	73%
BCCH	68%	EUST	68%	PSFL	65%	WEBL	79%
BEWR	74%	HEWA	44%	PUFI	62%	WETA	78%
BHCO	71%	HOFI	69%	RBSA	50%	WIWR	44%
BHGR	74%	HOWR	74%	RUHU	58%	WMLA	44%
BRCR	78%	HUVI	68%	RWBL	48%	WWPE	69%
BUOR	74%	LABU	66%	SCJA	54%	YBCH	72%
BUSH	44%	LEGO	62%	SOSP	64%	YEWA	58%

Supplementary Table 7. Summary Statistics for the canonical correspondence analysis (CCA) obtained from Monte Carlo significance tests and a step-wise approach for synanthropic species only. CCA explained 36.8% of the total variation in 45 bird species.

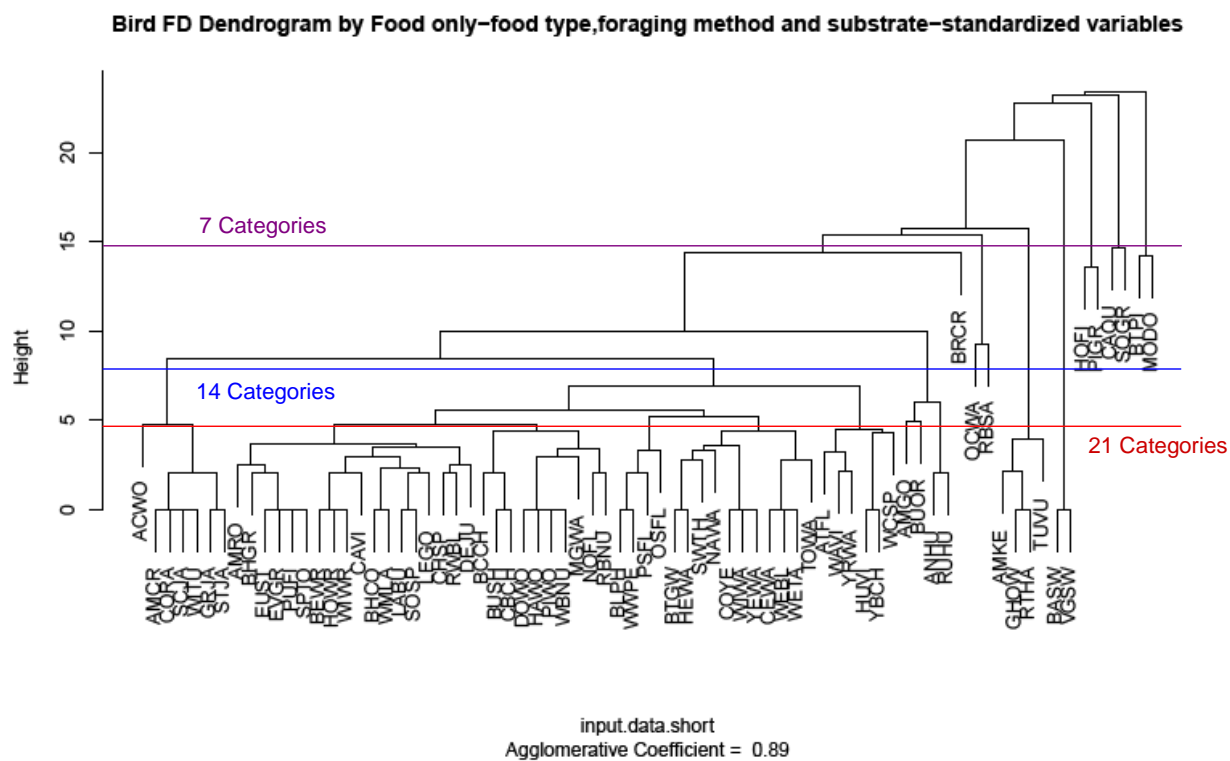
<i>Variable Code</i>	<i>F</i>	<i>P</i>	<i>Eigenvalue</i>	<i>Explained Variance</i>
<i>Developed (%)</i>	3.8355	0.01	0.209787476	8%
<i>Ag (%)</i>	2.3035	0.01	0.125994995	5%
<i>TotalStems (#)</i>	1.8101	0.04	0.099006088	4%
<i>CanopyHeight (m)</i>	1.6404	0.09	0.089722354	3%
<i>Perim (m)</i>	1.4897	0.1	0.081479097	3%
<i>SnagsAndLogs (#)</i>	1.2658	0.29	0.069233596	3%
<i>Oak (%)</i>	1.1357	0.36	0.062118929	2%
<i>Total Large Stems (#)</i>	1.126	0.38	0.061589314	2%
<i>Area (ha)</i>	1.0808	0.43	0.059115068	2%
<i>HD (#)</i>	0.9656	0.63	0.052812243	2%
<i>CanopyCover (%)</i>	0.841	0.68	0.046001203	2%
<i>Forest (%)</i>	0.7887	0.82	0.043139637	2%
Total				36.8%

Supplementary Table 8. Summary Statistics for the canonical correspondence analysis (CCA) obtained from Monte Carlo significance tests and a step-wise approach for non-synanthropic species only. CCA explained 35.3% of the total variation in 29 bird species.

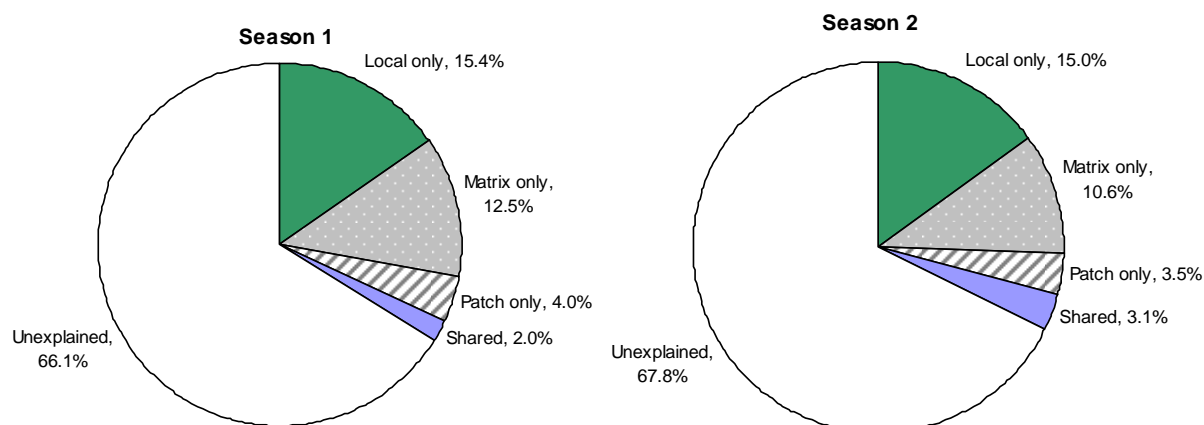
<i>Variable Code</i>	<i>F</i>	<i>P</i>	<i>Eigenvalue</i>	<i>Explained Variance</i>
<i>CanopyHeight (m)</i>	2.6712	0.03	0.158283016	6%
<i>HD (#)</i>	2.7347	0.03	0.162045733	6%
<i>CanopyCover (%)</i>	1.8843	0.08	0.111654944	4%
<i>Total Stems (#)</i>	1.6711	0.09	0.099021693	4%
<i>SnagsAndLogs (#)</i>	1.6582	0.2	0.098257299	4%
<i>Forest (%)</i>	1.2114	0.45	0.071781988	3%
<i>Ag (%)</i>	0.819	0.69	0.04853017	2%
<i>TotalStems (#)</i>	1.0181	0.59	0.060327919	2%
<i>Perim (m)</i>	0.7436	0.84	0.044062313	2%
<i>Area (ha)</i>	1.0094	0.49	0.059812397	2%
<i>Oak (%)</i>	0.861	0.6	0.051018897	2%
<i>Developed (%)</i>	0.5941	0.9	0.035203631	1%
Total				35.3%

Supplementary Table 9. Summary Statistics for the canonical correspondence analysis (CCA) obtained from Monte Carlo significance tests and a step-wise approach for twenty functional groups. CCA explained 35.6% of the total variation in 20 functional groups.

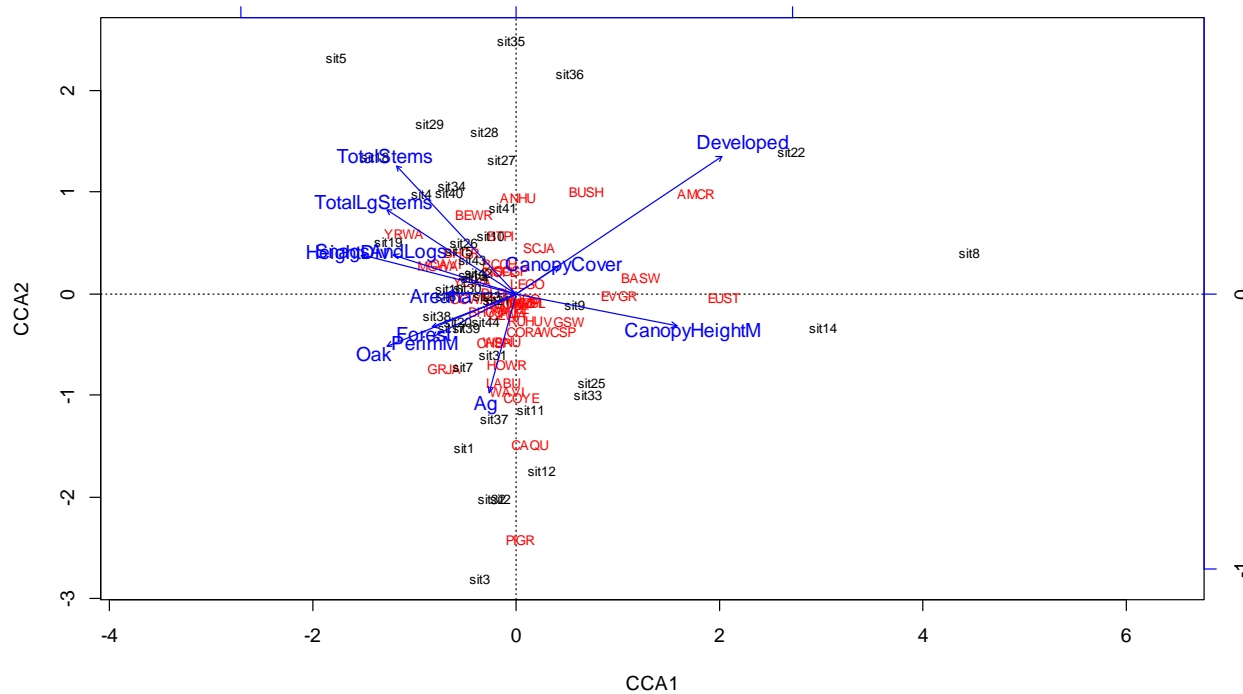
<i>Variable Code</i>	<i>F</i>	<i>P</i>	<i>Eigenvalue</i>	<i>Explained Variance</i>
<i>Ag (%)</i>	2.6399	0.03	0.15431875	6%
<i>CanopyHeight (m)</i>	2.5175	0.06	0.147163701	5%
<i>SnagsAndLogs (#)</i>	1.9507	0.1	0.114030678	4%
<i>Developed (%)</i>	1.6457	0.19	0.096201511	3%
<i>Total Large Stems (#)</i>	1.5617	0.24	0.091291182	3%
<i>TotalStems (#)</i>	1.2947	0.29	0.075683354	3%
<i>Area (ha)</i>	1.2808	0.33	0.074870812	3%
<i>CanopyCover (%)</i>	1.1346	0.31	0.066324503	2%
<i>HD (#)</i>	1.085	0.43	0.063425071	2%
<i>Forest (%)</i>	0.8867	0.53	0.051833189	2%
<i>Perim (m)</i>	0.6159	0.84	0.036003227	1%
<i>Oak (%)</i>	0.4936	0.89	0.028854023	1%
<i>Total</i>				35.6%



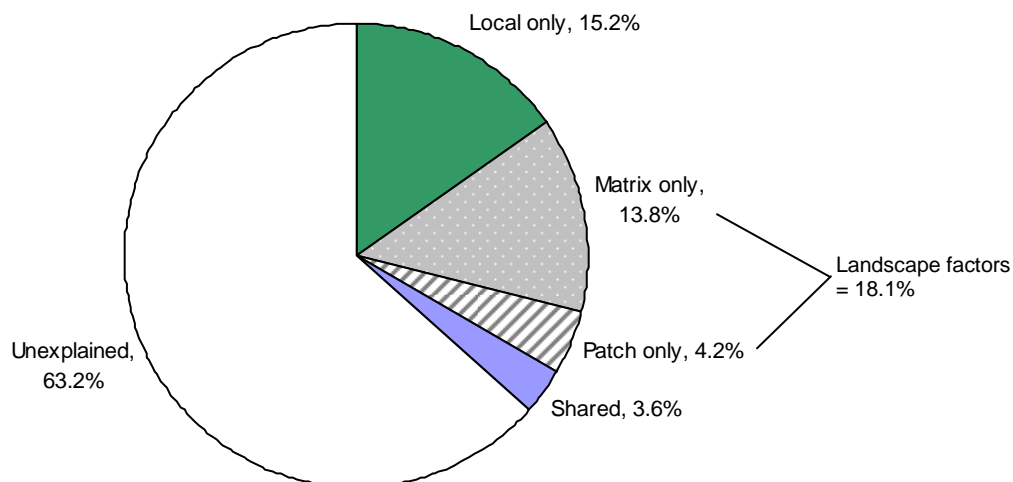
Supplementary Figure 1. Functional diversity dendrogram showing three grouping options – seven groups (purple line), fourteen groups (blue line), and twenty-one groups (red line). Twenty-one groups were chosen to minimize number of groups while maximizing the evenness of the number of species per group. One group of the twenty-one groups (American Kestrel – AMKE, Great Horned Owl – GHOW, Red-tailed Hawk – RTHA, and Turkey Vulture – TUVU) contained only raptors and nocturnal birds which were removed from further analyses. Hence, all functional diversity analyses were done on twenty groups. Species codes are given in Appendix, Supplementary Table 2.



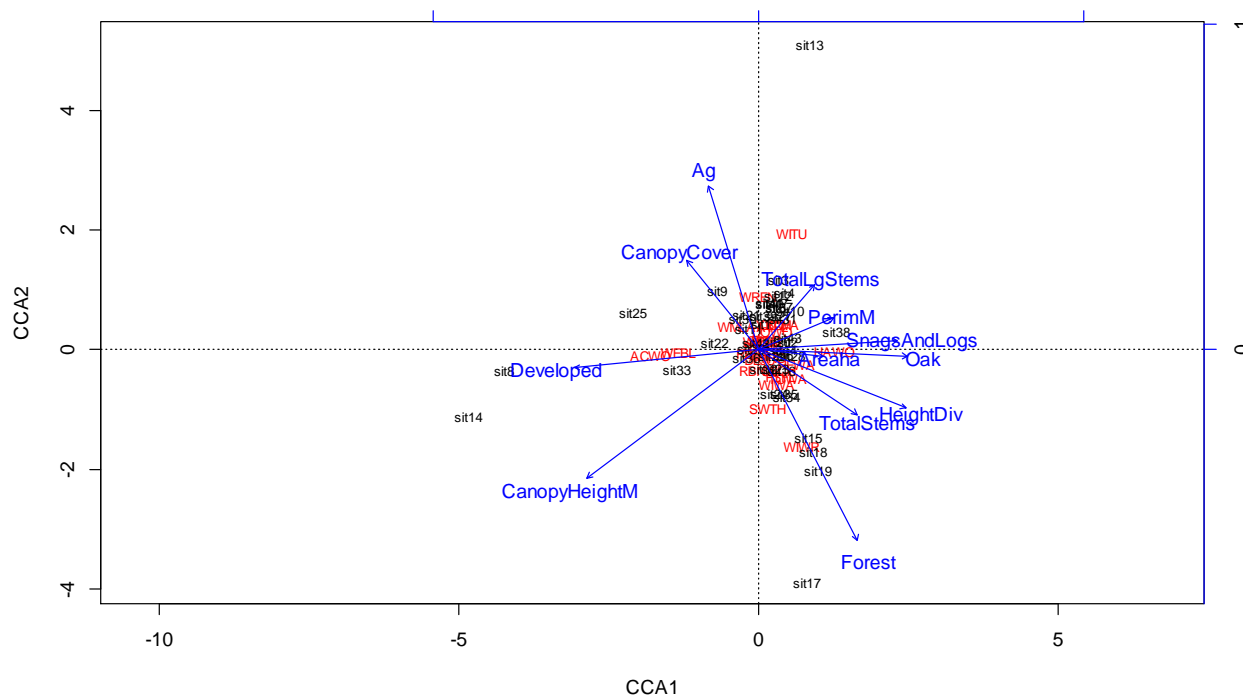
Supplementary Figure 2. Variation explained by local (solid green), landscape (grey patterns) and shared local and landscape (solid blue) factors for season one and season 2. Landscape factors include both patch (striped grey) and matrix (dotted grey) variables. Results are very similar both to each other and to overall bird diversity for both years combined, shown in Figure 2.



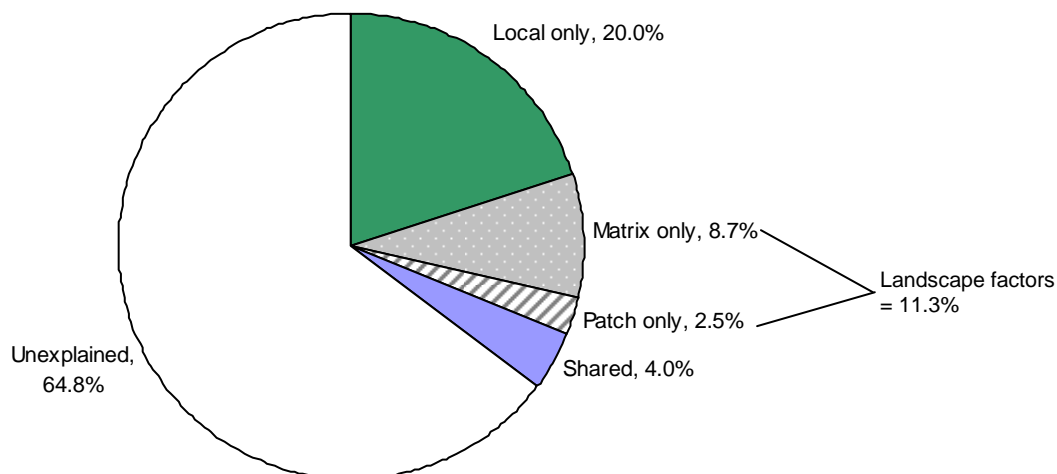
Supplementary Figure 3. Location of species and site scores defined by the first two axes of the canonical correspondence analysis for synanthropic birds only during the 2010-2011 breeding seasons. Environmental metrics are represented by arrows, sites as site numbers and species by their codes. Species codes are listed in Appendix, Supplementary Table 2.



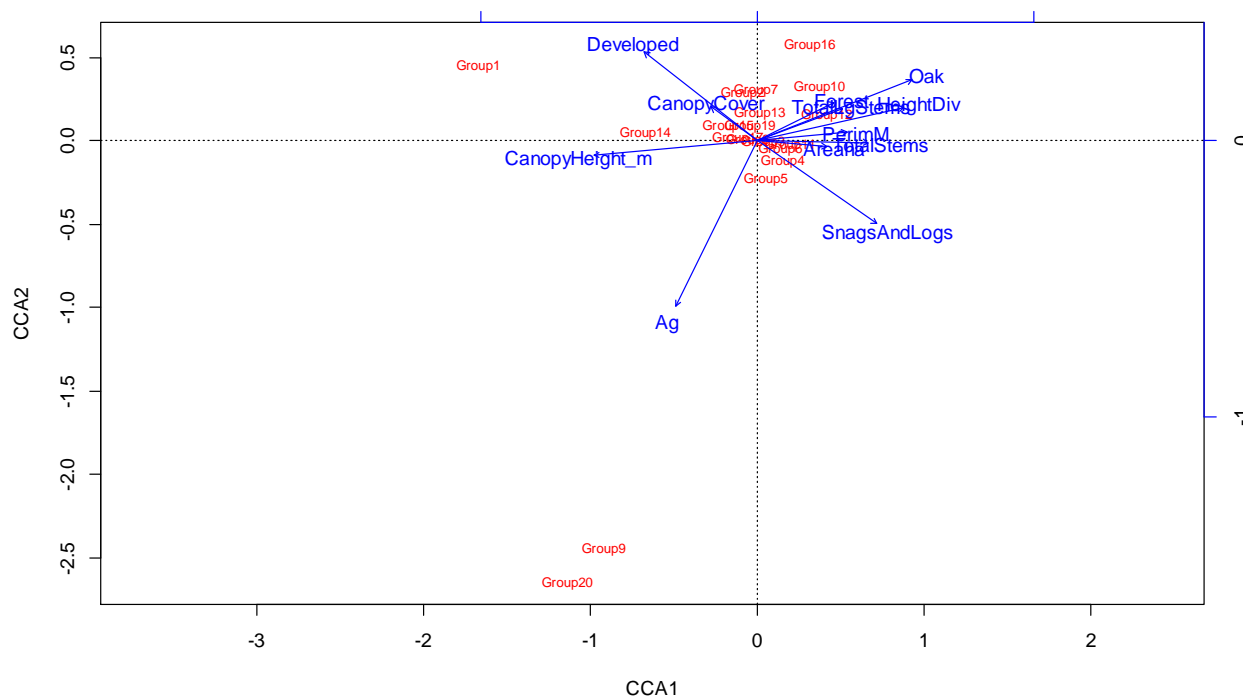
Supplementary Figure 4. Variation explained by local (solid green), landscape (grey patterns) and shared local and landscape (solid blue) factors for synanthropic birds only. Landscape factors include patch (striped grey) and matrix (dotted grey) variables. Results are very similar to overall bird diversity shown in Figure 2.



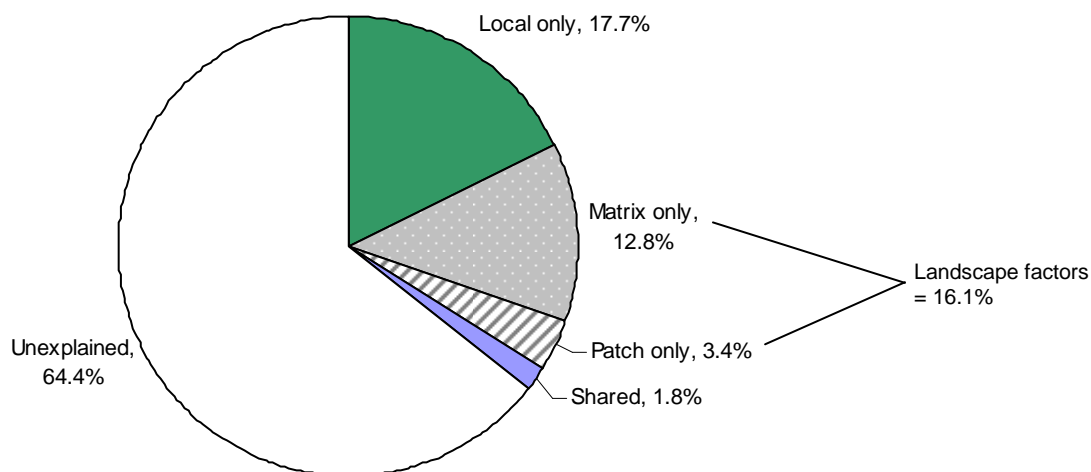
Supplementary Figure 5. Location of species and site scores defined by the first two axes of the canonical correspondence analysis for non-synanthropic birds only during the 2010-2011 breeding seasons. Environmental metrics are represented by arrows, sites as site numbers and species by their codes. Species codes are listed in Appendix, Supplementary Table 2.



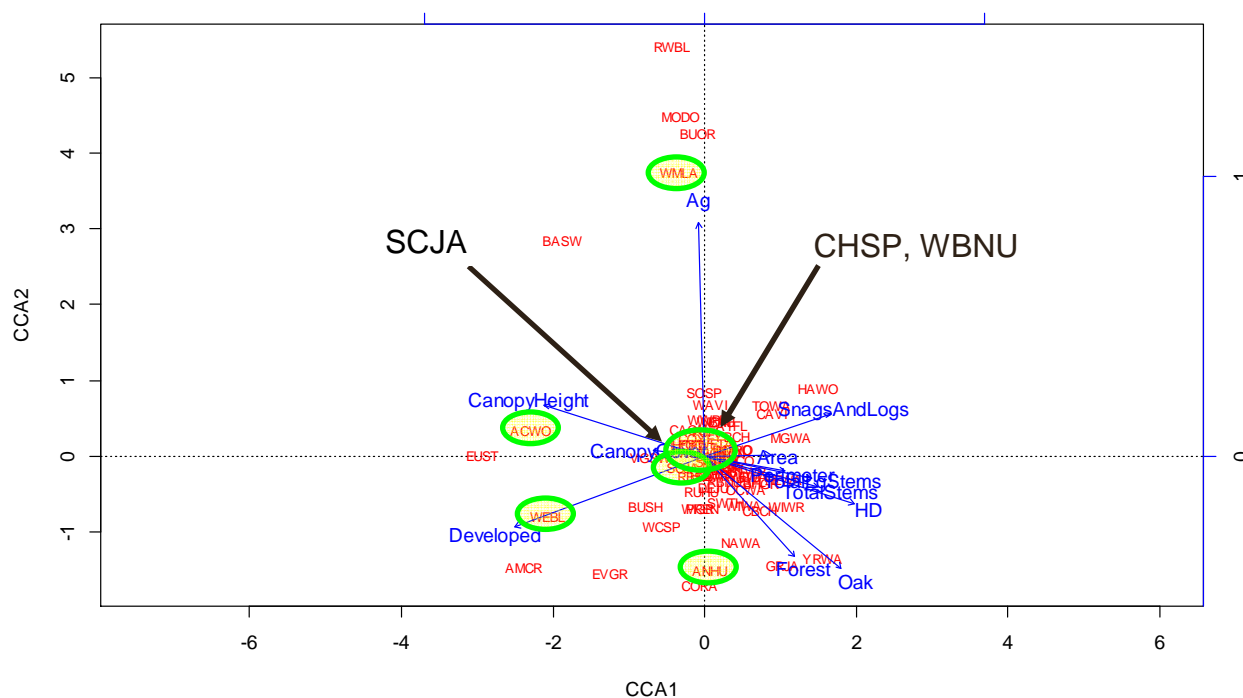
Supplementary Figure 6. Variation explained by local (solid green), landscape (grey patterns) and shared local and landscape (solid blue) factors for non-synanthropic birds only. Landscape factors include patch (striped grey) and matrix (dotted grey) variables. Local factors are more important for non-synanthropic bird community structure than for overall bird community structure (shown in Figure 2) or synanthropic bird community structure only (Appendix, Supplementary Figure 2).



Supplementary Figure 7. Location of functional group scores defined by the first two axes of the canonical correspondence analysis during the 2010-2011 breeding seasons. Environmental metrics are represented by arrows and functional groups by their group numbers. Functional groups are defined in Appendix, Supplementary Table 4.



Supplementary Figure 8. Variation explained by local (solid green), landscape (grey patterns) and shared local and landscape (solid blue) factors for 20 functional groups (functional groups are treated as the unique values for this CCA). Landscape factors include patch (striped grey) and matrix (dotted grey) variables.



Supplementary Figure 9. Location of species and site scores defined by the first two axes of the canonical correspondence analysis (CCA) for overall bird community composition during the 2010-2011 avian breeding seasons, with the seven species of concern circled. Environmental metrics are represented by lines, sites as site numbers and species by their codes. Species codes are listed in Appendix, Supplementary Table 2.