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Christopher J.W. McClure
The Peregrine Fund

Allison C. Korte
Boise State University

Julie A. Heath
Boise State University

Jesse R. Barber
Boise State University

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Original research article

Pavement and riparian forest shape the bird community along an urban river corridor

Christopher J.W. McClure[a,*], Allison C. Korte[b], Julie A. Heath[b], Jesse R. Barber[b]

[a] The Peregrine Fund, 5668 West Flying Hawk Lane, Boise, ID 83709, United States

[b] Department of Biological Sciences, Boise State University, 1910 University Drive, Boise, ID 83725, United States

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ABSTRACT

Knowledge of habitat use by animals within urban-riparian corridors during the breeding season is important for conservation, yet remains understudied. We examined the bird community along an urban-riparian corridor through metropolitan Boise, Idaho and predicted that occupancy of individual species and species richness would be greater in forested areas than in urbanized areas. We surveyed birds throughout the summers of 2009 and 2010 and quantified the m^2 of each cover-type within 50-m, 100-m, and 200-m buffers surrounding each survey location using satellite imagery. Occupancy modeling revealed that eight of 14 species analyzed were positively associated with riparian forest, and no species avoided forest. Species richness was negatively associated with the amount of paved surface within 100 m of a survey site with richness declining by more than two species for every hectare of paved surface. Most associations with cover-types – especially riparian forest – were at ⩾100 m. Therefore, the riparian forest within 100 m of a given site along an urban-riparian corridor should be the most important for maintaining species richness.

1. Introduction

Riparian areas provide water, increased nutrient cycling, and diverse vegetative structure, and are therefore essential for maintaining biodiversity within a region (Naiman and Decamps, 1997; Naiman et al., 1993; Sabo et al., 2005). For example, the interface of terrestrial and aquatic habitat provided by riparian areas affords breeding, feeding, and overwintering habitat for many amphibians and reptiles (Semlitsch and Bodie, 2003) as well as foraging habitat for bats (Grindal et al., 1999). For birds, riparian forests are important stopover areas for migrants (Carlisle et al., 2009; Pennington et al., 2008) and are important breeding areas, particularly in arid regions (e.g., Sanders and Edge, 1998; Sabo et al., 2005; Bennett et al., 2014). Information regarding habitat use within riparian zones is therefore a research priority (Donovan et al., 2002; Faaborg et al., 2010).

Despite its ecological importance, the amount of riparian habitat within the United States is declining, especially because of urbanization (Groffman et al., 2003; Jones et al., 2010). Urbanization not only leads to destruction of habitat but also degrades fragments remaining within an urban matrix. Indeed, some species avoid otherwise suitable areas – including riparian forest – within urban settings because of factors such as a high density of invasive predators, and increased disturbance, predation, brood parasitism, and exotic plant species (reviewed in; Marzluff, 2001; Alberti, 2005; Chace and

* Corresponding author.
E-mail addresses: cmcclure@peregrinefund.org (C.J.W. McClure), allikort26@hotmail.com (A.C. Korte), julieheath@boisestate.edu (J.A. Heath), jessebarber@boisestate.edu (J.R. Barber).

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Walsh, 2006; Marzluff and Rodewald, 2008). Urbanization therefore often leads to declines in biodiversity (e.g., Blair, 1996; Shochat et al., 2004; Magura et al., 2010), fewer forest insectivores (e.g., Beissinger and Osborne, 1982; DeGraaf and Wentworth, 1986), fewer migrants (e.g., Friesen et al., 1995; Stratford and Robinson, 2005), and increases of invasive species (e.g., Blair, 1996; Johnston, 2001; Riley et al., 2005).

Urban-riparian corridors therefore represent especially important areas for both conservation and ecological research because in those corridors the importance of preserving riparian habitat interacts with demands for development, water, recreation, and other ecological services. Despite the need for studies within urban-riparian corridors, relatively few studies have examined the importance of this interface for breeding birds (Miller et al., 2003) although several studies have recently supported the utility of creating or maintaining riparian areas for the management of birds within an urban matrix (e.g., Luther et al., 2008; Palmer et al., 2008; Ferenc et al., 2014).

Here, we examine the bird community within an urban-riparian corridor along a gradient from mostly forested to mostly urbanized. We surveyed birds during the breeding season along a 50-km stretch of the Boise River in southwest Idaho which passes through Boise as well as neighboring suburbs, agricultural, private, public, and preservation land. We examined whether occupancy of focal species and overall species richness were affected by measures of cover-type within our study area, predicting that occupancy and richness would be positively associated with forested areas and decline with measures of urbanization.

2. Methods

2.1. Study area

The study area was the riparian corridor along both sides of a 50-km stretch of the Boise River, ranging from Lucky Peak Dam to the southeast, and Star, Idaho to the northwest (Fig. 1(A)). The central stretch included the cities of Boise, Eagle, and Garden City, Idaho. Areas outside the riparian corridor consisted of varying degrees of paved surfaces, buildings, bare ground, and manicured grass. Intermixed within these features were varying levels of upland shrubs throughout the neighboring hills (Figs. 1, 2).

2.2. Sampling design

We placed 120 point count locations systematically along the centerline of the river with 0.4 km between points (Fig. 1(A)). The systematic sampling provided even coverage of the 50-km stretch of river, and the distance between points reduced the chances of overlap of detections of individual birds. Every other survey point was assigned to be surveyed during the first field season (summer 2009) and the remaining points were assigned to the second field season (summer 2010), resulting in 60 points per field season. For sites within a field season, we moved every-other point from the river's centerline to the north shoreline, and moved the remaining sites to the south shoreline. This movement of point count locations was performed before any measurements were taken. Ten survey points per season were not used because we were unable to obtain permission to conduct surveys on the property—leaving a total of 100 survey points.

2.3. Point count surveys

Three point count surveys were conducted within a season by trained observers at each of the 100 sites following standard point count methods (Ralph et al., 1995). We conducted surveys from mid-May through early July—dates that include the majority of the breeding season of most common birds in the study area and are similar to those of previous studies conducted in riparian areas of the western US (e.g., Rottenborn, 1999; Saab, 1999; Miller et al., 2003). We did not conduct surveys in rain or high winds. Each survey was 10 min and conducted within four hours after sunrise (range: 0645–1045 a.m.). Observers recorded each individual bird detected within 50 m, excluding flyovers. Because anthropogenic noise can affect bird communities (Barber et al., 2010; Francis and Barber, 2013), and detection rates (Griffith et al., 2010; Ortega and Francis, 2012), observers also recorded the noise level during each survey on a scale of 1–4.

During each field season, point count locations were visited three times by at least two (usually three) observers. Approximately 15–25 points were visited per week, with different portions of the river sampled throughout the week. Repeat visits to a point occurred on different days of the week and at different times of the morning. We restricted analysis mostly to species well-surveyed by point counts: *Passeriformes* (passerines), *Columbiformes* (doves), *Galliformes* (quail), and *Piciformes* (woodpeckers, Table 1). To aid in issues regarding statistical convergence of occupancy models, we only performed occupancy analysis for species that breed within the study area, and were detected on >25% of the survey sites (i.e., had a naïve occupancy rate of >0.25). The analysis of species richness included all species that are in the orders listed above and breed in the study area.

2.4. Landcover analysis

We quantified the percentage of the cover-types at 50 m, 100 m, and 200 m around each point count center using Arc GIS 9.3, 2007 Orthophotos, and 2009 National Agriculture Imagery Program (NAIP) aerial photographs (insideidaho.org). The NAIP imagery is of lower resolution than the orthophotos, but it was useful in identifying any major land use changes within

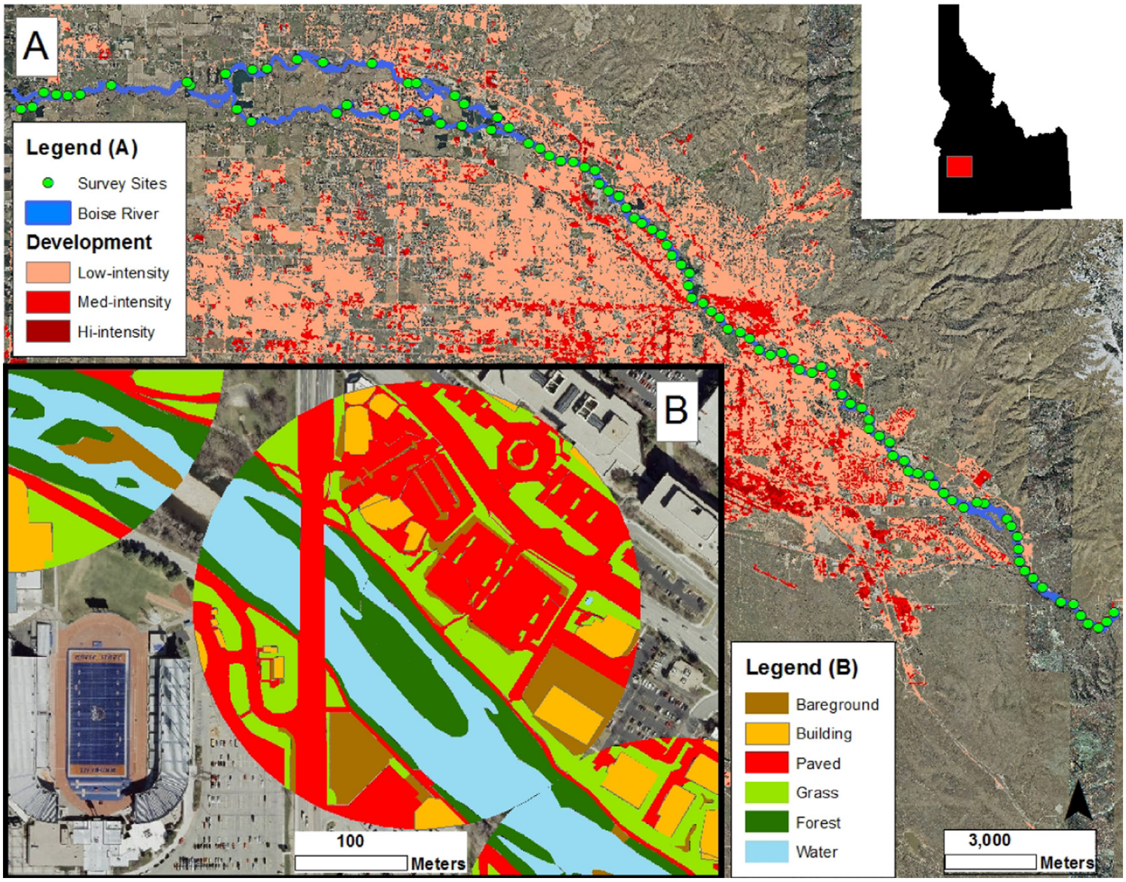

Fig. 1. (A) Boise River study area stretching from Lucky Peak Reservoir to the southeast and Star Idaho to the northwest. Development is presented using the National land-cover dataset (Homer et al., 2004). (B) Example of digitized polygons representing different types of cover within 200 m of survey sites.

point count circles throughout the river corridor. The NAIP imagery was supplemented with the orthophotos because the project did not begin until 2008, a year after the orthophotos were taken. Thus the NAIP imagery allowed us to determine major land use changes, such as development of new bridges, buildings, and parks that occurred between 2007 and 2009.

For each buffer extent, we visually categorized features on the orthophotos into seven cover types (bare ground, brushland, buildings, paved surface, grass, riparian forest, or water), digitized those features into individual polygons using ArcGIS, and calculated the area and percent of area comprised by each cover type within each buffer extent (Fig. 1(B)). The resolution of orthophotos (approximately 0.15 m in urban areas and 0.3 m in rural areas) allowed precise identification of buildings, patches of vegetation, and other landmarks—yielding total area (m^2) comprised by seven cover types (water, riparian forest, brushland, bare ground, building, grass, and paved surface) within the 200-m, 100-m, and 50-m-buffered areas for each of the 100 survey sites. We also created an "Urban" variable (i.e., an index of urbanization) which represented the sum of the area covered by buildings and paved surfaces. All land cover variables were z-transformed before analysis to place all area measurements on the same scale (Bradley et al., 2008; Steen et al., 2012).

2.5. Statistical analysis

To analyze the habitat associations of individual species, we used single-season occupancy models (MacKenzie et al., 2006, 2002), which both estimate and incorporate the probability of a species that is present being detected by an observer, using the package unmarked (Fiske and Chandler, 2011) in R (R Development Core Team, 2013). We first tested models that included only detection covariates and used an intercept-only model for occupancy. Detection models included both linear and quadratic effects of time of day and date, as well as observer and noise level, separately. We ranked and compared detection models for each species using Akaike's Information Criterion (AIC, Akaike, 1974) and considered the covariates in the AIC-best detection model as useful for accounting for variation in the probability of detection.

Once we identified the covariates that affected detection of a species, we incorporated those covariates into all models of occupancy for that species. We evaluated combinations of covariates that we hypothesized *a priori* would affect species occupancy or richness (Table 2). For models that contained more than one variable, covariates within each model were not highly correlated ($r < 0.5$). In addition, we evaluated each combination of covariates at three different spatial scales, 50-m,

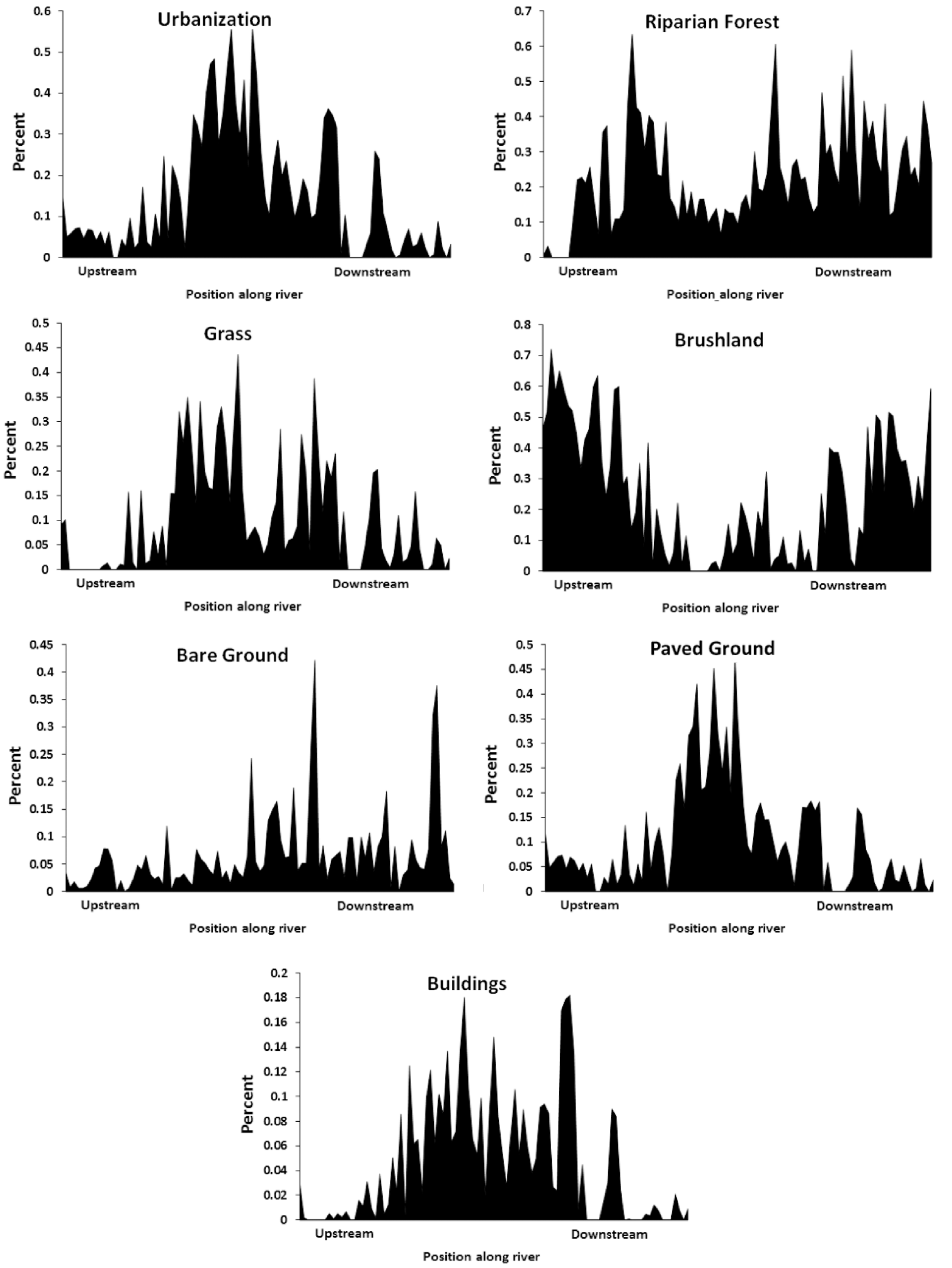

Fig. 2. Percent coverage of cover-types within 200-m buffers surrounding bird survey locations along the Boise River through metropolitan Boise Idaho. Note that patterns were similar within 50-m and 100-m buffers.

Table 1
Species, scientific name, number encountered and naïve occupancy rate of focal species breeding along the Boise River through metropolitan Boise, Idaho 2009–2010.

Species	Scientific name	# Encountered	Naïve occupancy
Song Sparrow	*Melospiza melodia*	313	0.9
Yellow Warbler	*Setophaga petechia*	273	0.84
European Starling	*Sturnus vulgaris*	430	0.81
American Robin	*Turdus migratorius*	266	0.8
Red-winged Blackbird	*Agelaius phoeniceus*	502	0.7
Mourning Dove	*Zenaida macroura*	177	0.65
Brown-headed Cowbird	*Molothrus ater*	157	0.64
Northern Flicker	*Colaptes auratus*	101	0.53
California Quail	*Callipepla californica*	109	0.42
Black-billed Magpie	*Pica hudsonia*	70	0.35
House Finch	*Carpodacus mexicanus*	93	0.3
Barn Swallow	*Hirundo rustica*	96	0.26
Western Tanager	*Piranga ludovicana*	70	0.26
Western-wood Pewee	*Contopus sordidulus*	35	0.26
Black-capped Chickadee	*Poecile atricapilla*	57	0.25
Black-headed Grosbeak	*Pheucticus melanocephalus*	39	0.23
House Sparrow	*Passer domesticus*	89	0.21
Bullocks Oriole	*Icterus bullockii*	73	0.21
Brewers Blackbird	*Euphagus cyanocephalus*	48	0.21
Belted Kingfisher	*Ceryle alcyon*	23	0.2
Downy Woodpecker	*Picoides pubescens*	23	0.18
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	42	0.17
House Wren	*Troglodytes aedon*	29	0.17
American Crow	*Corvus brachyrhynchos*	28	0.15
American Goldfinch	*Carduelis tristis*	22	0.15
Yellow-rumped Warbler	*Setophaga coronata*	20	0.12
Black-chinned Hummingbird	*Archilochus alexandri*	14	0.12
Violet-green Swallow	*Tachycienta thalassina*	75	0.11
Willow Flycatcher	*Empidonax traillii*	12	0.1
Rock Pigeon/Dove	*Columba livia*	71	0.09
Bank Swallow	*Riparia riparia*	62	0.08
Cedar Waxwing	*Bombycilla cedrorum*	18	0.08
Western Kingbird	*Tyrannus verticalis*	10	0.06
Yellow-breasted Chat	*Icteria virens*	8	0.05
Warbling Vireo	*Viero gilvus*	7	0.05
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	7	0.04
Rock Wren	*Salpinctes obsoletus*	5	0.04
Dusky Flycatcher	*Empidonax oberholseri*	4	0.04
Cassin's Finch	*Carpodacus cassinii*	5	0.03
Lewis's Woodpecker	*Melanerpes lewis*	4	0.03
Gray Catbird	*Dumetella carolinensis*	4	0.02
Red-breasted Nuthatch	*Sitta canadensis*	3	0.02
Ruby-crowned Kinglet	*Regulus calendula*	2	0.02
Chipping Sparrow	*Spizella passerina*	3	0.01
Nashville Warbler	*Oreothlypis ruficapilla*	3	0.01
Pine Siskin	*Spinus pinus*	3	0.01
Lark Sparrow	*Chondestes grammacus*	2	0.01
Canyon Wren	*Catherpes mexicanus*	1	0.01
Common Yellowthroat	*Geothlypis trichas*	1	0.01
Eurasian Collared Dove	*Streptopelia decaocto*	1	0.01
Lazuli Bunting	*Passerina amoena*	1	0.01
MacGillivarys Warbler	*Oporornis tolmiei*	1	0.01
Orange-crowned Warbler	*Vermivora celata*	1	0.01
Tree Swallow	*Tachycienta bicolor*	1	0.01
Western Meadwolark	*Sturnella neglecta*	1	0.01
Wilson's Warbler	*Wilsonia pusilla*	1	0.01

100-m, and 200-m radii. We also tested the effects of noise on species occupancy and richness using the average of the noise recorded by observers at a given point count location.

We ranked and compared occupancy models for each species using Akaike's Information Criterion (Akaike, 1974). We considered all models ΔAIC < 2 (Burnham and Anderson, 2002) that did not contain uninformative parameters (Arnold, 2010) and covariates with 85% confidence intervals that excluded zero were considered to be useful for inference. We used 85% confidence intervals because they are more appropriate than 95% confidence intervals when comparing models using AIC (Arnold, 2010). However, for aid in interpretation, we also present where 95% confidence intervals exclude zero (Tables 3 and 4). We tested the fit of the highest-ranked occupancy model using the parboot function in unmarked, which did not indicate overdispersion for occupancy models of our focal species ($p > 0.05$).

Table 2
List of hypotheses, and their sources, tested regarding the association of birds with the habitat. Each hypothesis was tested for each species for effects on abundance, recruitment, and apparent survival.

Covariates	Source of hypothesis
Urban	Beissinger and Osborne (1982), Stratford and Robinson (2005), Donnelly and Marzluff (2006), Oneal and Rotenberry (2009)
Brush land	Saab (1999), Oneal and Rotenberry (2009)
Paved surface	Germaine et al. (1998), Hennings and Edge (2003)
Brush land + Riparian forest	Hennings and Edge (2003), Sandström et al. (2006)
Riparian forest	Smith and Schaefer (1992), Miller et al. (2003), Pennington and Blair (2011)
Buildings	Miller et al. (2003), Pennington and Blair (2011)
Grass	Miller et al. (2003), Pennington and Blair (2011)
Urban + Riparian forest	Germaine et al. (1998), Hennings and Edge (2003), Oneal and Rotenberry (2009)
Buildings + Grass	Miller et al. (2003), Pennington and Blair (2011)
Urban + Urban^2	Crooks et al. (2004), Marzluff (2005), Pennington and Blair (2011)
Noise	Barber et al. (2010), Francis and Barber (2013)

We did not test for spatial autocorrelation, which, if present, would lead to an increased risk of type I error (Dormann et al., 2007). However, several studies of bird presence and richness found little or no evidence of spatial autocorrelation in urbanized landscapes (e.g., Husté et al., 2006; Lee and Carroll, 2014; Pautasso, 2007; Sims et al., 2008), perhaps because high degrees of spatial heterogeneity and fragmentation present in urban landscapes can eliminate spatial autocorrelation (Faeth et al., 2005). We therefore view the risk of type I error due to spatial autocorrelation as slight.

We assessed the effects of habitat on the observed species richness at our point count locations across all surveys using Poisson regression (Bennett et al., 2014; Stratford and Robinson, 2005) in R. We built models using the same combinations of covariates used for the occupancy modeling (Table 1), each at 50 m, 100 m, and 200 m. We determined whether covariates were useful for inference using the same model selection scheme described above for occupancy models.

3. Results

Measures of habitat varied substantially along the Boise River through our study site (Fig. 2). Spearman's rank correlations reveal a continuum of correlations between our measured habitat variables and our index of urbanization (area of buildings + area of pavement, Fig. 3). Unsurprisingly, area of buildings (hereafter, buildings) and area of pavement (hereafter, pavement) were highly correlated with urbanization. Area of grass (hereafter, grass) was also highly correlated with urbanization (Fig. 3) likely because of manicured lawns in residential areas, urban parks, and along roadsides. The areas of two more "natural" types of landcover that we classified – riparian forest and brush land – were both negatively correlated with urbanization (Fig. 3).

We detected 58 species of well-surveyed orders, 14 of these were analyzed individually (Table 1). These 14 species represented 78% of the total detections. By far, the most influential factor of the detection rates of the species analyzed was observer with the detection of 9 of 14 species (64%, Table 3) being most dependent upon which observer was conducting the survey. Detection of two species – American Robin and Black-billed Magpie (see Table 1 for scientific names) – were not affected by measured covariates. Noise negatively affected the detection of Red-winged Blackbirds and Mourning Doves (Table 3).

Of the individual species examined, eight of them (57%) were positively associated with riparian forest and no species appeared to avoid forests (Table 4, Appendix). Mourning Dove and California Quail were positively associated with brush land, while Western Wood-pewee appeared to avoid brush land (Table 4, Appendix). Four species were associated with types of landcover associated with urbanization, with only one species, the House Finch, being positively associated with buildings (Table 4, Appendix). The only species with any association with grass was the Black-billed Magpie and the association was negative (Table 4, Appendix). Three species, the Red-winged Blackbird, Brown-headed Cowbird, and Barn Swallow were positively associated with bare ground (Table 4, Appendix). The only species not associated with any cover-type was the Northern Flicker. Noise was not associated with the occupancy of any species.

Species richness observed at our point count locations ranged from zero to 14 with an average of 6.25 (SD = 2.28). All models within ΔAIC < 2 for observed species richness contained either pavement or urbanization (which includes pavement), with the best model containing the amount of pavement within a 100-m radius (Appendix). On average, observed species richness declined by 2.16 (CI = 0.70–3.60) species per hectare of pavement within a 100-m radius of a given point count location (Fig. 4).

We observed multiple scales of associations between different species and within different habitat types within a species. Of the 20 habitat associations we observed across our 14 focal species, nine were at 200 m, seven were at 100 m and four were at 50 m radius scales (Table 4). Half of the associations with riparian forest were at 200 m (Table 4). Two species were associated with variables across multiple scales with Brown-headed Cowbirds associated with bare ground at 100 m and riparian forest at 200 m and Song Sparrows affected by riparian forest at 200 m and urbanization at 100 m (Table 4).

Table 3
Beta coefficients (SE) of covariates associated with the detection of birds along the Boise River through metropolitan Boise, Idaho 2009–2010. Coefficients were within AIC top-ranked occupancy models that held occupancy constant at the intercept and had 85% confidence intervals that excluded zero.

Species	Time	Noise	Observer 1	Observer 2
Yellow Warbler			0.60 (0.33)	1.46 (0.32)[a]
Red-winged Blackbird		−0.53 (0.19)[a]		
Song Sparrow				1.19 (0.30)[a]
European Starling			−0.61 (0.28)[a]	
Mourning Dove		−0.49 (0.17)[a]		
Brown-headed Cowbird			1.55 (0.43)[a]	2.82 (0.43)[a]
California Quail			−1.76 (0.49)[a]	
Northern Flicker	−4.05 (1.60)[a]			
House Finch				1.07 (0.41)[a]
Barn Swallow			−1.24 (0.59)[a]	−0.86 (0.46)
Western Wood-pewee			1.00 (0.65)	1.75 (0.58)[a]
Black-capped Chickadee				−2.62 (1.04)[a]

[a] Indicate that 95% confidence intervals exclude zero.

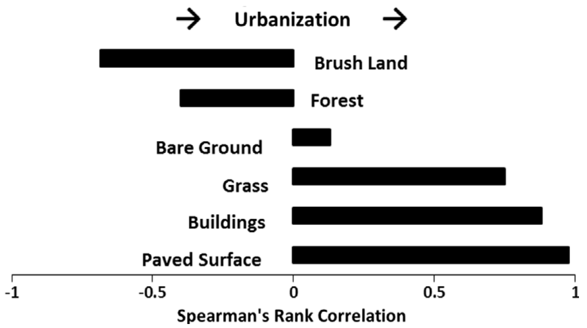

Fig. 3. Spearman's rank correlations of cover-types within 200-m buffers of bird survey locations along the Boise river through metropolitan Boise, Idaho. Note that the index of urbanization is the sum of the m^2 of paved surfaces and buildings and that patterns were similar within 50-m and 100-m buffers. This figure is fashioned after Fig. 3 in Miller et al. (2003).

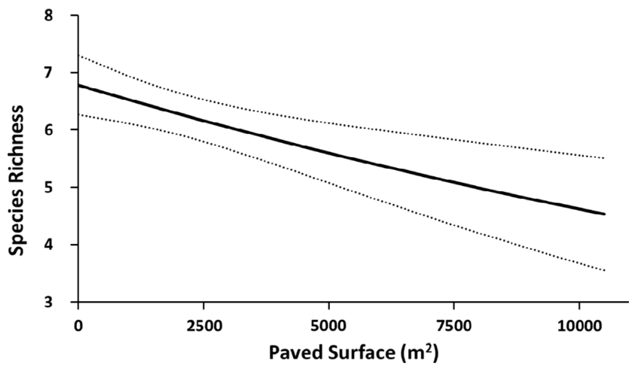

Fig. 4. Relationship (±85%CI) between predicted species richness and paved surfaces within 100-m buffers surrounding sites along the Boise River through metropolitan Boise, Idaho 2009–2010.

4. Discussion

Our study demonstrates the negative influences of paved surfaces and the positive influences of riparian forest on shaping avian communities in an urbanizing arid landscape. The results of the species-specific analyses demonstrated that the majority of our focal species were positively associated with riparian forest, and our community-wide analysis revealed that species richness was negatively associated with paved surface. Urbanization often occurs at the expense of riparian vegetation (Groffman et al., 2003; Jones et al., 2010). Therefore, the negative correlation between riparian forest and pavement (Fig. 3), the propensity of our focal species to use riparian forest, and the relative paucity of species present in paved areas (Fig. 4) are inter-related. Collectively, our results suggest a continuum of overall decreasing use of habitat by the bird community moving from areas with low to high levels of urbanization.

Table 4
Unconditional Beta coefficients (β) and associated standard errors of habitat covariates in occupancy models $\Delta AIC < 2$ with 85% confidence intervals excluding zero for breeding birds along the Boise River through metropolitan Boise, Idaho 2009–2010. If a species was associated with a covariate at multiple scales, we present the scale with the lowest AIC value.

Occupancy		Bare ground	Grass	Brush land	Forest	Buildings	Pavement	Urban	$Urban^2$
European Starling	β				8.88 (4.72)				
	Scale				200 m				
Yellow Warbler	β				1.83 (0.66)[a]				
	Scale				50 m				
Red-winged Blackbird	β	2.00 (0.90)[a]					−0.68 (0.27)[a]	−0.66 (0.26)[a]	
	Scale	200 m					100 m	50 m	
Song Sparrow	β				2.32 (1.13)[a]			−3.87 (2.15)	2.96 (1.76)
	Scale				200 m			100 m	100 m
American Robin	β				1.37 (0.66)[a]				
	Scale				50 m				
Mourning Dove	β			14.80 (8.90)					
	Scale			100 m					
Brown-headed Cowbird	β	2.41 (1.3)			8.68 (4.69)				
	Scale	100 m			200 m				
California Quail	β			1.52 (0.55)[a]	1.99 (1.1)		−1.24 (0.4)[a]	−1.11 (0.35)[a]	
	Scale			200 m	200 m		200 m	200 m	
House Finch	β					2.82 (1.49)			
	Scale					100 m			
Barn Swallow	β	9.5 (4.69)[a]							
	Scale	200 m							
Black-billed Magpie	β		−1.13 (0.52)[a]						
	Scale		200 m						
Western Wood-Pewee	β			−2.46 (1.47)	1.92 (0.93)[a]				
	Scale			50 m	50 m				
Black-capped Chickadee	β				1.22 (0.7)				
	Scale				100 m				

[a] Indicate that 95% confidence intervals exclude zero.

In general, birds choose sites using criteria across multiple scales based not only on cover-type, but also on aspects of vegetative structure—a pattern demonstrated across species, habitats, and seasons (e.g., Knick and Rotenberry, 1995; Hagan and Meehan, 2002; McClure et al., 2012, 2013a; Earnst and Holmes, 2012). Urban areas are no exception. For example, Pennington and Blair (2011) showed that models describing distributions of bird species in Cincinnati, Ohio performed best when including information regarding both vegetative structure and landscape composition (see also Germaine et al., 1998; Melles et al., 2003; Miller et al., 2003; Palmer et al., 2008). Further, Sandström et al. (2006) found that bird species richness was correlated with vegetative structure and was highest along a greenway and in the periphery of Örebro, Sweden. Inference from our study would therefore likely have been bolstered by measures of vegetative structure. For example, both Yellow Warblers and Song Sparrows are often associated with mesic shrubs (e.g., Sanders and Edge, 1998; Lowther et al., 1999; Arcese et al., 2002). Therefore, including measures of shrub-density might have allowed us to identify not only the importance of riparian forests to Yellow Warblers and Song Sparrows, but perhaps also that of a well-developed shrub-layer within those forests. We therefore emphasize the caveat that although our results identify the cover-types most often used by birds along the Boise River, we can only speculate as to whether there are certain aspects of vegetation structure within those cover-types that make them more attractive to birds.

Background noise levels have the ability to hinder the detection of birds (Griffith et al., 2010; Ortega and Francis, 2012). Therefore, if urban areas are louder than natural ones, birds might seem to avoid urban areas when in reality they are only more difficult to detect. Within our study site, the only type of cover correlated with noise ($r > 0.50$) was paved surface at 100 m ($r = 0.59$) and 200 m ($r = 0.54$)—correlations that are intuitive given the paved surfaces measured were generally roads or parking lots. It is unlikely, however, that the apparent avoidance of paved surface that we report here is simply an artifact of the detection process. Our occupancy analysis allowed us to estimate and account for the effects of noise on detectability with the detection of two species – Red-winged Blackbirds and Mourning Doves – affected by noise. Yet, even when we corrected occupancy estimates of Red-winged Blackbird for effects of noise on detection, our results still revealed an avoidance of paved surfaces. Further, although our estimates of species richness are not corrected for detection, the model including paved surfaces within 100 m far outperformed the model that accounted for noise (ΔAIC $= 4.45$), suggesting that effects of paved surfaces are not driven simply by a correlation with noise.

Although there was evidence of noise effects on the detection process, we found no evidence of effects of noise on the occupancy of individual species or species richness. Our results might seem in contrast to those of, e.g., Proppe et al. (2013) who demonstrated a decline in species richness along a gradient of urban noise, and McClure et al. (2013b) who experimentally caused migrating birds to avoid a high quality stopover site using playbacks of road noise. Further, studies in natural gas extraction fields demonstrated that noise generated by compressor stations affected species abundance (Bayne et al., 2008), occupancy (Francis et al., 2011, 2009), and richness (Francis et al., 2009). It is important to note that these past studies of anthropogenic noise were specifically designed to control for habitat – using matched quiet and noisy sites or sites along a gradient of noise, all within the same type of cover – whereas our study spans a broad range of disparate cover-types (Figs. 1, 2). Our results therefore suggest that settlement decisions of birds within our study area might be first based on cover-type and then perhaps on noise, structure of vegetation, and other aspects of microhabitat (Block and Brennan, 1993).

Our results should also be interpreted in light of the caveat that bird occupancy does not always correlate with habitat quality (Johnson, 2009; Van Horne, 1983). Knowledge of true habitat quality requires investigations into survival and fecundity (Johnson, 2009; Van Horne, 1983)—information that is relatively difficult to obtain (Johnson, 2009). Future studies should therefore examine whether measures of individual fitness also change along a gradient of urbanization (Chace and Walsh, 2006). Further, birds can shift habitat associations as the breeding season progresses (Betts et al., 2008; McClure and Hill, 2012; Webber et al., 2013). For example, Betts et al. (2008) demonstrated that Black-throated Blue Warblers (*Setophaga caerulescens*) occupy higher quality habitat as the breeding season progresses, and Webber et al. (2013) showed that Snowy Plovers (*Charadrius nivosus*) resettle away from human disturbance during the breeding season. Further inference could therefore be gained by examining within-season resettlements of birds in urban areas during the breeding season (McClure and Hill, 2012) and determining whether birds resettle in areas of higher quality.

That over half of the species we analyzed individually were positively associated with riparian forest corroborates past studies suggesting that riparian vegetation is important breeding habitat for birds (e.g., Sanders and Edge, 1998; Saab, 1999; Lees and Peres, 2008; Pennington and Blair, 2011; Bennett et al., 2014). Further highlighting the importance of riparian vegetation, four of the eight species associated with riparian forest – Yellow Warbler, Song Sparrow, Brown-headed Cowbird, and Western Wood-pewee – are native species experiencing range-wide population declines (Sauer et al., 2014). We therefore conclude that the conservation of riparian forest is important for the preservation of bird habitat along the Boise River.

Of course, to preserve riparian forest likely requires preventing it from being converted to other land-uses, particularly paved surface or buildings. In addition to our own study, several others have demonstrated declining species richness with urbanization (reviewed by; Marzluff, 2001; Chace and Walsh, 2006). For example, in metropolitan Columbus, GA, Stratford and Robinson (2005) observed bird species richness declined as the amount of urbanization within 1-km buffers increased. The pattern we observed of losing over two species per hectare of paved surface surrounding a site is particularly striking and useful for understanding the effects of future proposed development along the Boise River and perhaps other urban-riparian corridors. It should be noted, however, that potential differences in the patterns of surrounding land use, water management, and vegetation might hamper the generalizability of our results to other watersheds.

The goal of our study was to examine the cover-types used by birds along the Boise River, not necessarily to determine the optimal size of riparian forests or the width of buffers precluding development in riparian areas. However, our results are informative regarding the management of riparian areas for breeding birds in the western US and perhaps elsewhere. The most frequently occurring scale of habitat association by the individual species we examined was ≥100 m and species richness was best explained by paved surfaces within 100 m. Our results therefore suggest that management of riparian forests should focus at least within 100 m of a given area—reiterating recommendations of several past authors across broad geographic areas and a range of taxa. For example, Hodges and Krementz (1996) and Keller et al. (1993) recommended riparian buffers of 100 m based on data collected in Georgia and Maryland, respectively. Lees and Peres (2008) suggested buffers of >200 m for maintaining bird and mammal diversity within the Amazon. And, Gomez and Anthony (1996) recommended buffers of at least 75–100 m for amphibians and reptiles in western Oregon. Gergel et al. (2002) reviewed studies of riparian buffers finding that, generally, bird diversity increases with the width of a riparian buffer, with between 50–100 m needed to maintain bird diversity. Our results and those of others therefore suggest that, broadly, riparian buffers of ∼100 m should be a minimum to conserve diversity of birds along urban-riparian corridors.

Our study examines the determinants of species occupancy and richness at sites within a watershed and therefore our results are applicable to the maintenance of biodiversity at this scale. Maximizing or maintaining the diversity of birds within areas the size of entire watersheds or drainages will likely require a heterogeneous landscape that provides habitat for early and late successional species as well as synanthropic ones (Donnelly and Marzluff, 2006). Even at the scale of entire landscapes, however, riparian forests have a disproportionately large effect on the diversity of birds within an area (Bennett et al., 2014). Therefore, research and management actions regarding the effects of urbanization along riparian corridors should address scales ranging from local vegetation to entire watersheds.

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Appendix

Covariates, radius of buffer used to measure covariates, numbers of parameters (k), Akaike's Information Criterion (AIC) value, the difference in AIC between the model with the lowest AIC and a given model (ΔAIC), and Akaike weights (wi) of single-season occupancy models for breeding birds along the Boise River through metropolitan Boise, Idaho in 2009 and 2010. All covariates listed are for occupancy. For covariates used to model detection, see Table 3. DNC indicates models that did not converge.

Red-winged Blackbird	Covariates, scale	k	AIC	ΔAIC	wi
	Bare + Grass, 200 m	5	378.20	0.00	0.19
	Bare + Grass, 100 m	5	379.36	1.16	0.11
	Urban, 50 m	4	379.65	1.45	0.09
	Concrete, 100 m	4	380.13	1.93	0.07
	Urban, 100 m	4	380.45	2.25	0.06
	Urban + Forest, 50 m	5	380.70	2.50	0.06
	Concrete, 50 m	4	380.76	2.56	0.05
	Urban + Urban2, 200 m	5	381.00	2.80	0.05
	Concrete, 200 m	4	381.19	2.99	0.04
	Urban + Urban2, 50 m	5	381.46	3.26	0.04
	Urban, 200 m	4	381.85	3.65	0.03
	Urban + Forest, 100 m	5	382.40	4.20	0.02
	Urban + Urban2, 100 m	5	382.44	4.24	0.02
	Urban + Forest, 200 m	5	382.46	4.26	0.02
	Bare + Grass, 50 m	5	382.90	4.70	0.02
	Forest, 200 m	4	383.26	5.06	0.02
	Buildings + Forest, 200 m	5	384.10	5.90	0.01
	Null	3	384.37	6.17	0.01
	Noise	4	384.53	6.33	0.01
	Buildings + Forest, 100 m	5	384.78	6.58	0.01

	Brush + Forest, 200 m	5	384.84	6.64	0.01
	Buildings + Forest, 50 m	5	384.95	6.75	0.01
	Forest, 100 m	4	385.13	6.93	0.01
	Grass, 50 m	4	385.14	6.94	0.01
	Grass, 100 m	4	385.59	7.39	0.00
	Brush + Forest, 100 m	5	385.60	7.40	0.00
	Grass, 200 m	4	385.93	7.73	0.00
	Brush, 100 m	4	385.94	7.74	0.00
	Forest, 50 m	4	386.08	7.88	0.00
	Brush, 50 m	4	386.30	8.10	0.00
	Brush, 200 m	4	386.37	8.17	0.00
	Brush + Forest, 50 m	5	387.68	9.48	0.00
Yellow Warbler	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Buildings + Forest, 50 m	6	386.87	0.00	0.17
	Buildings + Forest, 100 m	6	387.37	0.50	0.13
	Forest, 100 m	5	387.61	0.74	0.12
	Forest, 50 m	5	387.66	0.79	0.11
	Forest, 200 m	5	388.20	1.33	0.09
	Urban + Forest, 50 m	6	388.88	2.00	0.06
	Urban + Forest, 100 m	6	389.29	2.41	0.05
	Buildings + Forest, 200 m	6	389.33	2.46	0.05
	Brush + Forest, 100 m	6	389.49	2.62	0.05
	Urban + Forest, 200 m	6	389.52	2.64	0.05
	Brush + Forest, 50 m	6	389.66	2.79	0.04
	Brush + Forest, 200 m	6	390.03	3.15	0.03
	Bare + Grass, 50 m	6	392.05	5.18	0.01
	Concrete, 50 m	5	394.25	7.38	0.00
	Grass, 50 m	5	394.50	7.63	0.00
	Brush, 200 m	5	394.59	7.72	0.00
	Bare + Grass, 100 m	6	394.65	7.77	0.00
	Urban + Urban2, 50 m	6	394.77	7.89	0.00
	Brush, 50 m	5	394.93	8.05	0.00
	Null	4	394.95	8.08	0.00
	Grass, 100 m	5	395.93	9.06	0.00
	Concrete, 100 m	5	395.99	9.12	0.00
	Urban + Urban2, 100 m	6	396.13	9.25	0.00
	Urban, 50 m	5	396.24	9.37	0.00
	Brush, 100 m	5	396.30	9.43	0.00
	Noise	5	396.86	9.98	0.00
	Urban, 100 m	5	396.90	10.03	0.00
	Urban, 200 m	5	396.91	10.03	0.00
	Concrete, 200 m	5	396.93	10.06	0.00
	Grass, 200 m	5	396.95	10.07	0.00
	Urban + Urban2, 200 m	6	397.84	10.96	0.00
	Bare + Grass, 200 m	6	398.02	11.15	0.00
Brown-headed Cowbird	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Bare + Grass, 100 m	6	307.66	0.00	0.22
	Bare + Grass, 200 m	6	308.08	0.41	0.18
	Forest, 200 m	5	308.78	1.12	0.12
	Brush + Forest, 200 m	6	310.14	2.47	0.06
	Buildings + Forest, 100 m	6	310.46	2.79	0.05
	Buildings + Forest, 200 m	6	310.59	2.93	0.05
	Urban + Forest, 200 m	6	310.78	3.11	0.05
	Buildings + Forest, 50 m	6	311.09	3.42	0.04
	Forest, 100 m	5	311.11	3.45	0.04
	Bare + Grass, 50 m	6	311.25	3.59	0.04
	Grass, 50 m	5	312.43	4.77	0.02
	Grass, 200 m	5	312.88	5.22	0.02

(*continued on next page*)

	Covariates, scale	k	AIC	ΔAIC	wi
	Brush + Forest, 100 m	6	313.10	5.44	0.01
	Urban + Forest, 100 m	6	313.10	5.44	0.01
	Grass, 100 m	5	313.27	5.61	0.01
	Null	4	313.71	6.05	0.01
	Urban + Urban2, 100 m	6	314.57	6.91	0.01
	Concrete, 50 m	5	314.60	6.93	0.01
	Concrete, 100 m	5	314.61	6.94	0.01
	Forest, 50 m	5	314.77	7.11	0.01
	Urban, 100 m	5	314.85	7.19	0.01
	Urban, 50 m	5	314.94	7.27	0.01
	Brush, 50 m	5	315.30	7.63	0.00
	Brush + Forest, 50 m	6	315.59	7.93	0.00
	Urban + Urban2, 50 m	6	315.62	7.96	0.00
	Concrete, 200 m	5	315.64	7.98	0.00
	Brush, 200 m	5	315.68	8.02	0.00
	Urban, 200 m	5	315.68	8.02	0.00
	Brush, 100 m	5	315.70	8.04	0.00
	Noise	5	315.71	8.04	0.00
	Urban + Forest, 50 m	6	316.65	8.98	0.00
	Urban + Urban2, 200 m	6	317.38	9.72	0.00
American Robin	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Buildings + Forest, 50 m	4	406.54	0.00	0.27
	Buildings + Forest, 100 m	4	407.87	1.33	0.14
	Concrete, 50 m	3	408.04	1.50	0.13
	Bare + Grass, 100 m	4	409.68	3.14	0.06
	Brush, 200 m	3	410.28	3.74	0.04
	Bare + Grass, 200 m	4	410.31	3.77	0.04
	Forest, 50 m	3	410.42	3.88	0.04
	Brush, 100 m	3	410.72	4.18	0.03
	Brush + Forest, 200 m	4	410.82	4.28	0.03
	Brush + Forest, 50 m	4	411.30	4.76	0.02
	Brush, 50 m	3	411.47	4.93	0.02
	Forest, 200 m	3	411.68	5.14	0.02
	Grass, 200 m	3	411.71	5.17	0.02
	Brush + Forest, 100 m	4	411.81	5.27	0.02
	Forest, 100 m	3	412.00	5.46	0.02
	Grass, 100 m	3	412.22	5.68	0.02
	Urban + Forest, 50 m	4	412.36	5.82	0.01
	Urban + Forest, 200 m	4	412.37	5.83	0.01
	Buildings + Forest, 200 m	4	412.52	5.98	0.01
	Urban + Forest, 100 m	4	413.24	6.70	0.01
	Null	2	413.88	7.34	0.01
	Bare + Grass, 50 m	4	414.43	7.89	0.01
	Grass, 50 m	3	414.59	8.05	0.00
	Urban, 50 m	3	415.52	8.98	0.00
	Concrete, 100 m	3	415.54	9.00	0.00
	Noise	3	415.65	9.10	0.00
	Urban, 200 m	3	415.69	9.15	0.00
	Urban, 100 m	3	415.76	9.22	0.00
	Urban + Urban2, 200 m	4	415.77	9.23	0.00
	Concrete, 200 m	3	415.86	9.32	0.00
	Urban + Urban2, 100 m	4	417.57	11.03	0.00
	Urban + Urban2, 50 m	4	420.83	14.29	0.00
California Quail	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Concrete, 200 m	4	269.36	0.00	0.27
	Urban, 200 m	4	269.95	0.59	0.20
	Brush + Forest, 200 m	5	270.68	1.32	0.14
	Urban + Urban2, 200 m	5	271.13	1.77	0.11
	Urban + Forest, 200 m	5	271.80	2.44	0.08
	Concrete, 100 m	4	272.47	3.11	0.06

	Brush + Forest, 100 m	5	273.28	3.92	0.04
	Urban + Urban2, 100 m	5	273.63	4.27	0.03
	Urban, 100 m	4	274.66	5.30	0.02
	Brush, 200 m	4	275.96	6.60	0.01
	Brush, 100 m	4	276.16	6.80	0.01
	Urban + Forest, 100 m	5	276.56	7.20	0.01
	Buildings + Forest, 200 m	5	276.83	7.47	0.01
	Brush + Forest, 50 m	5	277.98	8.62	0.00
	Concrete, 50 m	4	278.41	9.05	0.00
	Urban, 50 m	4	278.53	9.17	0.00
	Grass, 200 m	4	278.84	9.48	0.00
	Urban + Urban2, 50 m	5	280.18	10.82	0.00
	Urban + Forest, 50 m	5	280.25	10.89	0.00
	Bare + Grass, 200 m	5	280.43	11.07	0.00
	Grass, 100 m	4	280.98	11.62	0.00
	Noise	4	281.42	12.06	0.00
	Brush, 50 m	4	282.41	13.05	0.00
	Forest, 200 m	4	282.70	13.34	0.00
	Forest, 50 m	4	282.83	13.47	0.00
	Null	3	282.85	13.49	0.00
	Bare + Grass, 100 m	5	282.88	13.52	0.00
	Buildings + Forest, 100 m	5	283.16	13.80	0.00
	Buildings + Forest, 50 m	5	283.65	14.29	0.00
	Grass, 50 m	4	283.79	14.43	0.00
	Forest, 100 m	4	284.33	14.97	0.00
	Bare + Grass, 50 m	5	284.99	15.63	0.00
Northern Flicker	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Urban, 50 m	4	314.67	0.00	0.28
	Urban + Forest, 50 m	5	315.39	0.72	0.20
	Urban + Forest, 200 m	5	317.33	2.66	0.08
	Brush, 200 m	4	317.60	2.93	0.07
	Buildings + Forest, 50 m	5	317.78	3.11	0.06
	Concrete, 50 m	4	317.83	3.16	0.06
	Forest, 200 m	4	317.93	3.26	0.06
	Forest, 50 m	4	318.25	3.58	0.05
	Buildings + Forest, 200 m	5	318.94	4.27	0.03
	Brush + Forest, 200 m	5	319.44	4.77	0.03
	Brush + Forest, 50 m	5	320.25	5.58	0.02
	Urban + Forest, 100 m	5	320.60	5.93	0.02
	Forest, 100 m	4	320.98	6.31	0.01
	Buildings + Forest, 100 m	5	321.45	6.78	0.01
	Urban, 200 m	4	321.81	7.14	0.01
	Concrete, 200 m	4	321.89	7.22	0.01
	Concrete, 100 m	4	322.65	7.98	0.01
	Brush + Forest, 100 m	5	322.97	8.30	0.00
	Urban, 100 m	4	323.04	8.38	0.00
	Bare + Grass, 100 m	5	323.96	9.29	0.00
	Urban + Urban2, 100 m	5	323.96	9.29	0.00
	Urban + Urban2, 200 m	5	324.84	10.17	0.00
	Brush, 50 m	4	327.19	12.52	0.00
	Bare + Grass, 50 m	5	327.46	12.79	0.00
	Brush, 100 m	4	328.49	13.83	0.00
	Null	3	328.52	13.85	0.00
	Grass, 200 m	4	329.36	14.69	0.00
	Grass, 50 m	4	329.57	14.90	0.00
	Grass, 100 m	4	329.72	15.05	0.00
	Noise	4	331.13	16.46	0.00
	Bare + Grass, 200 m	5	333.96	19.29	0.00

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	Urban + Urban2, 50 m	DNC			
Barn Swallow	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Bare + Grass, 200 m	6	188.04	0.00	0.23
	Urban, 200 m	5	189.22	1.18	0.13
	Brush + Forest, 50 m	6	190.27	2.23	0.08
	Urban + Forest, 50 m	6	190.62	2.58	0.06
	Urban, 100 m	5	190.62	2.58	0.06
	Urban + Urban2, 200 m	6	190.88	2.84	0.06
	Urban + Forest, 200 m	6	190.95	2.91	0.05
	Urban + Urban2, 50 m	6	191.59	3.55	0.04
	Buildings + Forest, 50 m	6	191.74	3.69	0.04
	Concrete, 100 m	5	191.95	3.90	0.03
	Forest, 50 m	5	191.96	3.92	0.03
	Forest, 100 m	5	192.33	4.28	0.03
	Brush + Forest, 200 m	6	192.34	4.30	0.03
	Urban + Urban2, 100 m	6	192.62	4.57	0.02
	Concrete, 200 m	5	193.43	5.38	0.02
	Buildings + Forest, 100 m	6	193.56	5.52	0.01
	Concrete, 50 m	5	194.12	6.08	0.01
	Brush + Forest, 100 m	6	194.13	6.08	0.01
	Urban + Forest, 100 m	6	194.29	6.25	0.01
	Brush, 50 m	5	194.84	6.80	0.01
	Bare + Grass, 50 m	6	195.00	6.96	0.01
	Urban, 50 m	5	195.08	7.04	0.01
	Forest, 200 m	5	195.44	7.40	0.01
	Null	4	195.91	7.87	0.00
	Grass, 50 m	5	197.24	9.19	0.00
	Buildings + Forest, 200 m	6	197.43	9.38	0.00
	Noise	5	197.54	9.50	0.00
	Brush, 200 m	5	197.57	9.53	0.00
	Grass, 200 m	5	197.67	9.63	0.00
	Grass, 100 m	5	197.69	9.65	0.00
	Brush, 100 m	5	197.81	9.77	0.00
	Bare + Grass, 100 m	6	198.10	10.06	0.00
European Starling	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Forest, 200 m	4	400.65	0.00	0.25
	Buildings + Forest, 100 m	5	402.35	1.70	0.11
	Brush + Forest, 200 m	5	402.45	1.80	0.10
	Buildings + Forest, 200 m	5	402.51	1.86	0.10
	Urban + Forest, 200 m	5	402.63	1.98	0.09
	Buildings + Forest, 50 m	5	402.94	2.29	0.08
	Forest, 100 m	4	403.32	2.67	0.07
	Brush + Forest, 50 m	5	403.38	2.73	0.06
	Brush + Forest, 100 m	5	403.40	2.75	0.06
	Urban + Forest, 100 m	5	404.83	4.18	0.03
	Urban + Forest, 50 m	5	405.47	4.82	0.02
	Forest, 50 m	4	406.13	5.48	0.02
	Brush, 50 m	4	409.64	9.00	0.00
	Brush, 200 m	4	409.77	9.12	0.00
	Concrete, 50 m	4	409.98	9.33	0.00
	Urban + Urban2, 50 m	5	410.72	10.07	0.00
	Bare + Grass, 100 m	5	411.48	10.83	0.00
	Bare + Grass, 200 m	5	411.74	11.09	0.00
	Brush, 100 m	4	412.61	11.96	0.00
	Null	3	413.97	13.32	0.00
	Bare + Grass, 50 m	5	414.00	13.35	0.00
	Urban, 50 m	4	415.16	14.52	0.00
	Concrete, 100 m	4	415.30	14.65	0.00
	Concrete, 200 m	4	415.67	15.02	0.00
	Urban, 100 m	4	415.80	15.15	0.00

	Urban + Urban2, 100 m	5	415.81	15.16	0.00
	Urban, 200 m	4	415.92	15.27	0.00
	Noise	4	415.94	15.29	0.00
	Grass, 100 m	4	415.95	15.30	0.00
	Grass, 50 m	4	415.96	15.31	0.00
	Grass, 200 m	4	415.97	15.32	0.00
	Urban + Urban2, 200 m	5	417.16	16.51	0.00
Song Sparrow	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Forest, 200 m	4	378.50	0.00	0.25
	Urban + Urban2, 100 m	5	380.27	1.77	0.10
	Urban + Forest, 200 m	5	380.39	1.89	0.10
	Brush + Forest, 200 m	5	380.40	1.90	0.10
	Buildings + Forest, 200 m	5	380.47	1.97	0.09
	Forest, 100 m	4	380.84	2.34	0.08
	Brush + Forest, 100 m	5	382.28	3.78	0.04
	Buildings + Forest, 100 m	5	382.34	3.84	0.04
	Bare + Grass, 100 m	5	382.37	3.87	0.04
	Urban + Forest, 100 m	5	382.79	4.29	0.03
	Grass, 50 m	4	383.03	4.54	0.03
	Concrete, 50 m	4	383.46	4.96	0.02
	Grass, 100 m	4	384.55	6.05	0.01
	Forest, 50 m	4	384.90	6.40	0.01
	Bare + Grass, 200 m	5	385.09	6.59	0.01
	Null	3	385.48	6.98	0.01
	Urban + Urban2, 200 m	5	385.62	7.12	0.01
	Brush, 200 m	4	385.76	7.27	0.01
	Buildings + Forest, 50 m	5	385.89	7.39	0.01
	Urban, 50 m	4	386.10	7.60	0.01
	Concrete, 100 m	4	386.25	7.76	0.01
	Grass, 200 m	4	386.37	7.87	0.00
	Brush + Forest, 50 m	5	386.56	8.06	0.00
	Urban + Forest, 50 m	5	386.89	8.39	0.00
	Urban, 100 m	4	387.23	8.73	0.00
	Concrete, 200 m	4	387.28	8.78	0.00
	Urban, 200 m	4	387.29	8.79	0.00
	Brush, 100 m	4	387.34	8.85	0.00
	Brush, 50 m	4	387.44	8.94	0.00
	Noise	4	387.46	8.97	0.00
	Urban + Urban2, 50 m	5	391.25	12.75	0.00
	Bare + Grass, 50 m	DNC			
Black-Billed Magpie	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Grass, 200 m	3	245.96	0.00	0.33
	Bare + Grass, 200 m	4	247.55	1.59	0.15
	Brush, 200 m	3	248.53	2.57	0.09
	Brush, 100 m	3	249.00	3.04	0.07
	Brush + Forest, 200 m	4	250.36	4.40	0.04
	Urban + Urban2, 50 m	4	250.40	4.44	0.04
	Brush + Forest, 100 m	4	250.67	4.71	0.03
	Concrete, 200 m	3	251.35	5.39	0.02
	Bare + Grass, 100 m	4	251.44	5.48	0.02
	Urban, 200 m	3	251.57	5.61	0.02
	Grass, 100 m	3	251.58	5.62	0.02
	Null	2	252.00	6.04	0.02
	Urban + Forest, 200 m	4	252.31	6.35	0.01
	Brush, 50 m	3	252.41	6.45	0.01
	Noise	3	252.41	6.45	0.01
	Concrete, 100 m	3	252.48	6.52	0.01
	Grass, 50 m	3	252.91	6.95	0.01
	Urban, 50 m	3	253.16	7.20	0.01

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	Urban + Urban2, 200 m	4	253.25	7.29	0.01
	Urban, 100 m	3	253.29	7.33	0.01
	Bare + Grass, 50 m	4	253.65	7.69	0.01
	Concrete, 50 m	3	253.74	7.78	0.01
	Forest, 50 m	3	253.86	7.90	0.01
	Forest, 200 m	3	253.88	7.92	0.01
	Forest, 100 m	3	253.99	8.03	0.01
	Brush + Forest, 50 m	4	254.37	8.41	0.01
	Buildings + Forest, 50 m	4	254.55	8.59	0.00
	Urban + Forest, 100 m	4	254.94	8.98	0.00
	Buildings + Forest, 200 m	4	254.97	9.01	0.00
	Urban + Forest, 50 m	4	255.10	9.14	0.00
	Urban + Urban2, 100 m	4	255.16	9.20	0.00
	Buildings + Forest, 100 m	4	255.95	9.99	0.00
Mourning Dove	Covariates, scale	k	AIC	ΔAIC	wi
	Brush, 100 m	4	367.94	0.00	0.37
	Brush + Forest, 100 m	5	369.42	1.49	0.18
	Bare + Grass, 100 m	5	370.41	2.47	0.11
	Buildings + Forest, 50 m	5	370.83	2.90	0.09
	Urban + Forest, 50 m	5	372.06	4.12	0.05
	Forest, 100 m	4	372.35	4.41	0.04
	Forest, 200 m	4	372.67	4.73	0.03
	Forest, 50 m	4	373.77	5.84	0.02
	Urban + Forest, 200 m	5	374.41	6.47	0.01
	Buildings + Forest, 100 m	5	374.46	6.53	0.01
	Brush + Forest, 200 m	5	374.52	6.58	0.01
	Buildings + Forest, 200 m	5	374.54	6.60	0.01
	Brush, 50 m	4	374.90	6.96	0.01
	Urban + Forest, 100 m	5	375.96	8.03	0.01
	Brush + Forest, 50 m	5	376.51	8.57	0.01
	Concrete, 50 m	4	376.68	8.75	0.00
	Bare + Grass, 200 m	5	377.22	9.28	0.00
	Grass, 100 m	4	377.23	9.29	0.00
	Null	3	377.29	9.36	0.00
	Grass, 200 m	4	377.41	9.48	0.00
	Grass, 50 m	4	377.85	9.91	0.00
	Concrete, 200 m	4	378.31	10.38	0.00
	Concrete, 100 m	4	378.36	10.42	0.00
	Urban, 50 m	4	378.58	10.65	0.00
	Urban, 200 m	4	378.74	10.80	0.00
	Noise	4	379.12	11.18	0.00
	Brush, 200 m	4	379.14	11.20	0.00
	Urban, 100 m	4	379.19	11.26	0.00
	Urban + Urban2, 50 m	5	380.45	12.51	0.00
	Urban + Urban2, 200 m	5	380.62	12.69	0.00
	Urban + Urban2, 100 m	5	380.96	13.03	0.00
	Bare + Grass, 50 m	DNC			
House Finch	Covariates, scale	k	AIC	ΔAIC	wi
	Buildings + Forest, 100 m	5	208.75	0.00	0.69
	Bare + Grass, 100 m	5	212.72	3.97	0.10
	Brush + Forest, 50 m	5	213.35	4.60	0.07
	Grass, 50 m	4	213.79	5.04	0.06
	Grass, 100 m	4	214.45	5.71	0.04
	Bare + Grass, 50 m	5	214.78	6.03	0.03
	Buildings + Forest, 200 m	5	218.45	9.70	0.01
	Buildings + Forest, 50 m	5	218.78	10.04	0.00
	Grass, 200 m	4	219.47	10.73	0.00
	Bare + Grass, 200 m	5	220.70	11.95	0.00
	Brush + Forest, 100 m	5	221.08	12.33	0.00
	Urban, 100 m	4	221.94	13.20	0.00

	Urban + Forest, 100 m	5	222.41	13.66	0.00
	Urban + Urban2, 100 m	5	222.52	13.77	0.00
	Brush + Forest, 200 m	5	225.41	16.66	0.00
	Urban, 200 m	4	225.43	16.69	0.00
	Urban + Forest, 50 m	5	225.48	16.73	0.00
	Urban + Urban2, 200 m	5	225.55	16.80	0.00
	Urban + Forest, 200 m	5	225.82	17.07	0.00
	Forest, 50 m	4	226.76	18.02	0.00
	Urban, 50 m	4	229.13	20.38	0.00
	Urban + Urban2, 50 m	5	229.78	21.03	0.00
	Concrete, 200 m	4	230.96	22.21	0.00
	Forest, 100 m	4	231.30	22.56	0.00
	Concrete, 100 m	4	231.46	22.71	0.00
	Forest, 200 m	4	232.87	24.12	0.00
	Brush, 200 m	4	233.77	25.02	0.00
	Brush, 100 m	4	235.65	26.90	0.00
	Concrete, 50 m	4	235.76	27.02	0.00
	Noise	4	237.59	28.84	0.00
	Null	3	238.16	29.42	0.00
	Brush, 50 m	4	238.55	29.81	0.00
Western Wood-Pewee	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Forest, 50 m	5	180.78	0.00	0.15
	Buildings + Forest, 50 m	6	180.88	0.09	0.14
	Forest, 100 m	5	181.59	0.80	0.10
	Urban + Forest, 200 m	6	181.77	0.99	0.09
	Brush, 50 m	5	182.21	1.43	0.07
	Urban + Forest, 50 m	6	182.22	1.43	0.07
	Brush + Forest, 50 m	6	182.31	1.53	0.07
	Urban + Forest, 100 m	6	183.08	2.30	0.05
	Brush + Forest, 100 m	6	183.26	2.47	0.04
	Buildings + Forest, 100 m	6	183.55	2.76	0.04
	Grass, 50 m	5	184.46	3.68	0.02
	Bare + Grass, 50 m	6	184.57	3.78	0.02
	Urban, 100 m	5	184.63	3.85	0.02
	Concrete, 100 m	5	186.09	5.31	0.01
	Brush, 100 m	5	186.13	5.35	0.01
	Urban + Urban2, 100 m	6	186.25	5.47	0.01
	Brush, 200 m	5	186.57	5.79	0.01
	Null	4	186.67	5.89	0.01
	Concrete, 200 m	5	187.01	6.23	0.01
	Grass, 100 m	5	187.21	6.43	0.01
	Concrete, 50 m	5	187.43	6.65	0.01
	Urban, 50 m	5	187.53	6.75	0.01
	Urban, 200 m	5	187.77	6.99	0.00
	Bare + Grass, 100 m	6	187.91	7.13	0.00
	Noise	5	188.52	7.73	0.00
	Grass, 200 m	5	188.67	7.88	0.00
	Urban + Urban2, 50 m	6	188.98	8.19	0.00
	Urban + Urban2, 200 m	6	189.55	8.77	0.00
	Bare + Grass, 200 m	6	190.14	9.36	0.00
	Brush + Forest, 200 m	DNC			
	Forest, 200 m	DNC			
	Buildings + Forest, 200 m	DNC			
Black-capped Chickadee	Covariates, scale	*k*	AIC	ΔAIC	*wi*
	Brush + Forest, 50 m	5	186.14	0.00	0.26
	Forest, 100 m	4	187.54	1.39	0.13
	Buildings + Forest, 100 m	5	187.73	1.59	0.12
	Urban + Forest, 100 m	5	188.75	2.61	0.07
	Forest, 200 m	4	189.26	3.12	0.05

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	Brush + Forest, 200 m	5	189.68	3.54	0.04
	Buildings + Forest, 50 m	5	189.96	3.82	0.04
	Forest, 50 m	4	190.03	3.89	0.04
	Noise	4	190.60	4.46	0.03
	Buildings + Forest, 200 m	5	190.76	4.62	0.03
	Urban + Forest, 200 m	5	190.90	4.75	0.02
	Brush, 50 m	4	190.98	4.84	0.02
	Concrete, 50 m	4	191.14	5.00	0.02
	Null	3	191.78	5.64	0.02
	Urban + Forest, 50 m	5	191.86	5.72	0.01
	Concrete, 100 m	4	192.13	5.99	0.01
	Concrete, 200 m	4	192.87	6.73	0.01
	Urban, 50 m	4	193.09	6.95	0.01
	Brush, 100 m	4	193.11	6.97	0.01
	Urban, 200 m	4	193.20	7.06	0.01
	Urban, 100 m	4	193.28	7.14	0.01
	Grass, 100 m	4	193.62	7.48	0.01
	Brush, 200 m	4	193.71	7.57	0.01
	Grass, 50 m	4	193.73	7.59	0.01
	Grass, 200 m	4	193.74	7.60	0.01
	Bare + Grass, 100 m	5	194.83	8.69	0.00
	Urban + Urban2, 200 m	5	194.85	8.71	0.00
	Urban + Urban2, 100 m	5	194.89	8.74	0.00
	Urban + Urban2, 50 m	5	194.98	8.84	0.00
	Bare + Grass, 50 m	5	195.20	9.06	0.00
	Bare + Grass, 200 m	5	195.70	9.56	0.00
	Brush + Forest, 100 m	DNC			
Species Richness	Covariates, scale	*K*	AIC	ΔAIC	wi
	Concrete, 100 m	2	448.62	0.00	0.13
	Concrete, 200 m	2	449.19	0.57	0.10
	Urban + Urban2, 200 m	3	449.66	1.04	0.08
	Urban, 200 m	2	450.05	1.43	0.06
	Concrete, 50 m	2	450.21	1.59	0.06
	Urban, 50 m	2	450.28	1.66	0.06
	Urban, 100 m	2	450.49	1.87	0.05
	Bare + Grass, 100 m	3	450.88	2.26	0.04
	Grass, 100 m	2	450.93	2.31	0.04
	Brush + Forest, 50 m	3	451.20	2.58	0.04
	Grass, 200 m	2	451.80	3.18	0.03
	Urban + Urban2, 50 m	3	451.88	3.26	0.03
	Null	1	451.94	3.32	0.02
	Urban + Forest, 200 m	3	451.96	3.34	0.02
	Urban + Urban2, 100 m	3	452.19	3.57	0.02
	Urban + Forest, 50 m	3	452.38	3.76	0.02
	Brush, 50 m	2	452.41	3.79	0.02
	Grass, 50 m	2	452.60	3.98	0.02
	Urban + Forest, 100 m	3	452.60	3.98	0.02
	Forest, 200 m	2	452.66	4.04	0.02
	Bare + Grass, 200 m	3	452.72	4.10	0.02
	Brush, 100 m	2	452.75	4.13	0.02
	Forest, 50 m	2	452.99	4.37	0.01
	Noise	2	453.07	4.45	0.01
	Brush, 200 m	2	453.40	4.78	0.01
	Brush + Forest, 100 m	3	453.53	4.91	0.01
	Brush + Forest, 200 m	3	453.63	5.01	0.01
	Forest, 100 m	2	453.64	5.02	0.01
	Bare + Grass, 50 m	3	453.92	5.30	0.01
	Buildings + Forest, 200 m	3	453.96	5.34	0.01
	Buildings + Forest, 50 m	3	454.49	5.87	0.01
	Buildings + Forest, 100 m	3	455.49	6.87	0.00

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